DTU Management
Departmentof Technology, Management and Economics

PlasticScanner

Development and product realisation of a NIR polymer scanner

Master Thesis

Approval

This thesis has been prepared over six months at the Department of Technology, Management and Economics, at the Technical University of Denmark, DTU, in partial fulfilment for the degree Master of Science in Engineering (Design and Innovation), MSc Eng.

It is assumed that the reader has a basic knowledge in the areas of product development, Plastics design and electronics design.

Markus Glavind - s175046	Gustav Brandt Gregersen - s153930
	Gustav Gregersen
Signature	*Signature*
13-02-2023	*13-02-2023*
Date	*Date*

	Gustav	**Markus**
Introduction	X	X
Theory and methods	X	X
Development	X	X
Discussion	X	X
Conclusion	X	X
Future work	X	X

Table 1: Distribution of work

Acknowledgements

We would like to express our gratitude to all of those, who have supported us during this master thesis. We would especially like to thank our supervisor Tobias Eifer for his feedback, guidance and openness towards our project goals. We would also like to express our gratefulness to Jerry de Vos, for his financial support to the project, sharing of knowledge, feedback and continued support throughout the project.

Our appreciation extends to Plastix for their sharing of knowledge, company tour and enthusiasm towards the project. We would to thank the open source PlasticScanner community, especially Lawrence “Loki” Kincheloe for his feedback and sharing his knowledge in hardware development, and “Dataworm” for sparring on data quality.

Finally, we would like to extend our gratitude to our friends and family for their unwavering support and encouragement. Their feedback, participation in testing and inquiries about the project were invaluable and kept us motivated throughout the entire process.

Abstract

In this thesis, a handheld plastic identification tool has been developed to a state, where the physical and electronic hardware is manufacturable and functional. The plastic identification tool aims to help solve the global challenges of plastic sorting, by making identification of polymers more accessible.

Research indicates that a range of companies and individuals are working with sorting plastic, but the main focus of current solutions is industrial equipment or niche scientific purposes. The current market for handheld plastic identification is domi- nated by products that are inaccessible in most use cases due to the price range.

This thesis builds on the source project called ”PlasticScanner”, and aims to further develop and mature the existing design. The thesis researches the concept of open source hardware (OSH), the effect that open source has on a development project, and highlights challenges associated with OSH as a business model. The research identifies key aspects affecting success and replicability on OSH projects, and the findings are used to drive decisions in the development process, and recommenda- tions for future work.

A double diamond development process is applied to the development process, aiming to create a handheld and pilot production ready PlasticScanner.

The thesis propose a new modular design of electronics and hardware, that fits the use case of both commercial and open source community. The design has been tested and accompanying software has been developed in order to test the scanning performance of the solution.

The developed PlasticScanner is a solution enabling a wide range of users to more effectively handle an increasing level of plastic waste. By designing a development kit for the community and makers, the PlasticScanner lays the groundwork for future development within the project and enables other individuals to create new innovations.

The master thesis indicates the feasibility of creating a low cost plastic scanner, that highlights a potential for easy and accessible plastic identification. The design has reached 90 % accuracy when comparing two plastic types. The physical and electronic designs are validated and ready for pilot production. Furthermore, the thesis identifies two main use cases and propose a business case and a roadmap for the first year of business. In conclusion, the thesis indicates a strong case for continuing the project of delivering an open source handheld plastic identification tool, both as a commercial product and as an open source hardware offering, that can make plastic identification accessible to more people.

Table of contents

1. Introduction

Context

Plastic is an amazing material. It can be shaped and reshaped into an almost unlimited number of complex shapes, it is affordable, and it does not require a lot of energy to manufacture compared to steel or glass. It is durable, it is re-shapable and it can last an eternity.

The low price and easy manufacturing has made plastics the perfect material for single-use items. Items that could be used several times, but are designed to only last once. This results in our beaches, oceans, parks, and landfill filling up with plastic products that are not given a second chance. And the reason is simple. The second we mix a polymer with other unknown plastics, the valuable and reusable material is transformed into waste, because the best we can do is to use it as fossil fuel for the incineration plant.

The solution sounds simple: We need to sort plastic, so we can reuse the material for new products. But the reality is a lot more complicated. While the resource industry is trying to solve the challenge of sorting household waste, there is another strategy as well. Focusing on a relatively confined and consistent source makes it easier to have a consistent output. Around Europe, several companies have emerged working on this: Plastix in Lemvig, Denmark focuses on turning used fishing nets and ropes into pellets, BessTrade is focusing on PVC flooring to have a consistent output of PVC, and Matras Recycling Europe is recycling the various parts of the mattress. They all have one thing in common: a large, consistent source of the material that requires rough sorting.

Project description

In this project, the physical artefacts for a handheld plastic scanner is developed with the goal of making plastic identification more accessible, enabling individual and commercial users to identify and sort plastic waste.

This includes developing a plastic shell and accompanying electronics ready for production. Additionally, an initial set of software is created to verify the functionality of the designed hardware. The core principle used for polymer identification is the relative reflectance of light in the near-infrared (NIR) spectrum from different polymer types, which is determined through the use of discrete near-infrared spectroscopy, as described in section 2.3 and 3.3.1.

The project is completed at the Technical University of Denmark and is based on the open source project called “the PlasticScanner project” created by Jerry de Vos in 2021. Furthermore, this project builds upon the industrial design concept for the PlasticScanner project, developed by a group of students at TU Delft during spring 2022.

The PlasticScanner project is an open source project which affects the development process of this project. The subject of open source as a development strategy is researched and described, including a review of pros and cons of this method. The best-practices for successfully developing an open source project are reviewed. An emphasis is put on reviewing the challenges and strategies associated with open source hardware development driven by a community. The development process follows the Double Diamond process model and incorporates open source elements in the development process by continuously sharing work with the community and reviews of the development by the PlasticScanner community.

The main focus of the work done within this project is to complete the necessary hardware for a functional and manufacturable plastic scanner, as described in the next section. The report furthermore describes gathering of data and training of a machine learning model. This work is included to provide an preliminary proof-of-concept for the hardware capabilities. Furthermore, basic principles of NIR spectroscopy is applied to argue for implementation and methods previously developed by the PlasticScanner project. The project thus focuses on applying proven principles in a relevant context.

Problem Statement

The Plastic Scanner is an open source-based project, developing a discrete NIR polymer identification tool. To generate income for further development, the PlasticScanner project wants to develop a commercial version targeting European commercial customers. Currently, the scanner is at a Technology Readiness Level (TRL) 5 with working prototypes of various parts of the project tested.

In parallel to the continuous use as an open source concept, the aim of this master thesis is to further develop the technology and the current design towards use as a commercial scanner. It includes aspects such as the definition of markets and business models, alignment with open source strategy, as well as the further development of the current proof-of-concept prototype into a production-ready state. Key tasks are:

Review and apply relevant literature in the field of open source development.

1. Define target users and target use cases, develop and refine the business model, and define product requirements.
2. Evaluate the current state of the plastic scanner, and develop the physical and hardware aspects of the design to a higher TRL.
3. Analysis of current product and re-design towards the defined target use case(s).
4. Functional testing of designed prototypes.
5. Design for manufacturing analysis and evaluation of individual components for design refinements.

Reading the report

The thesis starts by introducing the theory and methods used throughout the report. After this comes the development section, which starts with a presentation of the final product to make the rest of the report easier to follow. The remaining sections in development follow the double diamond approach: discover, define, develop, deliver.

In the discover section, the problem space, user needs and NIR identification method is explored.

The define section builds on the learnings from the discover phase to describe the exact problem, market, requirements, and possible business model.

The define phase guides the development phase, where the iterative process of developing and testing the physical design, electronics and accompanying software is described.

Finally, the deliver phase reviews the developed product and open source process, and proposes a development roadmap for 2023.

The effects of design decision, error sources, business case and open source development are then discussed. Lastly, proposals for future development are described.

The report is set up as a two-page document, with an inner binding. Figures and test is therefore setup to best accommodate this view, but can be read as a single page document as well.

To highlight the development, decisions, and actions made by the authors of the master thesis project, the term “the team” will be used throughout the report. The development, previously done within the PlasticScanner community, is referred to, as done by “the PlasticScanner Project”.

To ease the reading experience, a list of abbreviations, a list of figures and a list of tables are attached in the appendix. See appendix A.1

References are styled according to IEEE standard.

2. Theory & Methods

2.1 Open source

2.1.1 Introduction to Open source

Open Source development, also known as the Open Source model, is a way of developing products while publishing the associated design documents, blueprints, source code etc. The word open source can be understood as a river. Everyone is free to follow the stream to the spring where it starts, study it, make adjustments and grab water to start another stream. In this analogy, free software would be to make it free to drink from the river, but not to create new streams or study the stream, or commercial software where it might cost resources to gain access to the stream. The term open source does not describe the quality of the source, but only defines the access and possible actions [1], [2].

The open source model has its roots in the early days of software at Bell Labs UCL Berkley. At that time there was a culture of software being shared among researchers. The Berkley team developed a set of add-ons to the UNIX operating system developed by Bell labs as Berkeley Software Distribution (BSD). This turned into a lawsuit, which sparked Richard Stallman to start the GNU (for Gnu's Not Unix) project. He justified the existence of the project as: *"So that I can continue to use computers without violating my principles, I have decided to put together a sufficient body of free software so that I will be able to get along without any software that is not free"* [3].

The term "free software", had the vulnerability that people intuitively related to the price, where it should be understood as *"the word free as in Freedom and not Free beer"*. To clarify the term, Christine Peterson coined the term "Open source" in 1998 while working as executive director of the Foresight Institute [3], [4].

Today, The Open Source Model is widely used in software, where it has its roots. It is estimated that over 96,4% of the top 1 million web servers' operating systems are Linux, and operating systems like Android are based on Linux that started the open source movement, and still, today depends on a vast amount of open source software components [5]. A survey by McKinsey suggests *"that the prospects for open innovation will only improve, as many executives expect a further blurring of boundaries between employees and people outside the enterprise"* [6]. Both professional and non-professional organisations are picking up on OSS, and hardware is also on its way.

Open source Software (OSS) itself is defined by the open-source organisation as:

> *"Open source software is software with source code that anyone can inspect, modify, and enhance"* [7].

OSS allows other interested parties to contribute to the proposed solution, thereby speeding up development and adding functionality needed by the contributor. More recently, the OS movement is spreading from community-driven software to the scene of hardware projects, and even into companies and major organisations.

2.1.2 Open source Hardware

To talk about open source hardware, we first need to take a step back and define the term "hardware". The DIN 3105 standard for open source hardware defines a piece of hardware as *"any discrete (i.e. countable) physical artefact"*, meaning that a piece of hardware is not limited to the classic idea of hardware: an electronic circuit board, but instead, a more general term for tangible physical objects [8]. Furthermore, specifying what an open source version of hardware is, is described by the Open Source Hardware Foundation (OSHF) as *"A term for tangible artefacts — machines, devices, or other physical things, whose design has been released to the public in such a way that anyone can make, modify, distribute, and use those things"*. This definition further includes that a piece of open source hardware does not appear out of the blue, but is the outcome of a design process that anyone can get involved in, which requires the process to be open.

While OSS has a long and established history of successful development and business operation, open source hardware (OSH) is a more recent operating model which is defined by the OSHF in DIN SPEC 3105-1 as:

> *"Open source hardware is hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design"* [8]

The standard creates a frame for the documentation of OSH projects and introduces a community-based assessment for projects to be certified in order to be labelled as OSH[9]. The OSH movement has gained significant momentum over the past 10 years with popular projects like the Arduino microcontroller, Adafruit and Sparkfun prototyping electronics, and 3D printers by Prusa research and the RepRap community [10]. Projects like Arduino have grown from relatively unstable and small scale, to actively challenging the industrial PLC market, and play a major role in prototype development of IoT solutions [11].

Through the teams research, is has been found that despite new standards, and an increasing number of publications addressing open source design, the application of OSH in the community is often looking unorganised and unstandardised. Since the contributors typically commit changes voluntarily, it appears as if documentation is not the part of the development typical OSH contributors find the most fulfilling to perform. This dynamic is showcased by how varying the level of documentation is on different projects. But the lack of documentation on some projects, sparks a question for future research: How much documentation is needed and what type of documentation is needed for new contributors to join?

Balka et al. found that the involvement of actors in an open source hardware community is driven by the transparency, accessibility, and replicability of a project. The better the actor finds the above-mentioned criteria, the more it contributes to the perceived openness of the project, thereby increasing the chance of an actor using or contributing to a project. [12]. Transparency, accessibility, and replicability can be seen as three tiers of openness. Transparency relates to the possibility to look at the design, and see and understand the decisions made during the development process. Accessibility is related to the possibility to access and modify the available information. This means using generally used formats of digital content. Especially for open source hardware, replicability is a major factor in the success of an OSH project [13]. For example, in an OSS project, the user just needs a computer to run a piece of code and thereby actively participate in the project. However, in open source hardware projects, the user needs the physical artefact to participate. This could be the need to order a custom PCB, 3D print or laser cut a number of CAD models and assemble everything together without feedback. This either requires the new actors to have a range of tools and machines available through ownership or membership in a community workspace or makerspace, and if not to pay a third party to create the artefacts. Additionally, the lack of scale has a significant impact on the cost to create an item, especially for electronic components. These factors create a financial hurdle, which new actors have to pass without a guarantee that the end product will work as expected, essentially requiring the actor to take a risk.

2.1.3 Replicability, Openness, and source quality

Antoniou et al. describe a process diagram to determine whether an OSH is replicable. The diagram can be seen on figure 2.1. Their findings were that the first step is to find and identify a project, hence the necessity to be available on a well-used platform, with sufficient information on specifications and documentation overview in order for the actor to assess if the project matches their requirements. When the project is identified, the actor then needs to read the documentation, to assess if it is possible for the actor to source, manufacture and assemble the parts. In this phase, the actor might already have initiated the manufacturing process to some degree, even though it can be hard for the actor to know if the project is replicable, which is not possible to fully determine before the project is fully assembled [14].

Bonvoisin et al. proposes an “open-o-meter” in an article from 2018. The open-o-meter is intended to output a value based on product openness and process openness. The product openness criteria align well with the factors affecting reproducibility described by Antoniou et al. regarding design files, assembly instructions and original files, but Bonvoisin further adds an OSH-compatible licence and a metric for process openness. By having an open version control system, contribution guide and issue tracking, which includes the development process as a part of OSH. The proposed criteria aligns with the requirements put forward by the DIN standard.

In 2020 the open source community standardised OSH with a DIN standard DIN 3105 [8], and in 2019 EU funded the OPEN!NEXT programme to transform collaborative product creation via the open source model, based on the acknowledgement that open source software created a billion-euro economy by making software open, and according to OPEN!NEXT it *“showed us that proprietary ownership often precludes innovation and that things move a lot faster when you don’t have to wait for patent lawyers.”* [15]

2.1.4 Elements in an open source project

The development of open source hardware projects can start in a variety of ways. It can range from an individual actor publishing a project that after completion, to large communities co-developing towards a shared goal. Typically, projects contain the following elements [16]:

- (Electronic) hardware design
- Software or firmware
- Mechanical design
- Documentation
- Community

The documentation has the goal of making the project easy to identify, and asses if the project fits ones needs and the chances of success with a possible quest of replication of electronic hardware, software and mechanical design. Additionally, there are three important properties of open source projects for them to succeed:

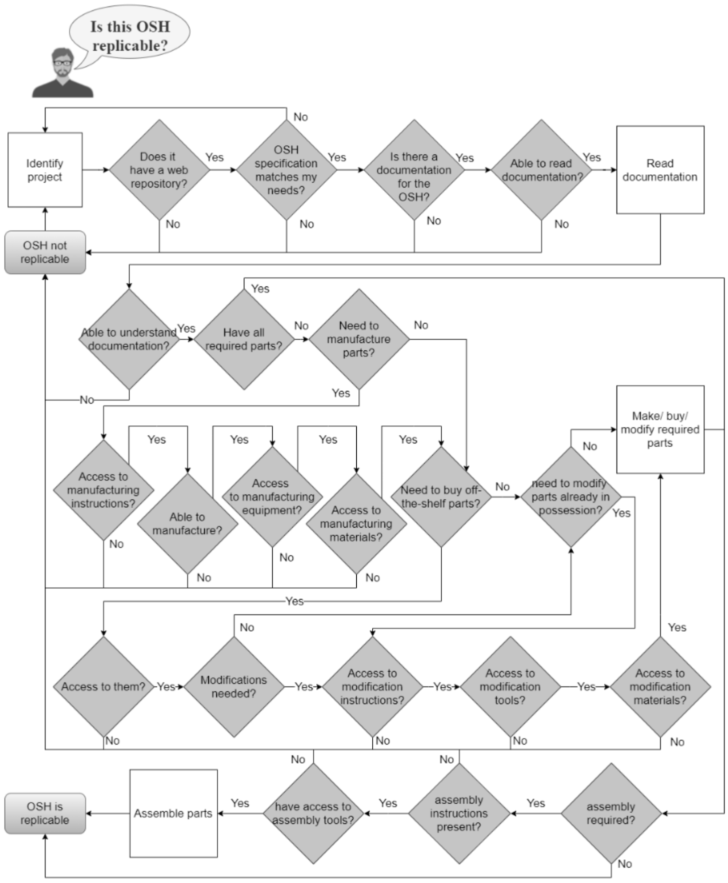


Figure 2.1: OSH replicability flowchart by Antoniou et al. [14]

- Discoverability, i.e. the ability to find the documentation regardless of where it resides on the internet, in part through making documentation accessible to web crawlers.
- Portability, i.e. the ability to share documentation on different platforms or to transfer it from one platform to another.
- Platform interoperability, i.e. the ability to update, relate and join documentation across different online repositories and documentation formats.

Organizing the collaboration

For an open source project to work, it needs a place to share, track, distribute, communicate and educate the continuously evolving design. In order to make it accessible to individuals all over the world, online services are often used to accomplish these things.

Various messaging and calling services such as Discord and Zoom are used to communicate on more developer-focused issues and subjects. By creating specific channels and threads based on the subject, for example, electronics, developers can contribute to the channels where they have expertise while still having access to the ideas and decisions in different channels with different subjects.

The project files are hosted on an online service, where the files are accessible to anyone, changes can be tracked, approved and documented, and developer-focused introductions can be made. One of the most popular services used to host projects is GitHub, where open source projects can host and collaborate for free, based on the Git framework for version control. This is also the service used by the PlasticScanner project.

2.1.5 Value creation of OSHW and associated challenges

Traditional businesses that sell or provide technical products often use a business model where their proprietary technology, business secrets and patents protect their ability to sell a unique product or service [17], [18]. An Open Source Hardware company has to consider how to protect or ensure its ability to generate revenue. There is a wide range of business models to consider, with a range of benefits and drawbacks. This section will explore a set of these business models and how they could affect the Plastic Scanner project and product. As Open Source Hardware is a very new phenomenon, only starting to gain traction as of 2012, the operating model is new to the industry. As a result, three main characteristics can increase the difficulty of gaining funding and market entry[19]:

Limited funding:

Investors are new to open source business models and how they can be an advantage. Typically, patents and other proprietary technology are seen as a good way for companies to protect their ability to make money and thereby the investor making a return[19].

Lack of exposure:

Open source hardware is not very widespread and known, leading to people looking for more conventional products. In some business areas, a long and proven track record is very important when purchasing equipment, for example in scientific work. Furthermore, open source hardware can require the user to do some manufacturing, assembly or calibration themselves, thereby turning away customers who might believe they are not able to do this. This means that the potential advantages of open source are less known in the industry, while the risk of copy-cats as a result of no design protections such as patents appears more obvious [19].

Advantages of the open source model (OSM)

According to Li Z. et al., there is a range of advantages to utilising an open-source model:

- Reduce risk, as more people will validate your design before entering manufacturing.
- Free advertising.
- Potentially a great way to hire people, as contributors have shown their abili-

ties in realising work on the project.
- Faster time to market – individuals around the world contribute to the design. For free!
- Instant feedback from the community.

This allows projects to directly provide the value that customers are actually asking for. A wider network gives the project a larger reach, as participants such as mentors and developers can help the company or project get in touch with beneficial resources or alike [10]. These benefits mostly originate from the same source: Community, community, community! Community is absolutely key and is seen as one of the primary benefits of open source. The community can lead to a range of benefits, from simply giving customers a higher perceived value to reducing development and sales expenses, shortening development time and increasing the knowledge available in the extended team [10].

Bankruptcy and vendor lock-in

In a modern, digitised world, an increasing number of connected products are made every year. In the industry of the Internet Of Things (IoT), it is currently an increasing concern for customers, as they are at the mercy of the company continuing to support their products. Major companies like the tech-giant Google have shown a great willingness to shut down online services and even services which support physical products. In 2016, Google-owned Nest shut down the service supporting their “Revolv” product line [20]. This meant customers were left with non-functional hardware, essentially e-waste, with no way of re-purposing the product or hosting their own service. The problem with Google shutting down services and products has become such a big problem that an entire website is being run to keep track of it [21] and a problem for their brand in its entirety [22]. And this problem is not limited to just Google.

Pearce is arguing that when choosing a product, a company is increasingly assessing the risks associated with implementing the product, and here vendor lock-in is a major concern, which is often overlooked [19]. Going open source is a way to minimise risk [23].

The research institute CERN has established a 3-year project called MALT, to avoid vendor lock-in, and to hopefully reduce the cost of software by demanding suppliers to deliver open source documentation wherever possible, and actively choosing open source products over proprietary if possible. This is done to avoid the end of a supplier company can result in the end to a research project [23]. In the same way, This can provide security for customers that their product will continue to work, can be updated by the community or get parts, even if the company stops.

Risks related to open source development

The above section describes potential benefits for both the company and the end user. However, choosing an open source strategy also includes risks and makes some traditional business models unsuitable. One of the major risks from open sourcing technology is the potential imitation from competitors, which is significantly easier and can be critical in especially earlier stages of development [10].

However, the success of open Source hardware projects has been varied, with Arduino still being successful, but projects like RepRap having shut down in 2016. One of the challenges RepRap faced as a commercial company was the significant range of 3rd party variations and offerings, based on their printer design. While RepRap is the most widely used 3d printing platform, the commercial aspect of the project was unable to compete with other low-cost companies selling printers, sometimes even based on the design of RepRap, thereby underlining the difficulty in remaining open source while offering a unique technical value proposition to the end customer [24].

OSH projects might have a competitive advantage over OSS since the nature of hardware requires sourcing, manufacturing and assembly. Running a larger production will give the manufacturer the benefit from economy of scale, which is not possible for an individual. At the same time, the ease of ordering a ready-to-go product will save hours of work. For a company, the latter will be a measurable expense, but for a private individual doing the project outside of work, time is “free” and might be part of the motivation for doing the project. This offers a potential revenue source for the open source company, as the company can sell finished boards and parts, thereby allowing individuals to both use the product, but also experiment with the design, as the schematics are available. This is not a possibility in the same way for OSS, since the user probably already has everything they need to try the OSS out: A computer.

Furthermore, relying on external open source products without support or service, which the enterprise is not in control of, is not an ideal situation for many enterprises. The risk associated with downtime of services can be substantial, which is why risk assessment is a part of product assessment for purchasing enterprises [19], and service and managed solutions are the basis of the business model of several large OSS companies like GitHub and RedHat.

Li Z. et al argues that *“In order for a business to thrive as an open source business, it must leverage the advantages of being open source to stay ahead of the competition trying to imitate the product”* [10]. For Arduino, that advantage has been its name, IDE and community. Having a platform of boards, firmware, guides, and an IDE that all work together seamlessly, makes it easier to start using the Arduino ecosystem for newcomers. This makes it easier for competitors to develop products that fit the Arduino ecosystem than to create their own ecosystem. This is amplified by Arduino’s trademark for the name “Arduino”, leading to most breakout boards being marketed for consumers as “Arduino compatible”. This indicates that customers value the original Arduino brand over third-party remakes, partly as a result of the complete and supported ecosystem. Lastly, it indicates that it is easy for individuals and small-scale manufacturers to replicate and remix the design and fit into the ecosystem, while still making room for the brand Arduino to succeed commercially.

Where the Arduino team leverages the community for development, is by welcoming new ideas and crowd-sourced development. The team argue that an OSH project with very high costs (e.g. a car) would not get the same effect from going open source, since the only ones capable of using, trying and testing the design are their existing competitors, and it would be hard to create a community, due to the large barrier of entry from cost alone. What they could do is take a smaller part of the product, like the infotainment system and make that part open source, and make it possible to buy a development kit, and thereby leverage on an OS Community on their weak areas. In this way, they open up for users to engage and contribute to a part of the project, which could drive sales, without giving away the design for manufacturing know-how. This would make it possible to remix the infotainment system, but you would still need to assemble a complete car to fully take advantage of it.

2.1.6 Strategic approaches for open source hardware development

The OPEN!NEXT project set off to discover how OSH companies gained momentum and became a success. They discovered that the OSH projects typically used a combination of six strategic approaches to develop it from an OSH concept for early adopters to a fully developed product for the mainstream market.

Leverage through communities

As previously mentioned by [10], the community is the heart that drives an open-source hardware project. The community serves as development help during the startup phase, while at the same time spreading the message about the project and creating publicity. When the product reaches the mainstream market, they might continue as customers as well [15].

Platforming

Companies like Sparkfun and Arduino have created online platforms for the sales and distribution of their products by connecting directly to their customer. Their sites combine hardware sales with well-document guides and inspiration, and a common ground for the community to share progress and ideas. This makes their websites a one-stop website, with everything needed to make OSH projects [15].

Crowd- and third-party funding

Compared to OSS, OSH has the challenge that physical manufacturing requires substantial financing, which is challenging to obtain without investors, public funding or grants. Another strategy is financing through small private donations and crowd-funding, where customers and community members alike pay upfront for your product and service [15].

Ecosystem infrastructure

Another strategy is to develop a whole ecosystem of products or services relevant to an ecosystem or one or more specific industries. This relates to building a platform of products, but is even more invested in a specific ecosystem [15].

Selling hardware

The basic idea of selling the hardware is developed by the OSH community. This makes OSH more accessible to less technical people, and can even make it cheaper to obtain a working product, due to economies of scale [15].

Consulting services

Another strategy is to have the whole project open source, but offer support, implementation, workshops or technical consulting either ad-hoc or on a subscription basis, and offer enterprise solutions for companies that want the product, but are not willing to invest the resources in building the product by themselves [15].

2.1.7 Strategies over time

OSH projects often start with individuals or small groups working on an idea and can develop into full-scale enterprises. The strategic approach and the product offered and needed will most likely change over time, as actors in the OSH project change from individual makers to large enterprises.

The OPEN!NEXT project identified three stages, that OSH projects typically have, that correspond to the first stages of the "Diffusion of Innovations" model proposed by Everett M. Rogers [25].

Innovators

The early innovators are the ones willing to co-create and build on top of the offering that the OSH project offers. They often play a role in the development of the project and community and are typically motivated by the goals of the OS project, and not for commercial reasons [15], [26].

Early adopters

Early market adopters accept the faults and missing aspects of the project, because they believe in the project, and have a need, for which the OSH product is a viable solution.

Mainstream market

The mainstream market is for everyone who sees an idea in the product, but values proven and polished offerings that they can trust, which early OSH projects cannot deliver.

2.2 Engineering aspects

2.2.1 Ergonomics

Working with a handheld, portable device, it is important to consider the ergonomics and the fit for the user. The design of the device should make it easy to hold and operate comfortably for extended periods of time. If a device is used in a working context with varying tasks, the risk of a repetitive strain is less of a risk, compared to a scenario where a worker would use it continuously at a conveyor belt. Nevertheless, it remains important to create a design, where the risk of repetitive strain is minimised and general comfort is prioritised.

There are multiple design considerations to be had, in order to achieve an ergonomic device. This includes considerations regarding weight, weight distribution, size, and shape of the handle, angle of scanner element, reducing bends of joints, length of the handle and material choices [27].

Weight and weight distribution

While using a one-handed tool away from the body, the weight should not surpass 2,3 kg. If the device is to be used in more accuracy-driven applications, the weight should reside below 0,4 kg. Additionally, the centre of gravity should be aligned with the centre of gravity of the hand [27].

In order to be easy to hold and easily and precisely place and angle, a device should aim to minimise weight. The weight of the enclosure will also be a compromise in offering sturdy and durable parts, without increasing the weight excessively. A lower weight can also offer more flexibility in the physical design, as the exact shape is less critical in reducing the strain on the wrist in a normal grip situation.

Size and shape of handle

The size of a handle on a handheld tool is recommended to be 30-50 mm in diameter

Figure 2.2: Strategic approaches for OSH development [15]

with 40mm being typical while being at least 100 mm in length to ensure a comfortable grip around the handle, while the handle extends to the full length of the palm. Selecting a handle diameter outside the recommended range will make it more difficult for most users to comfortably grip. A bad grip will be more straining for the user and result in less stability. Additionally, if the handle is too short, it can result in excessively compressing the middle of the palm [27].

The shape of a handle is also important to consider, as this can also affect the grip significantly. A cylindrical shape is practical to implement and widely used in a wide range of products. Adjusting the circle to an elliptical shape with a width-to-length ratio of 1:1.25 can lead to a better grip for users (see figure 2.4). Depending on the use case, various adjustments to the handle design can be made to best suit the situation[28]. It is also important to consider the aesthetics of the handle, as the affordance [29] of the product should guide the user to grip the scanner correctly without instructions.

Reducing bends in joints

One of the most important aspects of ergonomic design is to reduce bends of the joints of the hand. As far as possible, the wrist should be in its natural state [27]. A design should therefore attempt to reduce any need for the user to tip or flex their wrists when scanning a piece of plastic.

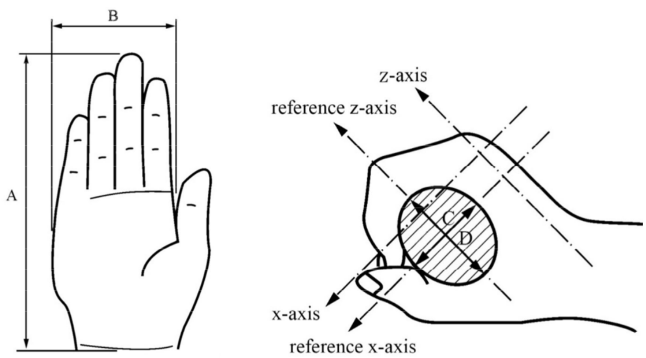


Figure 2.4: Illustration of optimal grip shape for hand tools [28]

Material choice

The material choices of a product influence everything from the perceived quality to how good the grip on the handle is. Ensuring a good grip, even with sweaty hands, is affected significantly by the material choice [27]. By defining fitting surface friction and texture for manufacturing, a good grip can in many situations be achieved. If the material is too smooth or with too little friction, the tool is more likely to slip out of hand or move in the hand when pressing against something. Not only does this result in a frustrating user experience, but it also forces the user to flex their wrist, which should be avoided.

The default grip angle of the hand

The grip line of an average human hand is 12 degrees. This is the forward angle from vertical at which an item is held naturally in the hand. A design should consider this natural angle of the tool held [30]. An example of this can be seen in figure 2.3.

2.2.2 Think aloud protocol for user testing

During user testing in this project, the testing protocol “think aloud protocol” was used as described by Steve Portigal in “Rocket Surgery Made Easy”. The think-aloud protocol is a user testing method to test everything from a website to a physical product [31]. It is applied by instructing the informant to complete a series of tasks, where

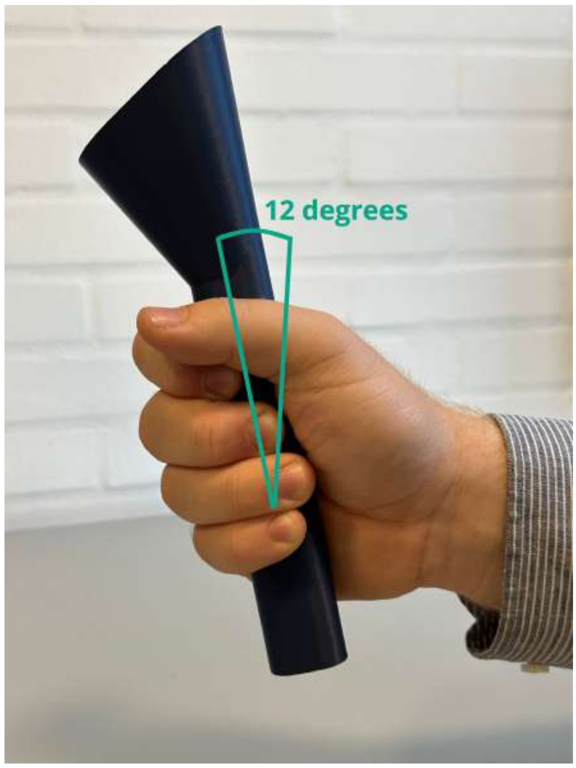


Figure 2.3: Illustration of the 12 degrees angle

they are instructed to say what comes into their mind during testing. These thoughts are not limited to just practical considerations, but can also include emotions when using the product, aesthetic opinions or just describing what they think they should do before doing it[31]. This method was chosen, as it allows for gathering a wide range of insights from just a few informants. Additionally, it allows for a more explorative process, where the interviewer can ask follow-up questions or simply perform observations of what the informant is doing.

2.2.3 Net Promoter Score

The Net Promoter Score (NPS) is a tool typically used to evaluate customers' satisfaction with a product, and thereby their loyalty as customers [32] and potentially predict growth. The fundamental idea is to ask customers "*How likely is it that you would recommend *brand* to a friend or colleague?*" on a scale from 0-10 where 0 is "Not at all likely" and 10 is "Extremely likely"[33].

Customers are then grouped into one of the following three groups depending on their answer, which aims to describe their characteristics as customers [33]:

- *Promoters* (9-10): Likely to purchase for the company again and promote it to others.
- *Neutral* (6-8): Satisfied with the product, but not loyal to the company or product.
- *Detractor* (0-6): Dissatisfied customers who are not expected to return and who can damage the brand through word-of-mouth.

With data from a range of customers, the Net Promoter Score itself can be calculated as $NPS = \%ofPromoters - \%ofDetractors$, resulting in a score from -100 to 100 with 100 being the best. In this project, the idea of the NPS system is used to evaluate prototypes. By asking users to rate different aspects from 0-10 and then using the NPS formula, specific aspects can be quantitatively compared.

2.3 Technology

The main technology used within the project is near-infrared (NIR) spectroscopy via discrete specific wavelength emitters and a broad spectrum sensor. Therefore, the coming section describes the principle of discrete NIR.

2.3.1 Polymer identification via NIR spectroscopy

The method of NIR spectroscopy used in the project, is based on measurements of the relative light intensity from a material caused by molecular overtones and vibrations of the material when exposed to electromagnetic radiation with a wavelength of 780 nm to 2500 nm. The typical molar absorbance is significantly weaker within the NIR spectrum than in the Midrange infrared (MIR) spectrum from 2500–25.000nm [34]. On figure 2.5, a full NIR spectrum scan is displayed with the specific wavelengths used by the PlasticScanner highlighted. These wavelength are selected based on a combination of specific polymer reflectance at certain wavelengths, general availability of LEDs with the wavelengths, established wavelength ratios and to conver a wide area of NIR.

The PlasticScanner concept uses relative reflectance, i.e. the ratio between absolute reflectance of two wavelengths measurements of the same environment, to estimate the material. This is based on Beer-Lamberts law.

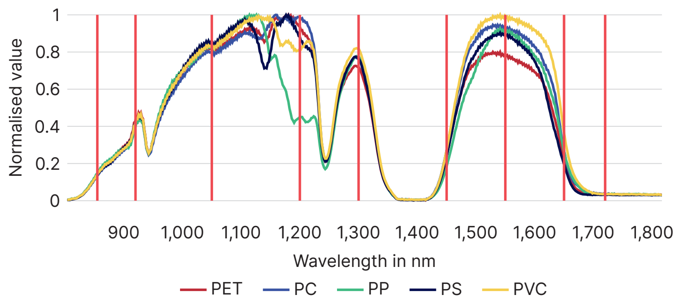


Figure 2.5: Spectroscopy plot, with PlasticScanner wavelengths (red lines).

Beer-Lambert Law

When light passes through an absorbing material, the intensity of the light emerging from the absorbing material is reduced. The incoming light intensity of monochromatic radiation is I_0 and the emitted radiation is I. If the material is absorbing the radiation $I_0 > I$ The transmittance (T) of a material exposed to a specific radiation, is described by the fraction of the original light emitted by the material [35]:

$$T = \frac{I}{I_0}$$

T remains relatively constant even if I_0 changes, because the emitted radiation is I will increase relatively proportional to I_0. Therefore, the transmittance is independent of the actual intensity of the incoming radiation I_0, but rather a material constant that can be measured from the ratio of the input and output [35]. The absorbance of a material is the opposite of transmittance, and is described by[35]:

$$A = \log \frac{I_0}{I} = \frac{1}{T} = -\log T$$

The Beer-Lambert Law describes the absolute absorbance of a material A is directly dependent on sample thickness b, the absorptivity a and the concentration of the absorbent c, expressed as: [35]

$$A = a \cdot b \cdot c$$

Beer's law shows that there is a linear relationship between absolute absorbance of a material A, the absorptivity a and the concentration of the absorbent c, if the thickness and radiation wavelength is constant. Furthermore, by using the relative absorbance between measurements, the transmission through a finite thickness of particulate material does not formally represent reflectance due to extinction, as a result of both transmission and reflection being as a function of the thickness [35], [36]. This enables the scanner to use the relative transmittance to identify polymers based on the material specific molar extinction a and the concentration of the absorbent [37], [38].

Related work

In 1995 D.M. Scott proposed a technique for distinguishing PET from PVC, by that PET may be distinguished from PVC due to the first overtone of C-H stretching. This makes it possible to distinguish the materials based on the ratio of reflectance at 1716 nm to that at 1660 nm [39].

In the same way, M.K. ALAM proposed that it was possible to use a few strategically chosen wavelengths in combination with neural networks, to successfully identify polymer resins, without the need for the whole spectrum, enabling identification through multivariate instead of the more costly hypervariate spectroscopy [40], and similar results have been obtained by a research team led by D. Wienke [41].

Masoumi et.al. further proved that it is possible to identify the five most common types of plastic, based on spectroscopy in combination with machine learning, and normalisation and data processing via Beer-Lambert law. While the team obtained a success rate of 90%, using NIR, the use of NIR which means that it is not possible to scan transparent and black plastics since the material absorbs all or nothing [42].

3. Development

This section first introduces the final product, and then describes the development process of the project, the decisions, the challenges and the found solutions.

3.1 Final product

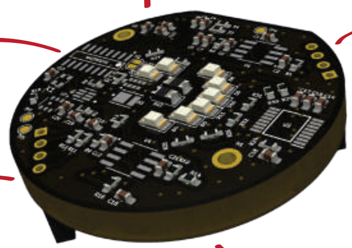
The developed product is an affordable handheld plastic scanner, capable of gathering and processing the data necessary to identify a polymer type.

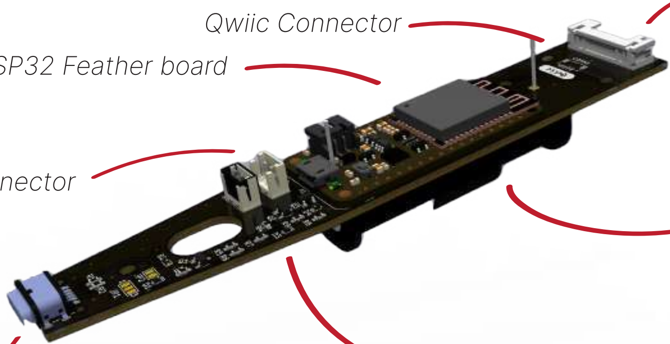
This enables users to easily identify and sort plastic waste. It includes three main physical artifacts and an accompanying firmware package.

The physical shape is a shell design consisting of two pieces for easy manufacturing and assembly, while including ingress protection.

The shape is designed and tested to ensure both comfort and functionality.

The electric functionality is driven by two separate modular PCBs: one for collecting data (called the scanner PCB) and one for computation and controlling the hardware (called the controller PCB).


Two InGaAs sensors
8 NIR emitting LED’s
NAU7802 24bit ADC
Pins for debugging
Qwiic connector


Screen
connector
Qwiic Connector
ESP32 Feather board
Button connector
14155 Battery
holder
Latching cirquit
USB-C

3.2 Development process

The development process follows the Double Diamond process, proposed by the British Design Council in 2005 [43], [44]. The Double Diamond process consists of four phases. Two phases are focusing on the process of exploring an issue or problem space (divergent thinking), and the other two phases are focusing on taking action and deciding on solutions (convergent thinking)[43], [44].

Since the development process followed this structure, it makes sense to structure of the development section to help the reader understand the process and progression in the same way as the actual development.

Discover

The discover phase is about discovering the context, the user, the user needs, and the problem. It requires interacting with the user and other people affected by the scope of the project.

Define

Based on the findings of the discover phase, the define phase is focusing on narrowing down the scope of the project, to a manageable problem space. The output should be a clearly defined problem, that should be sought to solve in the second diamond.

Develop

The development phase should explore the solution space and develop solutions to the clearly defined problem. This includes testing, prototyping and trying various solutions.

Deliver

The deliver phase is about shaping the developed solutions into a single output, that is tested, documented and made ready for implementation, and relevant reflections on improvement has been made.

Of course the process is not as linear as outlined above. A team will go back and forth. Findings of underlying problems can send a team back to start, or developed prototypes can indicate misunderstood user needs. The phases can be understood as mindsets and give the project team a common language to describe what kind of phase the team is in at a given time.

3.3 Discover

As this project is building upon previous work in both commercial and non-commercial directions, there has already been put in a lot of work into understanding the user, the needs and how a PlasticScanner product might solve these needs – and which functions a product should have. In this section we will take a step back, and try to explore the user context again, to see if the findings correlate with previous work within the PlasticScanner project. Furthermore, the section covers the process of exploring the problem space, describe and discuss the findings regarding the context, the user, their needs and the underlying problems found through the process.

3.3.1 Problem space

In 1997 the European Commission created a standard for voluntarily marking the resin type of polymer with a physical symbol on a product [45]. The standard was inspired by and compatible with the American RIC system, developed by the American Society of the Plastics Industry in 1988 [46]. The standards both agree on the symbol for the most commonly used consumer plastics: PET, HDPE, PVC, LDPE, PP, PS and "other". The symbols have since become the industry standard for sorting thermoplastics, since the 6 types of plastic covers about 87% of the global plastic waste [47]. The standard does not describe the additives of the polymers in question. Most commercial polymers contain added fillers or additives to customise the mechanical properties of the material or use a secondary material as filler for economical or mechanical purposes. This further adds to the complexity of plastic recycling, because even if a tonne of items is all labelled with a triangle with the number 5 inside for polypropylene, it is not necessarily good to mix them. Some items might contain chalk for giving a white colour, others bromide as a flame retardant and some a UV-stabilising additive, making it is hard to mix the unknown combinations in a way, that results in a relatively consistent output.

The chief quality engineer at Plastix compares their process to a whisky distillery with varying quality. In order to output a consistent output, they blend the various batches and even out the good and bad batches. The key to success is being good at blending, and knowing which parameters to blend.

Sorting strategies

There are two main strategies for sorting plastic in large quantities. The first is batch sorting, where the recycler has a diverse unknown batch of plastic as income, breaks down the incoming items into smaller parts, which are washed and dried before using a series of tests to separate one type of plastic at a time, via e.g. density/flotation, centrifugation, electrostatic sorting or laser aided separation [48], [49].

The other method is “in-line”, where each incoming plastic item is identified based on sensors, skill or visual marking. This method can either be done manually by hand or automated via process lines combined with robot arms, actuators or other means of separation [48], [49].

The automated in-line systems are commonly seen in modern recycling installations handling household and municipal waste, whereas the manual and handheld approach more often is used in research applications & quality assurance, due to the ease of implementation. Automated inline systems have a clear advantage when the input items are small and diverse in type, whereas manual identification and sorting have an advantage when applied in a context with items too large to enter process lines, or batches known to be equal, but unknown type. Furthermore, the movable design will have an advantage if the place of identification is not static, but subject to change.

Near-infrared spectroscopy

A popular identification method is NIR spectroscopy. Different companies use specialised equipment within various wavebands, in order to get the best results for their application. Several companies use the mid-infrared (MIR) waveband, where several atomic bonds have overtones, and therefore can be used for the characterisation of molecules.

There are two strategies for NIR spectroscopy. One is multivariate spectroscopy, where one measures a small series of strategically chosen wavelengths. The other is Hypervariate where one aims to minimise the difference in wavelengths between data point, making the spectroscopy graph as close to continuous as possible [40].

NIR emitting and metadata point

An often-used strategy in the industry is broad spectrum emittance, using e.g. quartz halogen light bulbs that emit a broad spectrum of wavelengths, which makes it necessary to use a selective wavelength sensor to get data on multiple wavelengths. Another strategy is to use specific wavelength LEDs and measure the intensity of the reflected light emitted by a specific emitter. The LEDs can both be produced as arrays or as individual LEDs. The broad spectrum strategy is often used in industrial settings, and with relatively high power consumption, but also a high light output making it possible to get lower noise levels on readings. The specific wavelength LEDs cost from 0,5-18 € depending on the wavelength, whereas tungsten halogen lamps are significantly more expensive [49], [50].

To measure the light intensity, there are various strategies as well. For single data point solutions, it is possible to have an InGaAs sensor capable of measuring the waveband from about 800-1800 nm, depending on the sensor. The InGaAs sensor will output one signal for the sum of intensity across the spectrum. To measure a specific wavelength, it is necessary to only emit the specified wavelength, or add a variable filter on top of the sensor, to only control which wavelengths are passed through the filter into the sensor. This is called a MEMS sensor.

Companies like ST microelectronics and Sony have developed digital camera-style sensor arrays, enabling camera-like outputs, as used in e.g. PolySort. These cameras have a price of about 10k$ USD [51], whereas a single MEMS sensor unit has a price of around €3000 [52], and a single InGaAs sensor costs €7 [53].

Current market

According to a report developed for COWI, the financially viable automated plastic sorting facilities have an estimated input capacity of 1-3t/hr, and costs for a plant are in the range of 2-4M €/(t/hr), with the smallest proposed setup being priced at 3M € for a 1.2t/hr setup and a 80% recovery rate of plastics [49]. A smaller setup has been proposed by The Danish Environmental Protection Agency as a part of the PolySort Project. The project utilises SWIR in combination with MIR and smaller conveyor belts. The test setup proved capable of 90% recovery and an input capacity of 0,2t/hr. The price is not disclosed, but based on price vs. input capacity tendency from [49], the price might be around 0,5M €. The PolySort project has not been continued, to the knowledge of the authors of this thesis.

A mobile manual identification device will not be able to identify as many items per hour as an automated setup, and the use of manual labour in high-wage countries will possibly make the running costs of manual identification not financially viable for sorting household waste. On the other hand, a machine with an input capacity of 1t and a price tag of 3M€ would need to be utilised fully, in order to make a sustainable business case, if the financial gain of 1t plastic is roughly €500, before considering maintenance, manual labour, service, or energy consumption or transport [48], [49].

The EU directive on single-use plastics, states that all member states must initiate plans for reducing the environmental impact of specific plastic products [54]. This has made European governments introduce legislation, requiring manufacturers of specific plastic products including fishing gear to cover costs associated with information measures, collection of end-of-life fishing gear and subsequent transport and treatment of the waste, as well as the costs associated with the collection and reporting of data [54], [55], which has been approved by the Danish government as of August 2022 [56]. This makes produces of ropes responsible for developing ways to get the ropes recycled, and it makes harbours responsible for rough sorting plastics on location in EU.

With fishing gear being a relatively consistent product, sorting a whole net, based on a few scans with a handheld scanner, might be more efficient than chopping the whole net into manageable chunks to run it through an automated sorting machine. Furthermore, it will only be possible for very large machines to handle a net. One net could weigh several tonnes [55], making one fishing net take up the sorting capacity of a small machine for hours.

Handheld scanners have been on the market for some time, with the Thermo Fisher being the industry standard for handheld spectroscopy. The price tag for a microPHAZIR is €30.000, making it difficult for small and medium-sized companies and startups to afford a scanner. Other Kickstarter projects and smaller startups have made their way to the general market, but are often characterised by a very specific application and unproven performance.

3.3.2 User research

Experience from BessTrade

Previous work in the PlasticScanner project includes a visit to Dutch PVC recycler BessTrade. During a visit to the company's site, their challenges with performing rough sorting were presented to the team. Currently, the team uses a worn miRoGun4.0 to scan plastics [57]. However, BessTrade experience that the miRoGun is heavy at 1,3 kg, cumbersomely designed, more advanced than what they need and too expensive at +€15.000. As a result of these drawbacks, the scanner was not used as much as they wanted. BessTrade described how a more accessible scanner would be desirable, in order to better fit the employees sorting material on the production floor. Additionally, an accessible scanner would also allow them to better help their suppliers in providing BessTrade with actual PVC, as it can be difficult for some suppliers to know the types of plastic they have. For BessTrade, a scanner should be durable, water-resistant, easy to use and inexpensive [57].

Online meeting with Plastix

Plastix in Lemvig, Denmark, is a company that specialises in recycling post consumer fishing nets and other types of rope products, by turning the ropes into plastic granulates, sold for production of new products. In order to gain a better understanding of the needs of plastic recyclers, an online interview was conducted on the 9th of September 2022 with Henrik Adam, who is head of quality at Plastix. As head of the quality, Henrik's main responsibility is ensuring Plastix create high-quality plastic, which can be sold to customers. This can be a challenge, as every delivery of rope is different, often with a wide span in fibre colours, materials, quality and mixes between multiple fibre types in one rope. Each time a new batch of material arrives at Plastix, they have to analyse the material to be able to create a consistent product. For Plastix, it is extremely beneficial to know what polymer type, e.g. PP, they are expecting to receive, as it enables them to easier find the required properties in the stock of ropes. If Plastix cannot reliably know what plastic-type they are expecting to receive, they risk purchasing material they cannot use, essentially waste they now have to handle.

Their current initial rough sorting system relies heavily on manual labour, experience and a polymer scanner. Once the rough sorting is done, Plastix has industrial process equipment for preparing the rope for recycling, and manufacturing pellets. The details of this process are kept as a trade secret.

Plastix site visit

As part of this thesis project, the group visited Plastix on the 20th of December 2022 to see their operation, better understand their needs and explore how a low-cost plastic scanner could be relevant for them. During the visit, the group spoke with Hans Axel Kristensen who is co-founder and CEO, and with Henrik Adam who is head of the laboratory.

During the visit, the need for a cheaper and more flexible plastic scanner became very clear. Plastix currently uses a Thermo Fisher Scientific microPHAZIR to identify polymers. This scanner is a handheld device weighing 1.2 kg. While it does provide Plastix with good results, it is cumbersome to use and takes up to 10 minutes for the light source to warm up. Furthermore, their scanner is getting worn, and a replacement costs €30.000. The steep price simply limits Plastix to acquiring just one scanner[58].

3.1 Visit at Plastix

The material Plastix receives typically arrives in mixed batches with a range of types of ropes. The ropes often consist of multiple types of polymers to give the ropes the specific properties needed. The first step in Plastix's recycling process is to do a rough sorting of the ropes, where the plastic types of the various ropes are identified and sorted accordingly. This identification is typically done with their microPHAZIR scanner, or a smaller sample is taken back to the laboratory for further analysis. This rough sorting is key for Plastix to create their PP and HDPE granulates. Hans described the urgent need for lower cost and simpler plastic identifying devices in the fishing industry, as a new EU directive is going into effect in 2025, where harbours are required to do a pre-sorting of all plastics they bring back [58]. Hans suggested

Thermo Fisher should lease their scanners to harbours, as the up-front price was too high, but they were not interested. Furthermore, Hans describes how employees at harbours do not have the expertise to effectively use a microPHAZIR due to its more complex interface and functionality. And even if they had the expertise, the price makes it so that people do not want to bring the microPHAZIR with them [58]. When introduced to the handheld version of the PlasticScanner project, the enthusiasm and need in the industry were clear:

> *"I think we should buy one in the beginning of the new year, and then you can just deliver it when it's ready".* — Hans Axel Kristensen
>
> *"We could get it to (harbours, red.) Norway tomorrow. They are desperate!"* — Hans Axel Kristensen

For Plastix, receiving material that has already been pre-sorted would improve their ability to quickly manufacture new high-quality materials. And with customers such as BMW and Rema1000 needing a continuously increasing amount of material, anything which allows Plastix to increase production is beneficial. When presented with a price estimate of €1000-€2000, Hans described that: *"€2000 would NOT disrupt any business case for Plastix"*.

3.3.3 The PlasticScanner ecosystem

OSH Considerations

The goal of the Plastic Scanner is to enable individuals, organisations and companies to better identify plastic types and thereby enable them to implement the knowledge in their situation, process, or product. As described in the Requirements section, different types of customers have a wide range of requirements and needs for the plastic scanner. It is important to recognise that customers also have requirements for the business and that the various needs of the customer types will influence the business model of the Plastic Scanner. For example, an individual at home might prefer the product to be hackable, have a low price and be available as a do-it-yourself (DIY) kit. Meanwhile, a business customer might rely on the Plastic Scanner as part of their operations and therefore value the reliability of purchasing through a company that offers official support, availability of finished products and repair services.

In its current form, the PlasticScanner project operates on an open source volunteer basis, with individuals who contribute to the design and development of the PlasticScanner. However, it is important to consider expenses for tools, parts, licences, prototyping and so on, which the project currently relies on grants for.

For the PlasticScanner organisation to offer services such as official support and repair services reliably to customers, the PlasticScanner needs to consider the business model and generate revenue to support employees, manufacturing, and development of future iterations. This way, the PlasticScanner organisation can keep supplying support, spare parts, repairs, new scanners, improvements and so on. At the same time, the PlasticScanner is an open source project and most, if not all, files to replicate the scanner will be available online. Considerations must be done regarding how to avoid another party copying the product and simply undercutting the PlasticScanner offering for the project to be sustainable. Thus, the strategy is to provide enterprises with a full stack from hardware, firmware, libraries and accessories to enable scaling from prototype to production seamlessly.

3.3.4 Open source hardware ecosystem

Through the teams research on value creation of open source hardware projects, one thing comes up repeatedly: community is everything [10], [59], [60] To find out how to design the business model for the PalsticScanner project, it made sense to not focus solely on the business model, but rather take a holistic approach, and look at the OSH ecosystem. As a part of OPEN!NEXT, the Danish Design Centre developed a framework for designing OSH ecosystems, which the team will use to lay out a strategy for the PlasticScanner Ecosystem.

Customer exploration

The first question to ask is "Who is the customer?". Next up is the question: what they want to do with the project, and what they want to achieve by using it. Lastly: How can the PlasticScanner OSH offering help them achieve this?

Based on the list, the team assessed where in the life-cycle of the PlasticScanner project the proposed customers would intervene, and mapped it in model 3.2. Here, makers, students, and maker spaces are listed as the early adopters. Potential commercial customers as mainstream customers and specific actors who need the technology to a degree, that makes them willing to compromise on maturity and accuracy are placed in the middle as early adopters.

The PlasticScanner has an online community, that engages through a messaging server on a service called Discord. When looking at who is active and contributing on the discord server, a pattern can be observed of individuals with a high level of interest in making a plastic identification tool themselves, and not necessarily for a specific or commercial application. Several of the contributors seem to have an interest or an involvement in maker communities. Of the contributors, several have publicly starred or forked several maker projects via their GitHub profile, which makes us classify them as "makers".

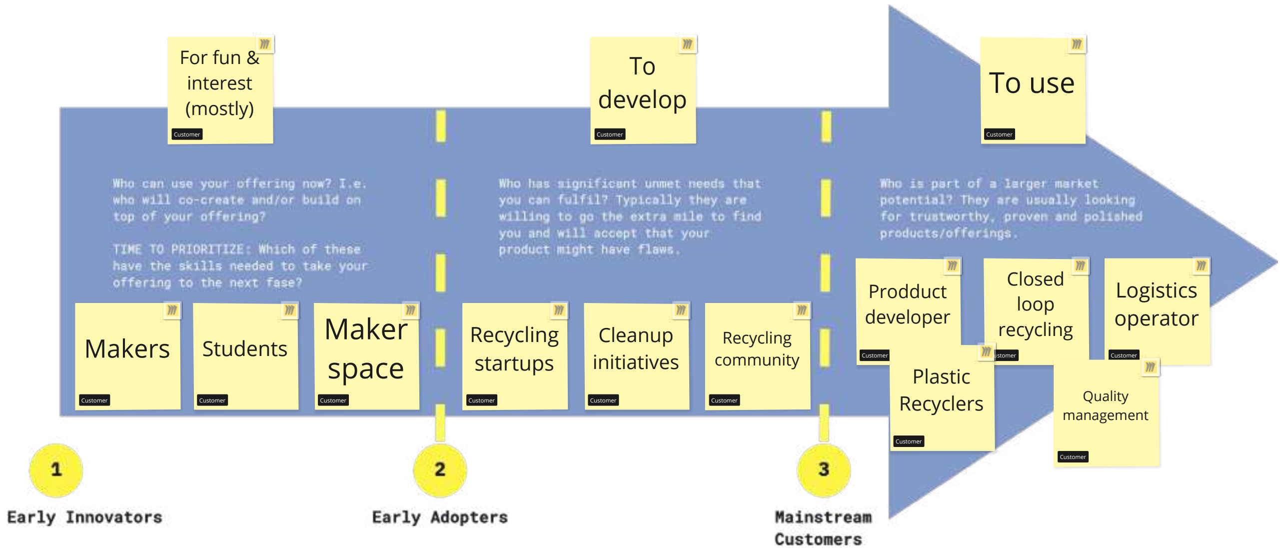
The CEO and Chief Quality engineer at Plastix both agree that they need a product like the PlasticScanner yesterday, and they made it clear that they are willing to put down the money now, even though it was made clear to them, that the maturity and scan quality of the scanner is not ready yet.

> *"We need it operational and quickly." "Then we can go from there". -Hans Axel Kristensen*

The full list of potential customers can be seen in the appendix A.2.

OSH Offerings

From the customer mapping, the team mapped out what OSH offerings the early innovators, early adopters and the mainstream market are interested in, and which early innovators might be willing to contribute to which offerings.



3.2 Customer mapping over time

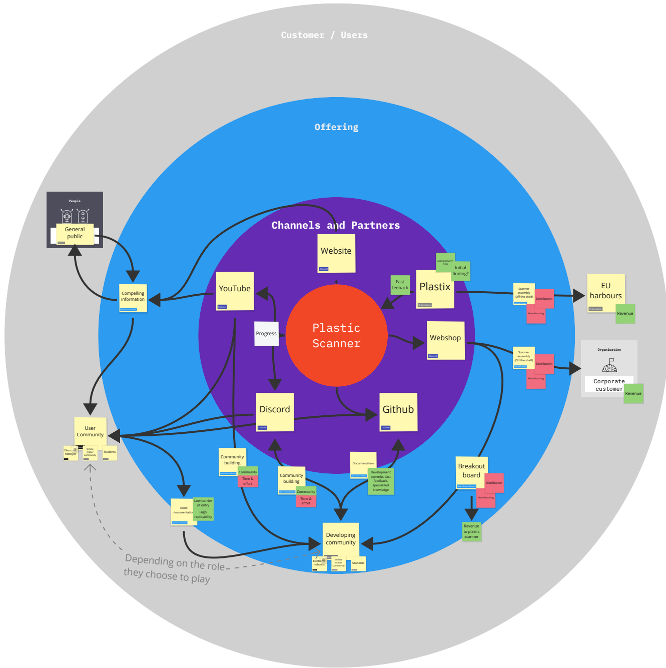
In figure 3.3 main OSH offerings are mapped for the early innovators as being a development board, good documentation and a community.

Offering

It was found that the development board is an offer directed at makers, students, and maker spaces. It is a tool to break down the barrier of entry, by making it something you can buy and tinker with, just like a temperature sensor or 8-digit screen off Sparkfun.com. It will enable the PlasticScanner project to make an educational kit, with guides, tasks, and ideas for further development.

Infrastructure

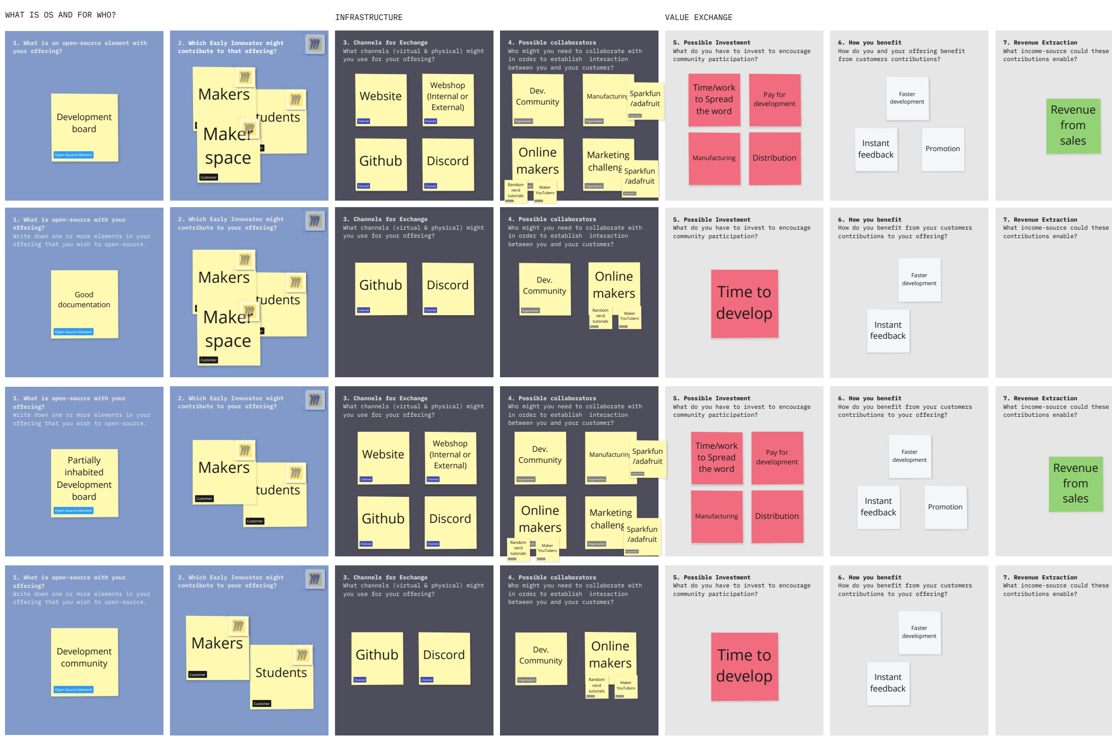
To get the offering out to the customers, infrastructure is needed. Here the community is again a key factor, which the project revolves around. By creating an independent sales channel or using an existing external one, the PlasticScanner project make it possible to get hands on the board and get information on how to use it via online documentation on the website and GitHub repository.



3.4 Ecosystem mapping

Value exchange

To have a populated development board that works, would cost resources for development, manufacturing, marketing, and distribution. But it will make the barrier of entry a lot lower, and thereby make the technology more accessible. It will make it easier to attract heavy contributors within software and data analysis, when electronics is not a necessary skill to master to make a board. Furthermore, it will become easier to just buy the board and implement it in other use cases, but in any case, generate sales revenue for the PlasticScanner project.



3.3 Ecosystem building

Ecosystem mapping

The team mapped the various offerings, partners, channels, and customers in an ecosystem map, which can be seen in figure 3.4. Here it becomes clear, that the discord and GitHub channels are the main value creators for the developer community, but the YouTube channel and website are what attracts the public into our ecosystem, from where good documentation and community knowledge can lower the barrier of entry from going from the public, to the user community and then to the developer community.

The sale of scanner PCB's online is a key channel to bring in revenue for the project. By initially selling development boards to the community, the PlasticScanner project can drastically lower the barrier of entry, and help the community to grow. When the scan unit matures over time, the natural expansion is to off-the-shelf scanners with support and potentially custom enterprise products as well. Here Plastix can be a main partner, making the connection to EU harbours who are required by EU law to perform rough sorting in 2025[58].

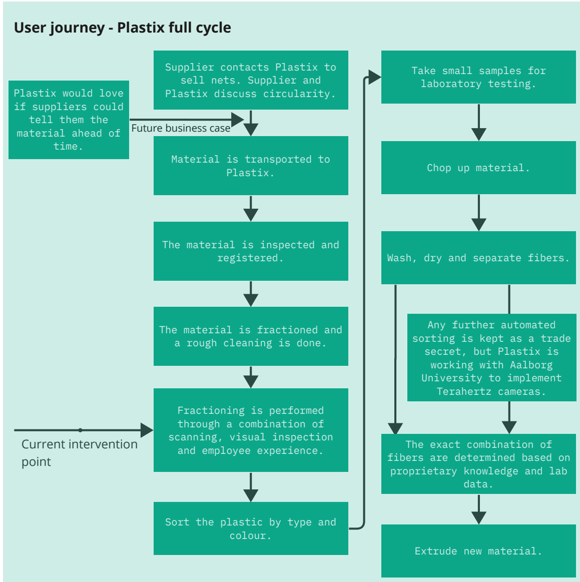
3.3.5 User journey

The OSH ecosystem mapping indicated two key user types. The commercial users and the community. In this section, the team will further explore how the users act, what their needs are and how a PlasticScanner can address those needs.

Small scale, specific source recycler

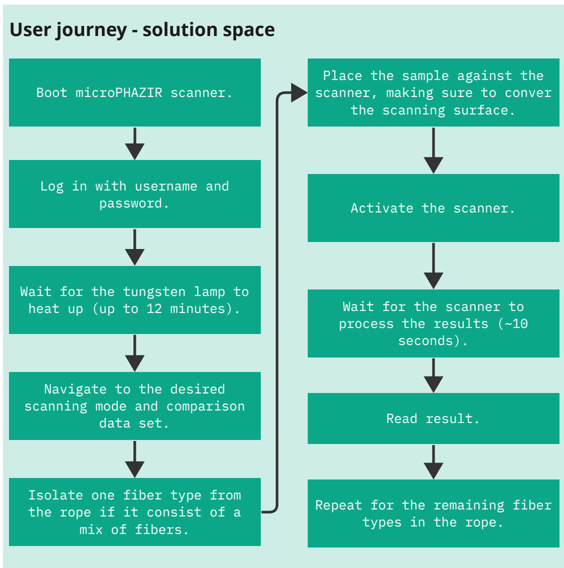
User journey: Plastix

An example of a commercial user is Plastix. They not only sort plastic post consumer waste, but also manufacture new material from the waste. An important part of Plastix' operation is the rough sorting performed of newly received material [61]. This rough sorting is a key area, where better process can improve the experience for Plastix, as they are limited by their current scanning solution. The scanning steps in the rough sorting task are highlighted on the user journey map on figure 3.5



3.5 User journey map for key activities at Plastix

Plastix face multiple challenges with their current scanner used in the rough sorting process. Firstly, new users have to receive training in using the device. While the microPHAZIR scanner is simple to use when the correct scanning mode has been selected, the path to getting there is not intuitive. It involves a login system, instructing the lamp to heat up, and selecting the specific scan mode the user wants to use. The steps are visualised on figure 3.6.



3.6 User journey map for Plastix identification process

The current scanner experience and use is overall slow or unresponsive. Not only does it take a long time to boot and warm up the scanner, but the user experience when navigating and awaiting scan results can also be experienced as unresponsive[58]. Amplifying the challenge is the very high price of the scanner, thereby limiting how many employees can effectively sort material at the same time. New sorting employees are more likely to need the scanner often, as they might not have the plastic fibre experience necessary to identify through a combination of experience, visual inspection and the feel of the fibres. And even experienced sorting employees often use the scanner regardless to ensure their sorting is correct [58].

Importantly, if Plastix could move the majority of the plastic identification from in-house after receiving the material to be done by the supplier, Plastix could benefit from increased flexibility with the additional knowledge of material expected to be delivered. It would allow Plastix to better predict future deliveries and thereby better plan production. While it would require the suppliers to perform a rough sorting, a system for documentation and checks between the source and Plastix would still need to be developed, to ensure that the plastic documented is also the plastic that is sent and received.

During the team's visit to Plastix, they expressed an interest in incorporating the PlasticScanner themselves, but were also prepared to require their suppliers to use the PlasticScanner devices: *"We could go out and support you by requiring our suppliers to use this, easily" -Hans Axel Kristensen*[58].

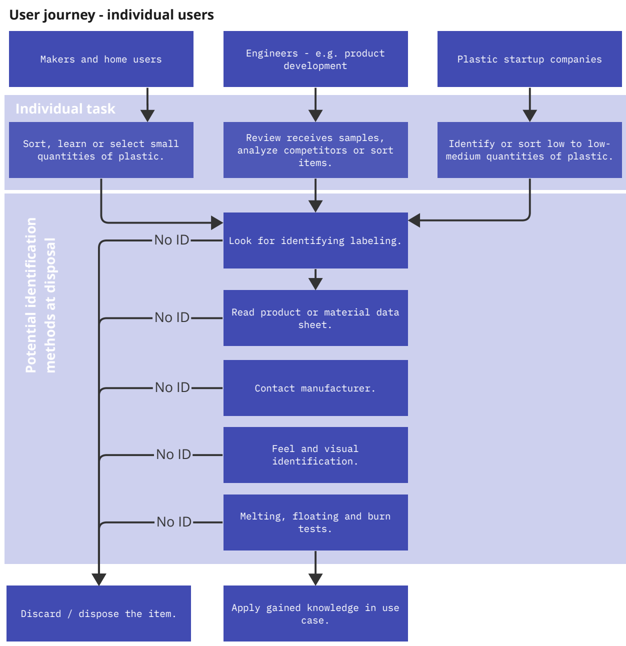
The need for an early identification method is also noted by the recycler BessTrade, who require potential suppliers to ship a sample to them for analysis before receiving any more material. If BessTrade or Plastix end up receiving another material than they were expecting, they essentially end up with waste they now have to find a way to dispose of.

These challenges are key areas where the PlasticScanner function as a remedy, by significantly reducing the time it takes from picking up the scanner, until the first results are displayed to the user. An affordable scanner would furthermore offer Plastix more flexibility, by simply allowing them to purchase additional scanners and thereby equipping more employees with scanners for reduced overhead in picking up the scanner and rotating between users.

User journey: Individuals

There are multiple individuals in various industries and situations who need to identify the type of plastic more occasionally. Currently, if a part is not labelled with the plastic type, the individual needs to perform a series of tests, including a float test and burn test to attempt to identify the material [62]. By considering the user journey for identifying a polymer and applying the knowledge to the required area, as seen on figure 3.7 , it becomes clear that the need to identify a polymer can quickly block a specific process, leaving the individual without a solution. Instead of relying on extensive polymer experience or complicated identification flowchart processes, the PlasticScanner allows these users to quickly and confidently identify the plastic type.

Easy and cheap polymer identification opens up the user journey for more possibilities for the individuals, allowing them to further develop their business or innovate new areas.



3.7 User journey for individuals needing to identify plastic

3.3.6 User needs

To understand the user of a proposed handheld scanner, a persona, or user definition, has been developed. As mentioned in section 3.3.5, the user of an open source handheld scanner can take two forms. A professional person, and a private person. The two personas are based on the teams' interaction with Plastix, BessTrade, other professionals and the interactions with the online community of PlasticScanner.

User A: A sorting professional

The user A is a sorting professional at an industrial resource facility.

Needs:

The user needs to identify the polymer in order to determine if the material can be used, and in the case of a possible use – how to handle the material.

Pains:

The user is lacking knowledge on what the type of polymer a given object is made of. The user want to obtain that knowledge because it enables the user to determine how to best utilise the material, and create as much value as possible for the company.

The barrier currently holding the user back from obtaining this knowledge is access to utilities, which are limited due to size and high price, which is not to allocated by the company for the user's tasks.

The product needs to make a shift from making plastic identification inaccessible to being a natural part of the user's routine.

User B: An individual maker.

The user B is a hobby maker. The user is interested in tinkering and programming of electronics, and finds the topic of solving environmental problems with technology interesting.

Needs:

The user need is not as present as the need of the professionals. The user needs are related to the interaction with the project, here the user need clear documentation, an overview of what to do and how to replicate the project. Furthermore, the user values an active community, where their opinions are heard.

Pains:

The user has previous experience with faulty or missing documentation. The user finds the barrier of entry high, due to the high cost and complexity of the project.

3.4 Define

In this section the findings of the discover phase, is processed, weighed and sought narrowed down to a clearly stated problem and a possible business case for a plastic scanner concept, to be developed in the next diamond (development and deliver).

3.4.1 Problem definition

With the current market of industrial sorting machines already using NIR spectroscopy with more advanced InGaAs image sensors, and combinations of NIR and MIR spectrum sensors, the assumption of the team is that the production volume of scanners for automated sorting facilities is rather low, and high precision and flow is required. MEMS sensors or variable filters have the benefit of enableling a single sensor, to filter out specific wavelengths, where a typical InGaAs sensor or image sensors let all infrared light within the specific spectrum, and the source or filter therefore need to be put in place to enable measurement of a single wavelength.

The current technology of the PlasticScanner Project is an ultra-low-cost discrete multivariate NIR spectroscopy, which utilises only off-the-shelf components. To obtain low noise reading with a high light intensity within the NIR waveband, it is necessary to get the sensor and emitting LED as close as possible to the subject as possible and block environment light as much as possible [38]. This requires the scanner to be physically moved to within 1 cm of the subject, and have a solution for environment light blocking. To scale up the PlasticScanner technology, to a fully automated setup, one would need to find a solution for identifying surfaces, moving the scanner and afterwards moving the subject based on the scan results. The team does not consider the existing technology of the PlasticScanner project to be competitive within the scope of in-line automated plastic sorting described in section 3.3.1 The sourcing of hardware of MEMS sensors is "on-demand", with prices being presented "on request", and typically with prices for components alone ranging from €1000 for a very limited wavelength spectrum, and upwards if the spectrum should match the current 850-1700 nm [52]. This makes the project inaccessible for an open-source hardware community, which does not have the financial capabilities to buy MEMS sensors for several thousand euros, and the barrier of entry is significantly raised, even for companies pursuing OSH projects, when the start-up costs are at the high end. Furthermore, the typical application of InGaAs image sensors seem to be focused on broad spectrum measurements, e.g. the sum of sensor response across the sensor spectrum, or in combination with a specific wavelength filter [63].

When analysing the user journey of a small-scale recycler with a focused source such as Plastix, it is clear that there is a challenge regarding measuring and documenting the input quality, which is affecting the effectiveness of the supply chain of input material, and the utilisation of the input material by Plastix. The current price of the major competitor of the Thermo Fisher microPHAZIR is astronomical, compared to the component prices of the previous work of the PlasticScanner project. Users like Plastix and Besstrade have both expressed that the price of the current handheld scanners, is making handheld scanning inaccessible. Furthermore, the current and upcoming legislation due to the EU directive on extended manufacturer responsibility and national implementations of this requires harbours to rough sort all plastic waste, but the harbours do not have an input volume large enough to sustain an automated setup [49], [55]. A handheld scanner for rough sorting would enable them to document the plastic type, thus enabling them to sell the material to plastic recycling plants, who in general require the input plastic-type to be known, like the largest plastic recycler in Denmark, AVL A/S [64].

Based on the findings in the Discover and Define sections, the team is of the impression, that the best application of the existing technology of the PlasticScanner project, is to further develop a price-competitive handheld plastic identification tool, that aims to make plastic identification accessible for most applications, with components that are accessible for regular consumers.

3.4.2 Usecases

Based on the problem definition, and the findings of the discover section, the intended use of the handheld scanner has been synthesised into two main use cases for a handheld scanner to fit into:

The screening process

During the screening process, recycling companies have multiple situations where they have to determine the type of material. The first one is if a sample has shipped to the recycler, where the plastic type of the sample now has to be verified to be the expected type. Some samples might contain multiple parts, containing multiple types of plastic, which all need to be identified.

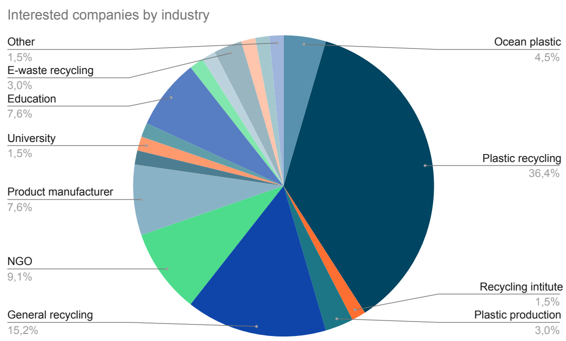
Secondly, a harbour or other material source has to identify the material of an object, to be able of communicating the type of plastic, to arrange further recycling or material handling by a partner company. Finally, when the product is ready to be recycled, it arrives in large quantities at the recycler. The recycler then need to verify the product is as expected and identify potential additional parts which have been included or are mounted to the main parts.

Maker space

The maker space are typically either private individuals or smaller institutions interested in creating artefacts themselves. Their plastic often comes from 3D-printed parts, samples, or parts purchased with no plastic type indicator included.

3.4.3 Interest from the market

While the previous three use cases present the main customer segments, there are other industries who are interested in utilising the PlasticScanner. For these companies, the PlasticScanner presents a value proposition to improve various parts of their business. From the original open source PlasticScanner project, a wide range of companies, NGOs, and government institutions have expressed interest in purchasing one or more PlasticScanners. In total, 67 actors from 17 different industries expressed interest with the majority being companies working in the plastic recycling industry (36 %), with general recycling (15 %), NGOs (9 %) and product manufacturers (8 %) following. The full breakdown can be seen on figure 3.8.



3.8 Companies interested in the PlasticScanner by industry.

3.4.4 Requirements

Based on the insights generated during the discover phase by talking to potential users like Plastix, BessTrade and the online PlasticScanner OSH community, a list of requirements was put together for the PlasticScanner. The requirements are ranked in importance from 1-5 for the scanner and categorised by area and topic. The requirement areas are: Electronics, software, physical design, business model, user experience and documentation. Some of the most critical requirements are now presented, with the full list of in appendix A.5.

Requirement no. 1: Can identify the 5 types of plastic with 90% accuracy when scanning virgin materials with a cross-section larger than 30 mm.

For the scanner to have a use case, it needs to enable the user to identify at least the five most common types op plastic. For makers, adding the typically FDM printer filament materials PLA, PETG and ABS, would be a great market opener for maker spaces as well, but it is not relevant for commercial customers.

Requirement no. 34: The product should enable use with gloves.

This requirement fits the use case of rough sorting on location, for example at harbours, BessTrade or Plastix all require the user so be able to use gloves, which are commonly used by sorting workers.

Requirement no. 16: The product should have a RRP lower than €2000.

The price tag is in the low end for a commercial customer, but for a maker space or developer, it is a high price to pay. To aim for a retail price of €2000 before VAT, is forcing the development process to be cost aware, which should help make sure the product finds a reasonable price. The price is a balance of precision and price, but increasing the retail price, would mean loosing non-commercial customers. Additionally, ensuring a low hardware manufacturing cost would allow PlasticScanner to offer an affordable development kit.

Requirement no. 44: The product should be easily recyclable by avoiding glue or permanent joining of components of different materials.

To have a product which goal is to fight the current plastic problems, also requires the design of the product itself to be designed for recycling. This means prioritising solutions without adhesives, thermosets and permanent joining of different materials like two-cavity injection moulding.

3.4.5 Business model

Going open source is typically something that makes investors turn your project down[65]. In recent years, companies like Arduino have managed to achieve series B investments while staying open [66]. In this subsection, it is described how a business model can be designed to fit the OSH PlasticScanner ecosystem.

3 main strategies has been identified for moving forward:

- Full open-source
- Royalty-based manufacturing
- Full value chain in-house

Full open source

The first option is to keep the PlasticScanner as a purely open source community-driven project. This way, anyone who wants a PlasticScanner would have to either manufacture the necessary parts, both in terms of the plastic shell and the electronic PCBs. This requires knowledge in several fields, everything from 3D printing, PCBs, soldering, assembling, loading firmware and so on. This creates a high barrier of entry to creating a functional Plastic Scanner.

The project would rely on grants and donations to cover expenses for future development, however, this would not guarantee stable and consistent future development, as the project remains a community-driven project. This means the project could be seen as vulnerable by companies, potentially making companies hesitant to invest the time and resources into getting the PlasticScanner made. On the other hand, if a company has the necessary resources, the company can simply fork (create their version) the project and ensure future development for their needs. This business model essentially leaves all primary activities and all supporting activities but community management and technology development to be grabbed by another party.

Royalty based manufacturing

The core of the PlasticScanner project is the community and data analysis for polymer identification. Therefore, it could make sense to outsource the hardware manufacturing and distribution to an external partner like Sparkfun or Adafruit. In this arrangement, the PlasticScanner project would send production files to the partner, and the partner handles manufacturing, logistics and distribution via their existing platform.

Building upon the full open source business model, the PlasticScanner project could choose to corporate with a manufacturer in a royalty-based agreement, where the manufacturer would be responsible for all primary value chain activities and support activities such as procurement and infrastructure. Furthermore, the existing platforms will work as a marketing channel for the PlasticScanner project, because the breakout board is placed where makers find inspiration and hardware components for potential projects.

The Royalty based model gives the advantage that the PlasticScanner project gets the revenue from sales without the cost of a production batch before sales. Partners like Adafruit and SparkFun are great options for breakout boards, which both companies specialise in. For sale of the full commercial handheld product, the project will either need to partner with an existing channel for selling products, or create a PlasticScanner webshop, to better targets commercial customers.

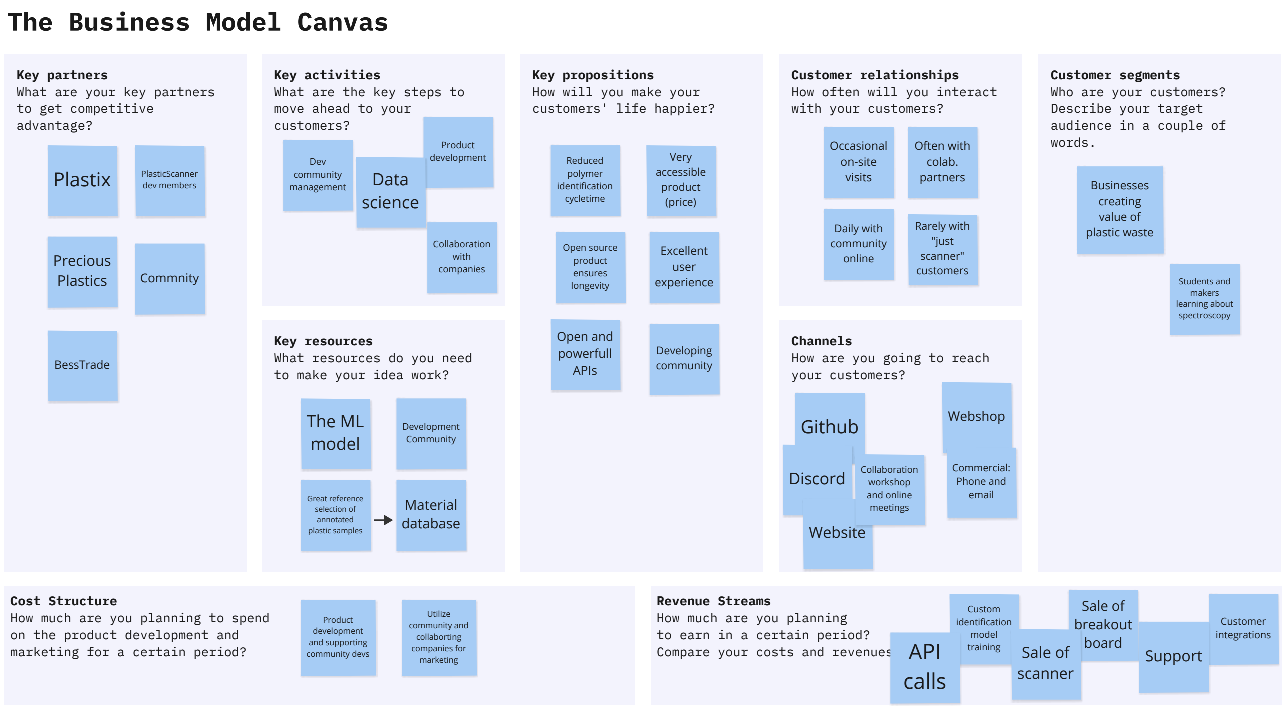
Full value chain in-house

The last option is to have the full value chain in-house, meaning that the PlasticScanner project handles the manufacturing, logistics and distribution of the scanners, and has full control of the whole value chain. This has the advantage that the project has full control of the hardware and distribution, and receives the full revenue. Having a self-hosted webshop will make it easier to handle the distribution and support for the off-the-shelf handheld scanner. On the other side, this strategy will introduce higher costs related to hosting, manufacturing investments, and possibly higher shipping prices compared to higher volume webshops, and the project would need to find marketing channels to drive customers into the PlasticScanner project. Furthermore, the PlasicScanner project will need to handle customer service, warranty etc.

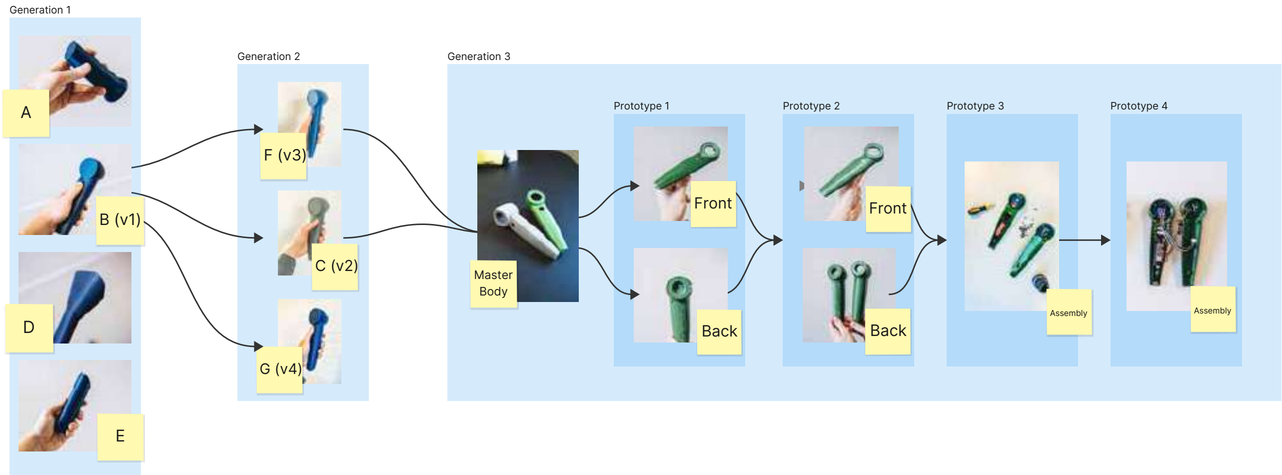
Proposed business model

A business model canvas is used to summarise the proposed business model for the PlasticScanner as a company (Figure 3.9). The key partners are especially the community and recycling companies such as Plastix or BessTrade. Key activities and key resources focus around data science, product development and community management. In terms of key propositions, the PlasticScanner main focus is a very competitive price, great user experience and flexible solution. The PlasticScanner company communications and customer relations are split in two to best fit the community and the commercial customers. Community communications are mainly through wider forums, chats and online workshops. Company customers are communicated with through more direct communications and occasional customer visits.

The primary revenue stream is the sale of products. Additional revenue will come from custom identification model training, online services and custom integrations. Associated expenditures are standard costs of development, manufacturing, and operations. Additional funds are to be spent on ensuring the community is cared for through hardware for active members and alike.



3.9 Business Model Canvas



3.10 Overview of the physical design iterations

3.5 Develop

The following section covers the development of the scanner. The development can be seen as three tracks, which interacts with each other, but are mostly running in parallel:

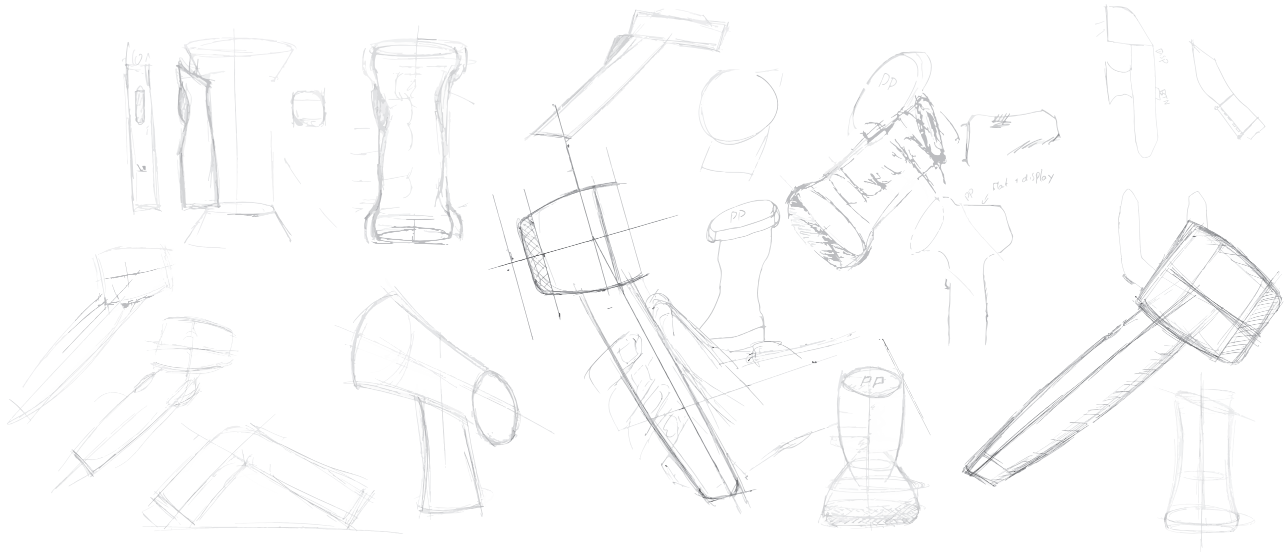
- The physical development of the scanner, focusing on aesthetics, design, mechanics, and manufacturing.
- The hardware development covers the electronics of the product, including the scanner module and the controller unit, and considerations regarding component choice, layout, and design.
- The last track is the software development, which covers the firmware controlling the hardware, and a proposed first draft of a machine learning model for polymer identification.

3.5.1 Physical development

The project builds upon two projects. Firstly, the original PlasticScanner project that aims to explore the functionality of an affordable plastic scanning unit, and secondly the industrial design concept of a commercial scanner, as described in the introduction. The original project focused on functionality, getting the electronics and software to work together, and printing values to a computer for manual processing. The industrial design concept focused on the industrial design of the exterior, and how the product could fit into a commercial context. This master thesis project aims to combine the hardware and functionality of the original project with the industrial design direction of the commercial project, and develop and mature the product as close as possible to a readiness level sufficient for pilot production. This section will cover the development of the physical and mechanical design of the proposed PlasticScanner.

Scope

A major problem with recycling plastics is plastic parts with more than one material. Multi cavity injection moulding makes it possible to have a part of rigid plastic with soft rubber features, making the product stiff where needed structurally, and soft with good grip where needed as well. The technology is well-used in consumer products like toothbrushes where a secure and firm grip is required, or for adding robustness to products meant for harsh conditions. The use of two cavity injection moulding was a part of the industrial design concept from the Delft report as well. The downside to the technology is, that it is (almost) impossible to recycle, as it can be very hard to effectively separate the two materials. To have a plastic scanner, made for recycling plastic, that cannot be easily recycled seems counterintuitive. Furthermore, 3D printing with soft plastics like TPU or creating moulds for casting PUR or silicone will increase the difficulty of making a plastic scanner at home. Therefore, this project aims for using one single material for the enclosure.



3.13 Overview of design sketches

Scanner Shell

The development of the scanner shell is divided into three generations. The goal of the first generation was to develop the general shape of the scanner. The goal of the second generation was to mature and tune the physical shape of the scanner, and develop a master body for further design. The third generation was focused on designing the mechanical design of the insides, based on the master body. An overview of the physical design process can be seen on figure 3.10. A printed version was then used for sketching on top of..

3.14 Component Mockup as underlay for sketching

Mood board

Mood boards were used to draw inspiration from products, designs and for the scanner. This included not only aesthetics, but also tactile details, user experiences, features, and potential scanner shapes and implementations. Two mood boards were created, as seen on figure 3.11 and 3.12, and later used for inspiration and perspective in both sketching and initial CAD models.

3.12 Moodboard 2

Sketching

The physical design exploration started before the electronics that should fit inside had been designed, thus creating the dilemma: How to design for something that is not designed yet?

3.11 Moodboard 1

A method called bounding box design, is often used in the automotive industry [67], and allows the engineering team to set rough bounding boxes that the engineers and designers agree on, which enables both parties to respectively within and around those boxes. Therefore, the size and shape of key components were identified for both PCB and controller, and a rough 3D assembly containing the models were created. Afterwards, printed screenshots from various angles as backgrounds were used for sketching. This enabled the team to take the physical aspects of the envisioned components into account from the first sketch.

3.16 Overview of the first generation designs

First generation

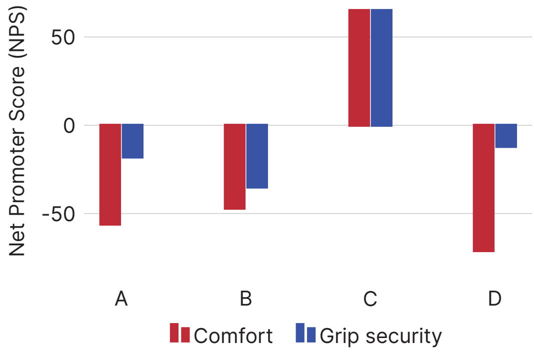
The goal of the first generation was to test if the overall shape of the scanner, presented in the Delft industrial design report [68], was still aligning with user needs. The scanner presented in the report is characterised by a rounded handle extending towards a circular scan head at the top, containing the scanner and screen (see figure 3.15). The full evaluation of the Delft design is attatched as Appendix A.25.

3.15 Scanner concept from Delft

To test whether the overall design concept was fitting the user needs, a series of alternative design concepts was developed and tested with users. These designs are shown on figure 3.16.

User test setup

The tests have been set up as semi-structured tests, based on the semi structured interview method, utilising the think aloud protocol (see section 2.2.2). The test person is first given the model being tested, without being explained how the product is intended to be used, in order to get the test subjects' intuitive idea of how the product is meant to be used. After asking for the immediate experience holding the unit, the interviewee was explained the functionality and intended use of the product. Afterwards, the interviewee was asked to try scanning a small object both standing by a table and sitting, to give the interviewee an idea of the experience of the intended context. Lastly, the interviewee is questioned about their experience both standing and sitting and their general idea of the product. The relatively open structure of the interview/test is intended to enable the conversation to flow freely and to follow insights given by the interviewee. This helps the interviewer to better understand the reasoning of the interviewee's answers, in-



3.17 First generation test

stead of following a strict interview guide that might not give the right insights to understand the whole picture. The downside of the interview strategy is, that it makes it hard to replicate the insights from the open part of the interview.

Finally, the interviewee is asked to rate how comfortable the scanner is to hold and use, followed by how good their grip of the device is, both on a scale from 0-10, where 0 is bad and 10 is great. The scoring builds upon the Net Promoter Score method to quantify the interviewee's satisfaction with the product (see section 2.2.3 for more info).

Learnings from the first generation

Based on our tests, concept c obtained an NPS score of 65, whereas the other concepts scored significantly lower, obtaining an average of about -40 across comfort and grip.

The overall comments and learnings from the first generation of prototypes indicate that the round scan head should be angled, but only with an angle of 10–20 degrees away from the user making the scan area easier to target, while also tilting the screen towards the user, making it easier to see. Furthermore, the interviews indicate that the handle shape should have a flat surface for the thumb and a curved face for the remaining fingers to comfortably grip around. The full testing notes can be seen in appendix A.8.

Second generation

Goals for the second generation

The intention of the second generation is to further ideate and develop a design of the physical shell, based on the insights from the first generation. The goal is to have detailed learnings regarding the outside shell based on tests, which a master shape for future development can be based on.

Design possibilities

Building upon the design of concept c, a set of adjustments have been made to shape of the Angled scanner v3 (on figure 3.18). The angle between the screen face and handle axis has been reduced to 12 degrees, based on the typical angle between the grip line and the wrist axis of the human body [30], thus matching the natural grip angle and making the screen more comfortable to look at. The Angled scanner v3 (figure 3.18) introduced a more rounded cross-section than v2. The edge from the flat top to the curved sides was given a larger rounding radius and the circumference was reduced. Furthermore, the handle length was increased, to give the same good gripping area, with a smooth fade out towards the end. Lastly, design v3 was developed (figure 3.18). The design has a shorter handle, and even smother transition than v3, to explore the effects of making the handle as small as possible while maintaining space enough for electronics.

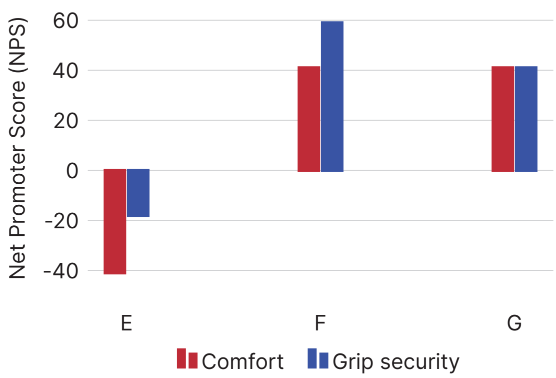
3.18 Overview of the second generation designs

Leanings from the second generation

The tests indicate that v3 is significantly more comfortable to hold and use than v2. The reduced angle from 20 to 12 is improving the user experience. The cross-subsection of the handle is slightly too large. The tests gave positive feedback on the button placement on the flat thumb face, close to the screen. The informants mentioned that the angle, rounded edges and oval shape of v3, are factors giving an overall positive response to this design of v3. The informants found the angle and grip geometry nice and found the strain on the wrist joint reduced, compared to the non-angled versions. For the last concept g (v4), the informants indicated that the shape was a slightly too small at the end, making it less comfortable and harder to have a secure grip of the scanner.

The tests indicated that concepts F (v3) and G (v4) have similar comfort, but the length and narrowing toward the handle end on concept G, gave it a lower score on grip security.

Based on the tests results (see figure 3.19), it is seen that the new concepts got a lower NPS score than the concept C that they were based on. Based on the negative feedback on the length of concept G and edge rounding of concept F, it is suggested to decrease edge rounding while keeping



3.19 Second generation test

the radii of the edges above 6 mm for the final model, and maintaining a longer profile, but reduce the narrowing towards the end, resulting in a circumference of about 40 mm, at a distance of 190 mm from the scan head, compared to the 35 mm in concept G. Finally, it is concluded that the button size and placement are intuitive and comfortable for the user.

Third generation: Design for manufacturing

The focus of the third generation was to decide on the outer perimeter of the scanner, create a parent shell and develop an easily manufacturable shell, based on the shell model. The scope of the third generation is therefore a transition from the conceptual and industrial design of the PlasticScanner, to design for manufacturing and product realisation.

A parent CAD model was developed in SolidWorks, using the “Master Model” (MM) Technique, where a part consisting of surface bodies, acts as the parent shape. The Master Model in SolidWorks can be seen on figure 3.20. The parent is imported to e.g. the top and bottom shell, where the detailed design is developed [69], [70]. This way of designing the CAD process gives the flexibility to change the parent shape, and the child models will follow along. The key to a good MM setup is to have as basic as possible information in the parent, while still fully defining the outer perimeter and other key design features. The following subsection will therefore be divided into sections related to the specific design features in the third generation and iterations thereof.

3.20 A view of the Master Model in SolidWorks

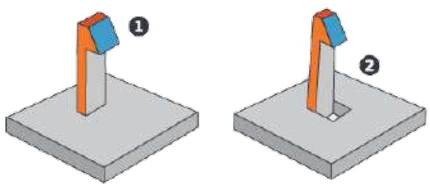
Mounting features

The goal is to have the components and the shells firmly fastened with a minimum of manual labour, without making the mould overly complicated. In general this is obtained by using as few screws as possible and by using in-mould features instead of manual assembly. The various considerations for placement and mounting of the different components are now discussed.

Scanner PCB

The custom PCB design of the team made it possible to shape the PCB into an ideal shape for the PlasticScanner shell. After several iterations, the simplest design was developed using two screws, and three platforms guiding the PCB into place in the Z direction. Two parallel platforms also guide the PCB into place, with the two screws locking the remaining directions. A design with four holes in the PCB (instead of the final two holes), where two were for screws, and two were for a pin-hole alignment has also been tested. The physical size of the PCB made it a challenge to palace the holes in the electronics design, where it was optimal for the mechanical design. Furthermore, the mechanical design of very thin pin towers (ø2mm, h25mm) was conflicting with good design practices for plastic injection moulding. As a result, the other design was chosen.

An easy way to remove undercuts, is to make a hole below the undercut surface (See figure 3.22-2), making it possible to expand the mould to fill the space and thus avoid the undercut. Because the scanner should be environmentally sealed to align with requirements, it is not possible to remove undercuts by creating a hole to fill the undercut with mould material from the opposite side.



3.22 Undercut from snap-fit and possible solution

Therefore, a snap-fit to hold the PCB down would result in multiple inserts or holes and therefore drive mould costs up. Instead, self-tapping screws for fastening of the scan PCB seem to be the easiest solution, despite extra running costs for screws and manual labour. The mounting system for the scanner

3.21 Close-up of the scanner PCB mount


3.23 Close-up view of the display mount

PCB can be seen on figure 3.21, with screws.

Screen

The screen is an off-the-shelf component, leaving little room for developing smart fastening methods. The components come with four mounting holes and a rough placement of the actual screen glass. A solution using the screen module to hold the protective glass in place, together with a circular indent in the top shell part, was developed. The solution was combined with an o-ring between the glass and enclosure for weather sealing of the assembly, held in place by the screen and fastened by self-tapping screws. The display mount is showed on figure 3.23 . The stacked thickness of the screen and glass is only 5mm, which is just too short for using the proposed ø2.2mm l6mm self-tapping screws. To offset the screw interface place, standard spacers on the back of the PCB were added, making the stacked distance longer, and thereby enabling the use of only one type of screw throughout the assembly.

Controller PCB

The controller PCB is shaped by the inner boundary of the enclosure and the vertical placement is dictated by the height of the battery holder and microcontroller. This leaves little space left for the placement of the controller PCB. The tight space forces the screw towers for enclosure fastening to go through the PCB. Furthermore, the USB connector’s gasket at the end of the PCB needs to be forced to-


3.24 Rendering of screw in front

wards the end chassis, in order to seal the assembly off. The PCB uses the sides of the enclosure screw-tower to orient in the x-y plane and is guided and pushed towards the gasket when put in place, by two angled towers. Lastly, three screws fasten the PCB in all directions, leaving the long a little over constrained, but pushed towards the gasket. As with the screen PCB, self-tapping screws can help reduce the initial cost for mould design. Alternatively, the PCB could mechanically snap into place, and use the gasket-enclosure interface as a guiding face. Here, the undercut holes could be sealed by the adhesive for the soft ambient light blocker. This option has been depreciated, in order to avoid reliance on non-recyclable adhesives.

Shells

The shells are challenging to fasten properly as a result of their size, thickness, required split line consistency and sealing of the internal components from the outside environment. Furthermore, the design of the fastening has a direct effect on the visual and aesthetic of the exterior and therefore the perceived quality of the product. The first iteration used only screws, to keep the initial costs down. This resulted in a design with one screw towards the USB end, one at the head and two on the grip just before the head.

This resulted in a large screw hole on the outside of the bottom shell at the head, to give room for insertion of a screw to interface the top shell. Furthermore, the screw tower took up space on the inside, thus forcing a redesign of the scanner PCB. To explore other options, the team went to get feedback on the design from Guido Tusello, an injection moulding tool design specialist at DTU, who suggested pursuing a design with a snap-fit at the head replacing a screw, resulting in a more even wall thickness in the front, and better aesthetics of the exterior overall, without excessively adding complexity. Based on this recommendation, a snap-fit solution was designed. To guide the shells into the correct position, a boss around the indented screw tower on the lower part was created. This makes the screw tower of the top part fit into an indent at the lower part, guiding the shells correctly together, and positioning the groove-lip seal along the edge of the shells. This could also have been obtained by creating guide pins and corresponding guide holes. This would have added at least two extra features to each part. Furthermore, the insides were already getting filled up with electronics. Combining the screw tower with guide holes enabled the team to add guiding features without taking away more space from the cross-subsection of the x-y plane, and making the number of faces with high-impact tolerances low.

Fastening in general

The choice of fastening method in the PlasticScanner is a compromise between features that work well for injection moulded parts and FDM 3D printed parts. FDM 3D printing is commonly done with PLA or PETG, which results in a brittle printed model, making self-tapping screws hard to gain success with. The same goes for snap-fits, due to the uneven strength (especially in the z-direction) of the layered manufacturing method of FDM printing. A common solution is to use regular bolts instead of screws, and design with shorter interference in the hole design than one would with injection moulded parts or SLS printed parts. Another strategy is to use threaded inserts, applied with heated tools after printing, or pausing prints and adding in nuts specifically designed gaps during printing. The team experimented with FDM printing and threaded inserts with mixed results due to the low precision of placement. The advantage of nuts and inserts is the longevity of the thread, making it possible to re-tighten the bolt more times than with self-tapping screws. The disadvantage is that it has higher initial and running costs financially due to an added part and expensive mould. Furthermore, the brass inserts increase the environmental footprint compared to self-tapping screws, if the product is not required to be opened and closed many times but only a few. Based on the above, the team considers using self-tapping screws in combination with a single snap-fit to be the best option in balancing the quality of assembled product and costs. To make it possible for makers to decide themselves, if they would rather use threaded inserts or self-tapping screws, the screw tower design is designed parametrial, making it easy to adjust the screw tower dimensions for specific inserts or screws, and upload 3D printable files for each solution.

Environmental protection

The intended environment of the PlasticScanner can be pictured as a windy and rainy day at an industrial fishing harbour on the west coast of Denmark. This sets requirements for the environmental protection the scanner needs to withstand the elements. The scanner has five possible points of entry for water or dust:

- The seam between the shells
- The screen glass
- The Scanner glass
- The USB
- The button

Sealing of shell seam

The seam between the shells has been designed with a groove in the bottom shell, for a 1mm o-ring string to be placed within, and pushed down in place by a lip feature in the top part. The lip is pushed down when the screws are tightened and the space between the lip and groove is designed for the specifications for compression of the o-ring-string. This adds flexibility to the tolerance of the seam gap, resulting in more relaxed tolerances. Furthermore, the shells have screws connecting the two parts, which could not be placed on the outside of the lip-groove feature, therefore a small silicone washer is put in place, to seal the screw joint off from the inside of the shells. The design has been reviewed by Bo Larsen, an injection moulding tool designer at DTU, who deemed it manufacturable, and suggested implementing a deformation rib (also called crush-rib) in the shell design.

Close up of USB gasket and hole placement

This would reduce the need for o-rings or gaskets between the shells, but it would not be possible to ensure proper sealing if the product has been disassembled, and put back together. Therefore, it has been decided to use traditional gasket solutions for longevity.

Sealing off-the-shelves components

The sealing of the USB and button has been managed by choosing components with IP-rated seals and technical specifications on interface design, to ensure IP rating, which has been followed. The design was challenging to implement, because the hole for the USB needed to not cause undercuts, and therefore had to be placed in the seam between the two shells. This further created challenges with creating a face for the USB gasket to interface properly, according to the specifications.

Sealing of glass components

The two pieces of glass protecting the screen and NIR LEDs have been sealed by an o-ring, as a part of the fastening of the component, adding flexibility to the assembly. The potential for using adhesive material to fix the pieces of glass in place has also been researched. This would make it easy to make the design sleeker, and remove features in the shell design. A disadvantage of adhesives is the negative effect on the recallability of the product. The screen glass could help as a spacer for the screen, while the o-ring is fastened by pushing the glass towards the o-ring with the screen fastening instead of glue, thus making glue unnecessary.

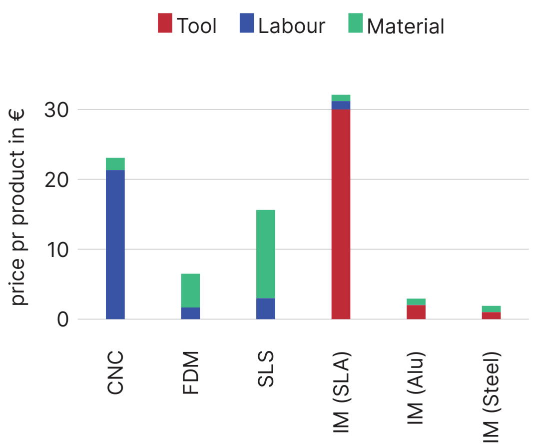
For the scan-led glass, the team has chosen to use adhesives to bond the glass to the shells. The development of this specific feature has been deprecated by the team, due to the PlasticScanner project currently undergoing research into the development of reflector and optics design for the scanner, which is to be implemented when the research is finished.

Selection of manufacturing method

With a goal of reaching a production volume of 500–1000 units (see 3.4.4), the chosen manufacturing process need to fulfil the requirements, while minimising costs as relatively low production volumes. There are a number of possible manufacturing methods for small plastic enclosures, which are compared in the graph on figure 3.25.

Manufacturing method

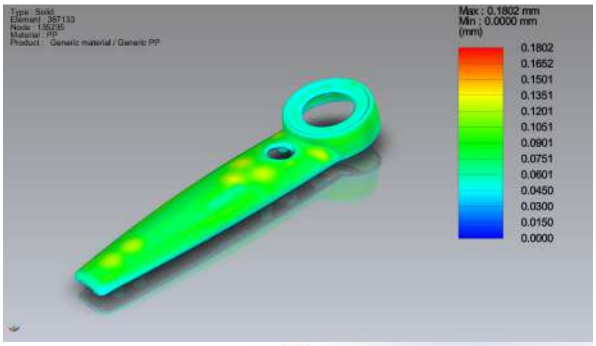
The estimate of production costs for CNC, FDM and SLS print is based on the price to make a single set of parts (Top + bottom shell). The injection moulding in an SLA printed mould is rated for 100 cycles per mould, Aluminium mould for 1000 cycles and steel moulds for 50.000 cycles. The price estimates for FDM are based on a model developed by Prusa research, and SLS printing is based on a concrete offer from a manufacturer. The same goes for the two injection moulding price estimates. If only 1000pcs of the plastic scanner is needed, and the price per piece is adjusted to cover the tool cost for the steel mould capable of 50k cycles, the price jumps from €1,3 to €20,95. CNC tooling and resin-printed mould design seem to be the most expensive options and are therefore ruled out. FDM and SLS printing have the benefit of

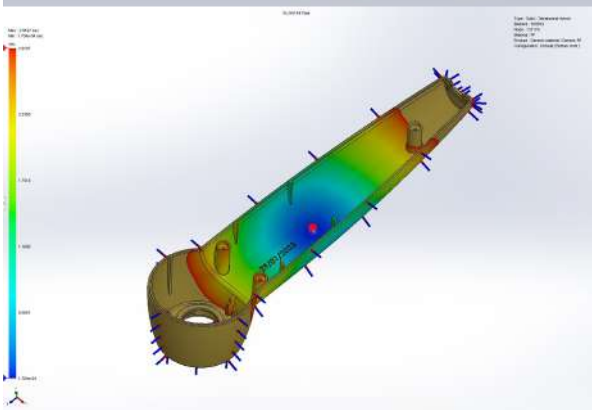


3.25 Manufacturing estimate

having very low startup costs, but SLS has significantly higher running costs – but a much better finish, enhancing user experience. FDM printing seems price competitive if done in-house. If outsourced, the price is closing in on SLS print. The product finish of FDM printed items are not at level

3.26 Sink mark analysis of the top shell





3.27 Mid-cycle image from fill simulation

with injection moulded parts. SLS printed parts have an even and semi-rough finish from the powder, which resembles in-mould finishes (e.g. SPI D2 or D3 [71]) in consideration for the outside surface of the scanner, thus living up to the UX requirements for commercial customers. Injection moulding in aluminium seems like a viable option, which would result in a price from €5,98 to €2,94 for a volume of 500 to 1.000 sets of parts. If the plastic scanner was more mature, and the production volume was surpassing 5000 units, the steel tools for IM would be the better choice. For production volumes of less than 100pcs, with requirements for aesthetics, SLS is recommended, and could be challenged by FDM printing in combination with post-processing for better finish. For all calculations, sources and estimates, see the appendix A.9

Design for Injection moulding

The development of the shell parts took advantage of the parent shell of the Master model setup only defining the outer faces, thus ensuring an even thickness of the material, and easy changing of the wall thickness to the specifications of the chosen material. All screw towers and stand-off walls have been designed to be 0.8x wall thickness to minimise sink marks on the outside, and are parametrically defined for easy adjustment. Furthermore, drafts of 1-3% has been added on all features from the start, ensuring easily removal from the mould. Lastly, flow, fill, shrink, and warp simulations has been done to validate the mouldability of the parts . The simulations have been done based on specifications for the OceanicX rPP material, and the simulation results are attached in the A.6.

The screw towers will cause minor sink marks on the front, which a surface treatment of SPI D-3 should hide sufficiently.

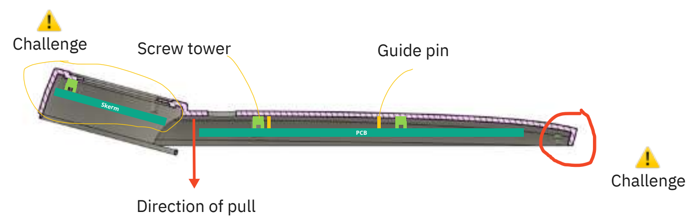
The part does have overhangs at intended areas, due to the use of snap-fits at specific places. These undercuts have received feedback from toolmakers, and should not be complex to make according to them. Furthermore, the team has requested offers for production from three companies, all stating that the parts are manufacturable at a reasonable complexity.

The technical description of assembly, drawings, surface finish and other relevant information will be described in the technical design package of section 3.6.2.

Direction of pull

The angled scan head, turned out to cause challenges when designing for injection moulding. As shown on figure 3.28, the fastening features had to not cause overhangs, and holes and walls therefore needed to be parallel with the direction of pull. To have the two shells mate together, further required both shapes to have a direction of pull, where the axis of the mounting features are parallel.

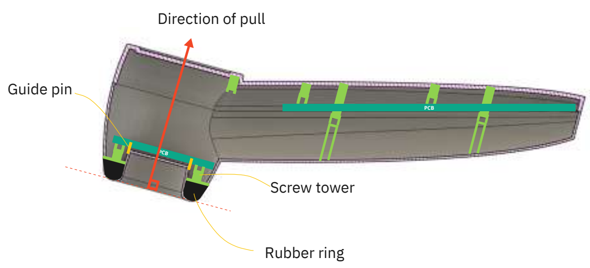
The design that proved to be the simplest solution, was to angle the direction of pull to be parallel with the revolve axis of the round scan head, as shown on figure 3.29. This does have the downside that the centre axis of the screws fastening the control-



3.28 Challanges regarding direction of pull and fastening features ler PCB are not perpendicular to the surface of the controller PCB, which can cause the PCB to be misaligned while fastening.

Design for 3d print

The open source hardware nature of the



3.29 Proposed direction of pull and fastening features

project, makes it necessary to have a shell which can be produced by makers in low quantities. Therefore, the CAD design has two possible configurations. One for injection moulding, and one for 3D printing via FDM, which has larger holes for replacing the self-tapping screws with M2 threaded inserts. FDM printing has been used by the team for prototyping throughout the project, including experimentation with various printing alignments, materials and support structures, in order to get stable results.

The team found that FDM printing the two enclosure parts in one print, with the parts standing upright but tilted 12 degrees forward, gives the best results, as it leaves only the exterior USB face as a supported face. Additionally, the layer direction is optimal for using the screw towers for guidance and keeping both the groove and lip free of support and layer-seams. This has the downside that the scanner is too tall for Prusa printers, but fits perfectly in the Ultimaker and Creality Ender 3 printers.

A final print has been done with the SLS method to obtain a higher fidelity prototype of an injection moulded part for verifying screw towers and interfaces.

Material selection

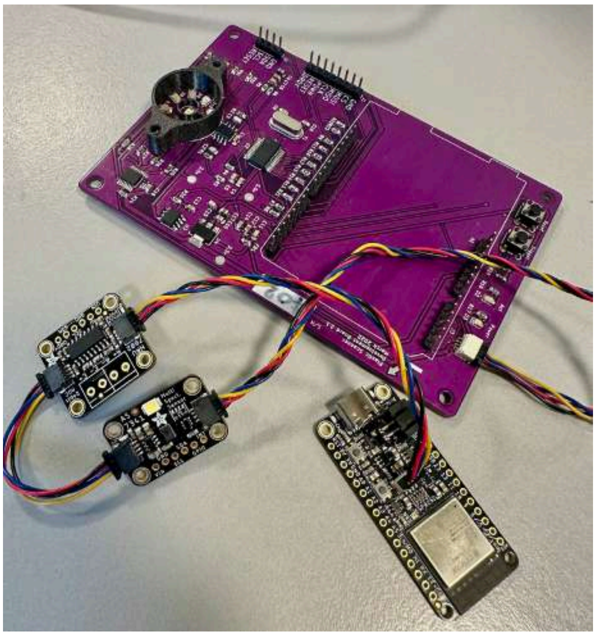
The general requirements for the material is to be suitable for injection moulding, snap-fits, self-tapping screws, have good impact strength and good resistance to salty environments, sunlight, and fuel. Lastly, the material should have a fairly low price. The general material that all fulfilled these requirements was PP, PE, PVC and ABS, with PP having the best score based on [72]. The team researched for specific polymers to use for injection moulding, and circled back to Oceanix rPP from Plastix, which is a PP material in the iconic forest green made from recycled fishing nets and ropes. Besides fulfilling the general material requirements, using the Oceanix rPP will be a symbol of what can be achieved with a PlasticScanner, right there in your hand. The Oceanix has a slightly higher market price than regular PP, but it comes with “colourants”, meaning the colour from the input of used ropes and nets. For the full material selection matrix, see A.6.

3.5.2 Hardware design

To enable the industrial design of the scanner to have working plastic identification electronics inside, the team has developed two pieces of electronics, based on previous work of the PlasticScanner community. This section describes the work, challenges, and solutions developed for the proposed PlasticScanner.

Modular design

One of the great successes of open source hardware is the world of breakout boards. The breakout boards are PCBs designed with a specific purpose, with clear contact labelling and documentation, extending the functionality of a microcontroller. Companies like Adafruit and SparkFun have made a business out of designing and selling open source breakout boards and creating ecosystems that lower the bar of entry into making prototyping and tinkering accessible to more people. The idea is that the user buys a breakout board that can e.g. measure temperature or show information on an OLED screen and control it with whatever microcontroller the user has already. Furthermore, the user can combine various breakout boards to design custom setups that fit a specific purpose, without designing a new PCB from scratch. An example of these breakout boards in use can be seen on figure 3.30, where multiple breakout boards are connected to a microcontroller.



3.30 Example of daisy-chaining via Qwiic I2C

From a systems point of view, the modularity can enhance the robustness of a design, by separating the functionality into physically separated boards, thus enabling separate development timelines and versioning frequency of the boards, and thus help mitigate the risk of PCB's with design flaws. For example, it would be possible to keep the scanner PCB, but change the design of a battery management system for the microcontroller, if a design flaw was discovered or a better design was developed for a new generation. In a complete scanner, the modular design could enable the customer to upgrade or repair part of their scanner, thereby offering additional value.

Furthermore, it would enable the PlasticScanner project to sell the scanner as a breakout board with the bare minimum of components, have the computing, control and connectivity functionality located on a board made for the handheld scanner and have another for desktop use. The disadvantage of a modular design is that more fastening is needed, which drives costs, and cabling between boards needs to withstand general use, and cables and connectors are an extra cost as well. Lastly, maintaining multiple PCBs require more logistics and handling than a single PCB, and the cost of two PCBs might be higher than one, even though the surface area is the same.

Based on the argumentation above and discussions with the OSH community via discord, the team decided to try to design a small round PlasticScanner PCB, that could fit into a number of applications. Several users on the discord server of the PlasticScanner community argue that a small breakout board would make it easier for them to start prototyping scan setups and that a breakout board might be a better OSH product for a lot of makers, than a handheld scanner.

Scanner PCB

The idea of a dedicated scanner PCB is to have a small PCB, containing the IR LEDs, the InGaAs sensor, an Analogue to Digital Converter (ADC) for reading measurements, and a connector to communicate with a controller. Reducing the form factor would give the physical design greater freedom in placing the scan PCB within the scan head. Furthermore, the existing design used different protocols for the ADC, screen and LED driver, which was causing problems with the amount of physical pins needed, and several smaller design flaws which the new compact modular design aim to solve.

The original LED and sensor setup was kept, to align the data output with the existing scanners and build on a verified configuration. The choices of the surrounding components were reevaluated. Furthermore, there had been discussions in the PlasticScanner OS community of a colour sensor that could help enhance the scan results by adjusting for the colour of the material, and a colour sensor was therefore implemented as a test. More detailed information on the various improvements and design considerations are covered below.

Sensor reading

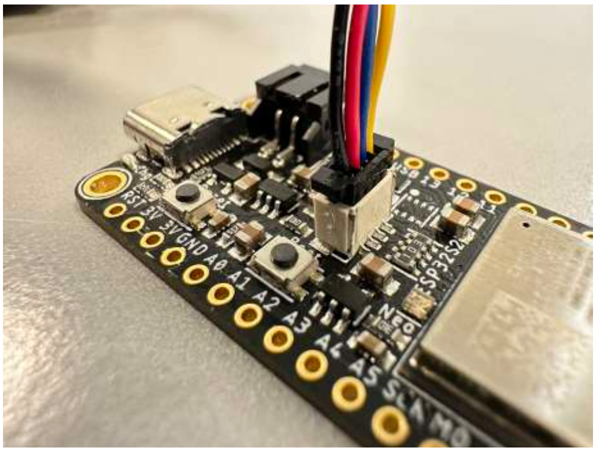
The previously used ADC ADS1256 was causing problems when using other controllers than an Arduino UNO, was not well documented and used SPI instead of I2C. The routing design additionally had a flaw that blocked all other SPI communication by populating the CS wire. SPI is characterised by a dedicated Chip-Select (CS) wire used for initiating communication to and from the controller to the peripherals via the two wires CIPO and COPI combined with a clock on SCL, resulting in the number of wires being $3 + n_{components}$. This means that for each component using SPI, a dedicated CS attached pin would be required on the controller board. The LED driver already used I2C, which uses a hardware address instead of a dedicated physical wire to address components, allowing for multiple components on the same wires. As a result, the number of components would not affect the number of wires, as long as they have different addresses. Therefore, the team searched for a well-documented ADC with a similar resolution of 24bit, and found that both Adafruit and Sparkfun sell a breakout board with a NAU7802 ADC controlled via I2C. The chip is widely used commercially for kitchen scales, and there are numerous OSH projects using the chip for weight-related applications.

Both Adafruit and Sparkfun distribute all documentation as open source, allowing for easy prototyping and testing of the setup with their breakout boards, before using their schematic as inspiration for implementing the ADC in the PlasticScanner electronics design.

As for the colour sensor, the OSH community proposed the use of the AS7341 colour sensor. The sensor is available as a I2C connected module from Adafruit with accompanying open source schematics, allowing for easier implementation.

Connectivity

Adafruit and Sparkfun both use a JST SH4 connector with a standard for pin assignment, which they respectively call Stemma-QT and Qwiic. Both standards have the same pin arrangement made for I2C communication and allow daisy-chaining of breakout boards. The standard connectors are used in most new microcontroller designs from both companies, which enables tapping into their existing OSH ecosystem of products with full compatibility. Figure 3.30 shows an example of daisy-chaining, where various breakout boards for components used in this project are connected to the microcontroller used, as well as a development board from the original PlasticScanner project. The used Qwiic connector is highlighted on figure 3.31.



3.31 Qwiic connector on an ESP32 Feather

Version 0 - existing design

The existing PCB had a single board layout, with an ESP32-devkit-C microcontroller soldered on via through-hole soldering. The Devkit-c does not have a battery management system (BMS), meaning that an external off-the-shelf BMS was also mounted within the case. This made the design practically a PCB relying on two external designs, where only the BMS from Adafruit was open source. Furthermore, the devkit-c has been marked with “not for new design” due to upcoming end-of-life, and the proposed replacement from the manufacturer has a inconsistent pinout design, and thus new generations will not fit the board. The microcontroller, therefore, needed to be replaced. The recommendation from the Delft report [68] was to move to a SOC version of the ESP32 based on open-source designs and move away from external components. As described earlier, the ADC of the previous design was causing problems by occupying the SPI communication lines. Therefore, a solution to fix the ADC was needed. Lastly, the one-board design made it impossible to have the scan direction at an angle to the handle direction. Tests of overall shapes, and academic research indicated that the angled scan head was increasing ergonomics and user perception of the product, thus a new design is needed.

Version 1 - Circular

The first iteration of the circular design aimed to get all scan-related components to fit on a circular ø50mm PCB and integrate a new I2C-supported ADS and colour sensor on the board. The approach was to use only the LED, power and sensor layout from the existing design, leaving out the ADC and controller design, and then combine it with the schematic of the AS7341 colour sensor from Adafruit [73], and the I2C-supported NAU7802 ADC design by Adafruit [74]. To be able to fit all components into the circular design, it was decided to switch the size of passive components (resistors and capacitors) from a 1206 to a 0603 footprint. This change makes it harder, but still possible, to hand solder the components, but made it possible to fit all components on the PCB.


First PCB being soldered

The board was presented for feedback and review of the online community. The community identified two design flaws concerning four duplicate pull-up resistors and a pin that was connected to the ground mistakenly. Without the feedback of the community, the board would not be functional.

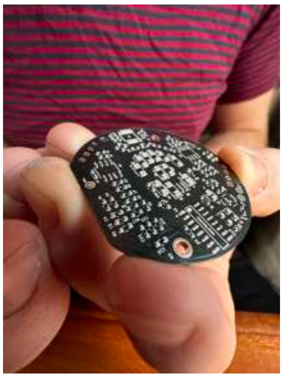
Based on the recommendation from the community and general cleanup of tracing, the board was ordered with component assembly by the manufacturer. The board was working after an incorrectly dimensioned resistor was discovered by the community and therefore replaced, and the board has been delivering promising scan results.

Version 2 - Circular with indent and Four layers

The development of the third generation of the physical enclosure made it clear that the fastening of the shells to each other required room, which the scanner PCB was blocking. Therefore, it was necessary to further compact the component placement of the scanner PCB. A community member suggested changing the arrangement of the LEDs to a more compact design instead of the current circular design, to save space. The existing routing was removed, components rearranged and re-routed, and the team managed to fit the components on a slightly smaller PCB, with a horizontal cut-off in the top, to make room for fastening features in the physical design.

The reduced footprint of the second version made the routing traces become very thin and close together. For high-precision signals such as the signal from the sensor to the ADC, this has the potential to create signal noise. During a discussion at an online developers meeting, the opportunity of switching from a 2 layer (front and back) PCB design to a four-layer design was proposed, enabling the possibility of a signal layer and a 3.3v layer, thus giving room for wider traces and better separation of signal types via dedicated layers, which should reduce the signal to noise ratio.

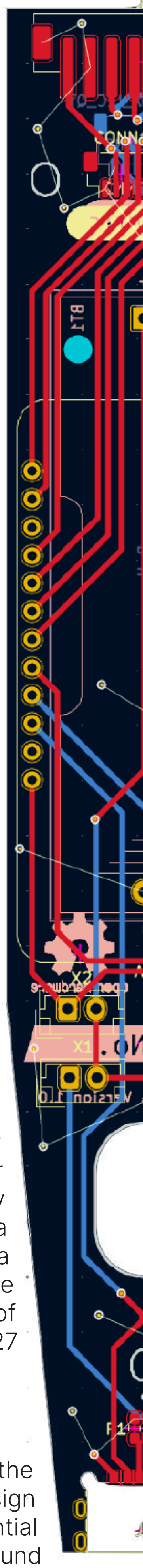
The hole layout of the first generation was purely based on where it was possible to place plated holes when the routing was done. This resulted in a rather random placement of holes. In the second version, the hole placement was simplified to two holes, diagonally placed, in favour of the existing four holes. The four-layer PCB design is slightly thicker than a two-layer design and does have a slightly higher cost. A quick estimate via JLCPCB found that the price of 1000 units changes from €0,19 to €0,27 per board when adding two layers.


Second generation PCB with solderpaste

Version 3

After the second PCB was ordered, the team found minor errors in the design primarily related to routing and potential improvements. Temporarily workaround

Controller P



PCB design

did solve the problems, but changes are required in the design for a polished and release-ready design. Therefore the whole PCB was reviewed, and minor changes to the connector routing and placement were made, to make cabling easier, and less strain on the cables. Additionally, an oscillating crystal was added to improve the accuracy of the ADC. Lastly, the team tried to find European manufacturers to cut down on shipping time, while keeping costs down and managed to find a partner called AISLER B.V with the potential to be a future partner for small-scale manufacturing of up to 500 units, including assembly at prices competitive to east-Asian competitors.

Third generation PCB with solder stencil

Controller PCB

The modular design introduced the scanner PCB and the controller PCB. The role of the controller PCB is to connect the different electronic parts of the PlasticScanner, and based on inputs from these perform various actions required for the scanner to function. Two versions of the controller PCB were designed and manufactured.

Version 1

The first version of the controller PCB houses the ESP32 microcontroller (MCU), interconnects for display and scanner PCB (JST SR and QWIIC connector), button connector, power switch solder pads, 14500 lithium-ion battery mount and USB-C connector for charging. In the following section, the major design aspects of the controller board is described, argumentation for the choice is discussed.

ESP32

The ESP32 is a low-power system-on-a-chip microcontroller with built-in WiFi capabilities. The ESP32 exists in various configurations with two of the newer models being the S2 and S3 variants. The S2 variant is focused on keeping the power consumption as low as possible by offering less computational power and no built-in Bluetooth capabilities. The S3 variant doubles the number of processing cores to two, and includes Bluetooth, more SRAM and AI-acceleration vector instructions [75], however at the cost of higher power consumption and 50 % price increase for a module with a built-in antenna [76], [77]. The controller PCB implements an ESP32 developer board from Adafruit called Feather. The Feather design from Adafruit is a family of boards, with the same footprint and pinout, with several generations and variations of microcontrollers. This enables the controller board to change feather board, and thus gain Bluetooth, lower power consumption or use a board with cellular connectivity in the future, without changing the controller design. all newer feather boards use a USB-C port to connect to a computer for programming and power.

The AI acceleration features are beneficial as the plastic identification model increases in size. By utilizing the vector instructions and accompanying library, a 2.5-6.25x performance improvement can be expected compared to the S2 [78]. As the microcontroller in the device, the ESP32 also controls the other integrated circuits such as the LED controller and colour sensor and receives inputs from the buttons, InGaAs sensor analogue-to-digital converter (ADC) and colour sensor ADC.

On version 1 of the controller board, the S2 variant was used, however, the two variants are physically interchangeable and as the features of the scanner are expanded, the additional performance of the S3 makes it an obvious choice to upgrade to. All variants of the ESP32 can largely run the same software with only some custom libraries requiring compatibility improvements. This enables an easy upgrade path and ensures modularity.

Battery and power consumption

The device has to be able to run without being plugged in. For this reason, he team has implemented a 14500 lithium-ion battery. the battery has a smaller form factor than the widely used 18650, and closely resembles a regular type AA battery in size. Due to the compact design of the handle, the 14500 battery better fits the scanner. As the electronics in the PlasticScanner are low-power devices with a combined peak draw of 1.3 W, it is not as important to consider the possible discharge rate of the cell, as it is selecting a cell with a high capacity. The highest power capacity cells in the 14500 form factor have 1100 mAh at 3.7 = 4 Wh of power. While the power draws peaks at 1.3 W, this is only expected at most 10 % of the time while the device is on. The power consumption of the scanner depends on the parts connected and their state. For example, connecting the scanner PCB not only adds new components but also increases the load on the ESP32 Feather. This results in the following levels of power consumption, measured with a TC66C for the full system power:

Controller PCB idle: 0.134 W

1. Controller with Scanner PCB connected idle: 0.39 W
2. Controller with scanner and display connected idle: 0.57 W
3. Controller with scanner and display connected scanning: 1.3 W

Assuming an idle state 90 % of the time and 10 % scanning, the expected battery life is 5-6 hours, where 10 % of the battery capacity is unused for battery health. However, this battery life calculation assumes the current state of the scanner without implementing further battery-saving measures. The ESP32 is designed for ultra-low power IoT applications and has a range of ways to reduce its power consumption, for example by entering a sleep state. In this state, the power draw can fall to just 20 mA at 3.3 V = 0.066 W. Further battery optimisations include turning off I2C power to the scanner PCB, thereby dropping the consumption by 0.256 W to state 1, or dimming the display when idle.

The final option to increase the battery time is by changing the battery to a pouch cell design to better utilise the width of the scanner. However, pouch cells are more fragile and typically glued to the device they are used in. The 14500 cells in the scanner is mounted in a standard battery mount, allowing for easy replacement should it wear out, potentially leading to a longer device life.

Buttons and connectors

The controller board includes multiple connectors for various components.

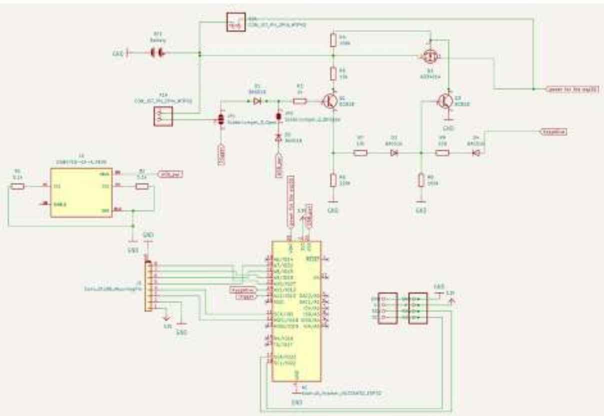
- As the final location of the button in the physical design could change, it was decided to create solder pads, where connectors from the button could be attach with wires. This allows for flexibility in incorporating the button into the design and allows for easy replacement if it should e.g. break.
- The display connector was placed at the top of the board to reduce the length of the cable run. As the display cables are larger than other connectors, this would also reduce potential obstruction from other components.
- The final method of turning the scanner on and off had not yet been decided on. The initial idea was to implement a sliding switch on the side of the scanner to achive this. However, as the options were still explored simple solder pads were created for connecting a switch.
- The JST Qwiic connector for connecting to the scanner PCB located further down on the PCB to spread out components. This did result in a slightly longer cable run and had left considerations for the second revision.

Size and shape

The hollow handle of the scanner allows for a long, thin PCB at 25mm wide and 125 mm long. The USB-C port is located at the bottom of the handle and serves as the external power source to charge the Plastic Scanner. To simplify the design, the PCB was extended to the bottom of the scanner, allowing the port to be mounted directly on the PCB.

It was initially considered to also mount a push-button directly on the PCB. The idea was dismissed, as it increased the complexity of the mounting system, design of the shell and required a custom button design to reach a state of some water resistance. From an economic standpoint, the cost of manufacturing additional parts for this button were also not considered viable for a smaller production run.

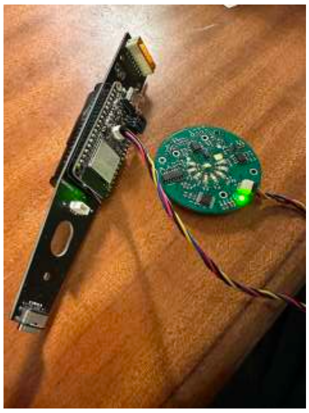
The width of the PCB was determined based on the space available in the handle, as well as the width of the ESP32 Feather board, leading to a PCB that is only slightly wider than the ESP32 Feather itself. An important aspect of the PCB design is the mounting system, which has to fit the angled plastic shell screw towers. For this to fit, the necessary screw towers were designed and marked on a dummy PCB in CAD. The dummy PCB could then be exported as a drawing and imported into the PCB design, thereby providing accurate mounting and through holes.


3.32 Schematic of controllerboard V2

Testing

Connecting the display to the controller PCB worked as intended. The display showed the expected colours, refresh rate and brightness. With the display connected, the vertical display connector itself proved to interfere with the USB-C port on the ESP32 Feather, making it difficult to connect a USB-C cable while the display was plugged in. Furthermore, the vertical mount of the connector also meant the display cables would press against the shell, a sub-optimal situation, which could result in failure over time or if assembled without care.


Full test of electronics


Controller PCB being tested withh Scanner PCB

The USB-C port mounted on the controller PCB itself is only meant to provide power for the PlasticScanner, as the ESP32 Feather has no USB serial pins. As a result of missing 5.1 k resistors for the USB-C port [79], charging via this port only worked sporadically. A community member introduced the group to the need for these resistors upon reviewing the design, allowing the issue to be fixed quickly. Connecting to the USB-C port on the ESP32 Feather worked without problem, and successfully charged the battery. With the battery charged, the scanner also ran on battery power.

The location of the I2C interconnect port for the scanner module was far from the module itself, leading to a long wire run. While the I2C signal integrity is expected to be fine [80], the cable would require additional fixation to not rattle around the case.

Version 2

Version two of the controller PCB included a range of improvements and a few new features. The schematic can be seen on figure 3.32. To get a better fit and easier connection, the ESP32 was turned 180 degrees and moved slightly. The battery mount was only moved slightly to fit minor changes in the casing. The necessary 5.1k resistors were added to the USB-C port to allow for charging. The vertical display connector was swapped for an angled connector to better fit inside the casing. The I2C Qwiic JST connector was moved to the top of the board to reduce the cable run. In order to make space for this, the button connector was moved to below the ESP32 Feather.

Implementing a dedicated power switch in the physical design would require an additional insert or new shell shape when injection moulding. Furthermore, the opening would make another way for water to enter the device, creating a requirement for additional water ingress protection. This would increase the cost and complexity of the device. By replacing the dedicated power button with a latching circuit connected to the main button, the additional opening can be avoided. The latching circuit works by latching a power mosfet to a connected position after holding the button for a short moment. The mosfet is kept on by powering it from a pin on the ESP32, which can be set to high when the device powers on, thereby latching the circuit. The same pin on the ESP32 can then be turned low after holding the button for a programmed duration, leading to the mosfet and device turning off. This ensures the device can be completely turned off with no power consumption. Compared to the Thermo Fisher Scientific microPHAZIR plastic scanner, which requires 20 seconds to boot, the user to login and 10 minutes for the light source to power up, the PlasticScanner is ready to scan in less that 5 seconds [58]. As a result, turning on and off the PlasticScanner is not hastle for the user, allowing them to easily conserve power.

Price estimate

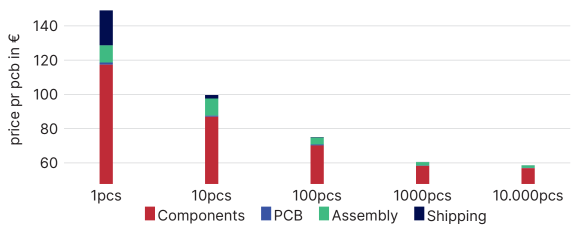
To estimate the price of the whole product, the product was cut down into individual parts, for which realistic prices were identified. To compare the price of various production volumes for the various cost drivers, a series of examples were calculated; for an individual making 1 scanner, a group making 10 scanners and commercial batches of 100-10.000 scanners.

Scanner PCB

For the estimated PCB cost, an online instant quote tool build into JLCPCB and Aisler PCB was used. For 1-100 pcs, the European company Aisler was competitive, but on higher production volumes, the Chinese companies like PCBway and JLCPCB pulled ahead. For the price of the components, a tool build into the major component supplier called Digikey was used. The majority of components used in this project were ordered from Digikey, as they offer relatively low shipping costs and had all components required - except specific components that are out of stock globally, due to the ongoing chip shortage.

The major cost of our design, as seen on figure 3.33, is clearly the components, which account for 78% of the cost of a single PCB, and +95% when the production volume goes above 1000 units. It is clear that the costs of small batches are significantly higher than the larger quantities, which underlines the potential of buying large batches of PCBs to sell at a lower price than an individual would be able to produce a single board for, cutting the sourcing and self-assembly price in half, already at 100pcs.

The major driver of cost for the scanner PCB is the NIR emitting LEDs, the InGaAs sensor including ADC and colour sensor, which in total take up 86% of the component costs.

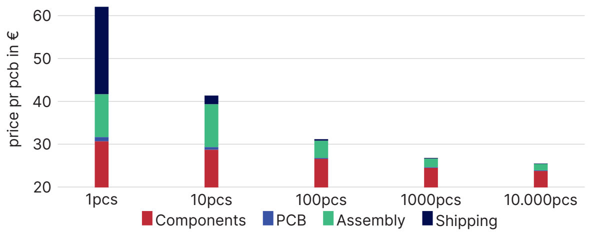


3.33 Scanner PCB Price estimate

Controller PCB

The components of the controller PCB are significantly lower, but the shipping costs and assembly take up a higher percentage. Again, a tendency of very high prices for low production volumes is observed in figure 3.34, and a significant decrease in price as volumes go up. Where component costs for the scanner PCB drove the price drop, the drop for the controller board is an equally cost reduction due to bulk shipping and assembly-related costs. The prices do not fall as drastically as with the scanner PCB. This is in part due to one component: The Adafruit ESP32-S3 feather board, which costs €16 and does not fall significantly in price as volume increases.

For production volumes of more than 100, it could make sense to move away from the Adafruit development board, and create an



3.34 Controller PCB Price estimate

ESP32-S3 microcontroller design directly on the controller board. This will reduce cost, but at the same time close the system, because the microcontroller cannot be switched, without changing the PCB design. This will make it easier to do quality control, eliminate manual errors and problems relating to un-tested or unknown hardware, which is well suited for commercial applications. It is however a step away from the open hardware community, making the board less accessible to tinker with for experienced makers, but at the same time making it more "plug-n-play" which is a plus for newcomers.

It is also an option to sell the controller PCB without the Feather board, thereby further reducing cost.

3.5.3 Software

The hardware of the scanner needs firmware to control peripherals, get data from the ADC and process the data in order to output a user-understandable result. This section is covering of the firmware design of the scanner and discusses the choices made during the development of the firmware and training of a test machine learning model for polymer identification

Scanner firmware

The ESP32 is programmed in C++ using the Arduino framework. The firmware of the scanner utilises a range of open-source libraries, for easier and previously tested interfacing with the implemented components, described in the hardware section 3.5.2. The team does not have a background in electronics nor embedded software engineering, and the community around the used libraries has been an invaluable help to get the firmware up and running smoothly. A list of all used libraries used is added as appendix A.4.

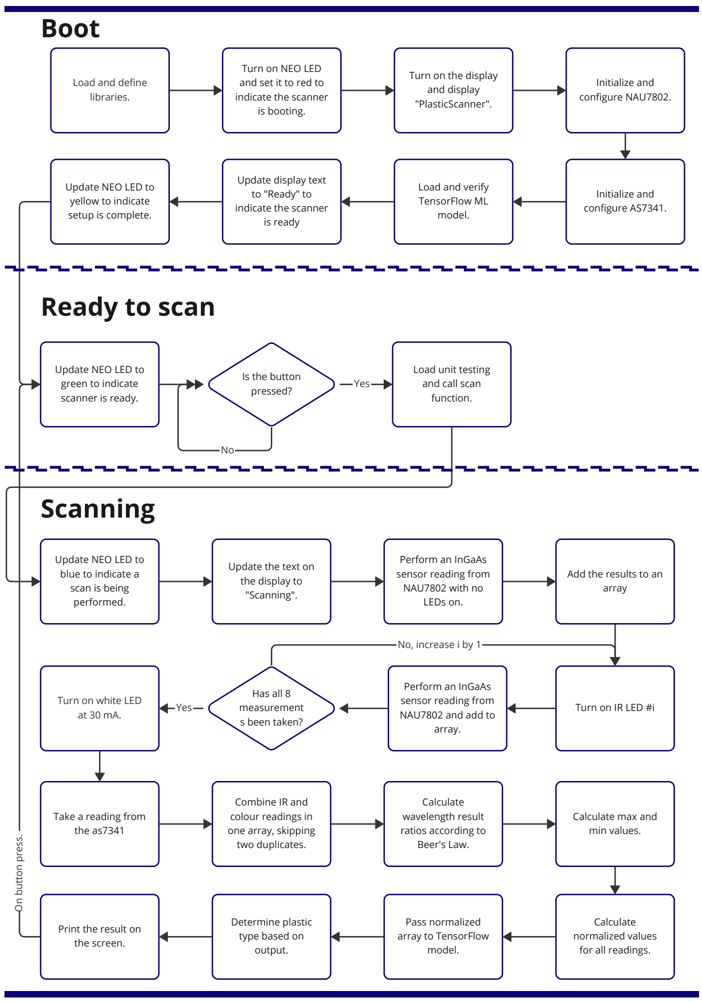
Development process

The software development has been running in parallel with the hardware design. From the first hardware prototype, where breakout boards were put together in series with Qwiic connectors, The team first got each component running alone with an ESP32. When software for a component was working, it was merged into the main sketch and tested. the software for each component was added one by one, incrementally moving towards a fully working software sketch, controlling and retrieving data from the components.

The software, running the plastic scanner, is based on libraries intended for interfacing the breakout boards used for prototyping. Since the hardware design of the used breakout boards is used as the basis for the hardware design of the proposed scanner, the software should therefore also work in theory. After some minor changes, the software in general did work in practice.

The transition from off-the-shelves breakout boards to custom-designed PCBs, posed a challenge, due to the I²C addresses of the components can be changed by changing the resistor setup, which accidentally happened during hardware design. This posed a challenge as I²C addresses are the basis of all communication with components. In the later iterations, the hardware bugs were fixed with help from the community, and the software implementation in the newer generations went smoother.

The implementation of the machine learning model, used for processing scan results, was not a part of the scope of the project. However, when the team managed to get all software and hardware working together, and therefore decided to integrate the machine learning model and extend computational possibilities, which would enable the handheld scanner to identify polymers, thus getting one step closer to a working product ready for commercialisation.



3.35 Scanner firmware flowchart

Firmware structure

The firmware itself has three main stages: boot, ready to scan and scanning. The most important functions are described in this section, while the full flow of actions can be seen in figure 3.35. During the boot stage, the pin for the latching circuit is pulled high, the various libraries are loaded, connections to components are checked, some settings are configured and the display is turned on. Importantly, the size of the TensorFlow arena is also defined and initialized in the library. The size of the model is further described in the next section.

Following the boot sequence, the scanner enters a waiting state listening for input on from the button. When the button is pressed, the scanner starts a scan. The scanner first updates the display to show the status to the user and then instructs the TLC59208 to turn on one infrared LED at a time, a reading from the InGaAs sensor is taken through the NAU7802 ADC, while each LED is on individually.

The scanner takes a reading for each specific wavelength LED, one by one. The LED is given 10ms from turn on to get "warmed up", to ensure stable output, before taking a reading. Afterwards the LED is turned off, and the next LED on. Additionally, the scanner takes a baseline reading before and after the loop scanning for all LEDs wavelength. the baseline reading indicates the amount of environment noise affecting the scanner, and what levels of NIR light intensity the scanner should expect. The baseline is used for two things in the software. Firstly the value is used normalising the data, together with a calibration scan of the material spectralon, which has the characteristic that is has a very high reflectance. this enables us to normalise the data based on the maximum light intensity of spectralon, and the baseline background reading, for each LED. Secondly, the baseline reading before and after can be used to test if the light environment has changes significantly during the scanning, which can affect the data quality.

When all eight readings have been read from the ADC, the scanner has acquired the data necessary to identify the plastic type and thereby the scoped goal of this project. Following the NIR readings, a white LED is turned on to allow the colour sensor to take a reading. The NIR and colour readings are combined in an array. The array containing all 17 raw values for each scanned sample is stored locally on the ESP32, which fulfils the initial goal of the project: to build a handheld Plastic scanner, that outputs relevant sensor data. As an example, the sample of white PP has the following values read from the ADC:

Table 3.1: A Sample reading of PP

850nm	940nm	1050nm	1200nm	1300nm	1450nm	1550nm	1650nm
3481180	3481377	6975238	5914975	3477298	5367029	5382992	7027341

To further develop the plastic scanner towards a production ready product, the team decided to put more research into developing the data processing and explore opportunities for data infrastructure.

To prepare the data for the trained model, Beer-Lamberts law is first applied, followed by normalisation. This data process is described further in the section 2.2 on data processing. When the data is normalised, it is now in the same format used when training the machine learning model as described in section 2.2 and can then be used as input in the model, to try to determine the plastic which is scanned. Depending on the output of the model, the determined plastic or error is displayed on the display.

Data processing and recognition model training

The Plastic Scanner identifies plastic through pattern recognition in the readings from the InGaAs sensor and the spectral colour sensor. With the project succeeding in developing a working sensor module, controller PCB and firmware, the team chose to develop an initial version of a machine-learning model for testing. The model enables the team to test if the scan data is of sufficient quality to train a model, and potentially highlight new challenges for the development. This section covers the initial attempt to create a plastic recognition model with a very limited data set and the accompanying results, retrieved by using the developed scanner to scan known plastics. The process builds on an open source guide for implementation of TensorFlowLite for Arduino by Sandeep Mistry and Don

Coleman [82], and its PlasticScanner adaptation by Jerry de Vos [83].

Creating a data set

As plastic can have wide range of properties from the type, colour to surface finish and additives, a large data set is required to effectively recognise patterns and thereby predict the plastic type. Machine learning models generally increase in accuracy as more data is added, until a point of diminishing return is reached[84]. The developed machine learning model is trained with 17 different data inputs, of which 1 is a baseline reading, 7 are discrete infrared readings from the InGaAs sensor and the remaining readings from the AS7341 spectral colour sensor, including 8 colour readings between 415 nm and 680 nm, an IR reading at 950 nm and a clear general light intensity measurement within the span of 350 nm to 1000 nm. The baseline reading aims to compensate for the varying levels of light bleed in the scanning chamber, by reading the data from the InGaAs sensor with no LEDs enabled. Additionally, the data set contains a reading of a reference material. This reference material is either smooth PTFE (called Spectralon) or a polished piece of aluminium, as these are very reflective materials and therefore would return the highest value to expect from the sensor.

As the number of input parameters increase, the number of samples required also increase. While there is no predetermined amount of samples required for machine learning, to the knowledge of the team, a rule of thumb is to use 10 times the amount of samples as you have parameters, suggesting the Plastic Scanner model should use at least 80 samples if using just the IR data or 170 if training the model with all colour readings included as well [85]. As the model increases in complexity and size such as increased polymer types attempting to identify, additional data will be required. Furthermore, the samples gathered need to be of consistent quality, as bad or wrong readings can throw the model off. In machine learning, a common phrase is garbage in, garbage out [86].

Consistent process for data collection and data quality

For the Plastic Scanner to avoid gathering garbage data and thereby train a garbage model, a consistent and systematic process for gathering data was used. One data set should only contain data from the same scanner PCB generation, scanner environment and scanner housing. Each sample was labelled for future reference, to enable comparison of data sets with different setups, but with scans of the same samples. Each data set only contains data from a scanner PCB of the same generation, scanner environment and scanner housing. Each sample was labelled for future reference, to enable comparison of data sets with different setups, but with scanning of the same samples. Each sample is scanned one time and added to the data set. Care was taken to ensure the scanner head sat flush against the sample to reduce light bleed.

For the data set used in the project, data was gathered in real-world scenarios by taking measurements in a lit room. Another option would be to scan the samples in a dark box, thereby ensuring the sensors only saw the light from the built-in LEDs. However, this would create a data set, which would not reflect the real-world usage scenarios, potentially leading to a lower success rate of scans with the finished product. The choice to gather data in a more realistic use case did come with the risk of increased light bleed, resulting in noise in the data set. A number of mitigations can be done to lower this risk and reduce the effects of environmental variables when taking readings. These mitigations include both physical and software considerations and are discussed in section 3.5.3

Relative reflectance

Based on Beer-Lambers law, described in section 2.3.1, the data is processed, for the machine learning model. The rarios used for polymer identification is based on previous research. Masoumi et.al, propose to use the ratio of reflectance at 1650*nm* and 1720*nm*, to identify PET, PS, PVC, PP and HDPE. The authors reported reasonable results, but expressed concerns regarding the cost, due to high cost of optical and NIR components. [87] proposes a more cost friendly alternative with the ReReMeter. [87] Proposes the use of the three ratios:

$$Ratio_1 = R_{1200nm}/R_{1300nm}$$
$$Ratio_2 = R_{1450nm}/R_{1550nm}$$
$$Ratio_3 = R_{1550nm}/R_{1650nm}$$

When scanning a sample, the absorbance of the sample and the absorbance of the photodiode or system itself cannot be separated in a single measurement by the system. Furthermore, some radiation in the NIR spectrum is typically present due to, e.g. lightbulbs and sunlight. Therefore [87] proposes a correction with a baseline measurement of the scanner, without LED's turned on, before and after the measurements as mentioned earlier. This enables the scanner to measure the relative reflectance caused by the LED's emittance, thus removing noise from the measurements.

Preparation for machine learning

The PlasticScanner project has developed a method for model training, which uses the tensor flow framework [88], which is a continuation of the development of ReReMeter [89]. Since development of a Machine learning model is not within the scope of this project, the project will follow this methodology.

The method is using normalisation to better compare the different readings on a reduced scale, which is recommended by the TensorFlow documentation [90]. When data is min-max normalised, all data points are scaled to be in between 0 and 1. This is done through the following formula, $x' = (x - x_{m}in)/(x_{m}ax - x - min)$ which is done in the model training scrip by the following script

```
for i in range(17):
    max.append(np.max(law[0::, i]))
    min.append(np.min(law[0::, i]))
item_normalized += [
(law[i][0]-min[0])/(max[0]-min[0])
..
]
```

Listing 3.1: Normalizing of data

The normalisation of data furthermore makes the scanning results from different scanners possible, since the baseline and spectralon scan in combination with min-max normalisation will make all scanners output data within the same range [87], [91].

Data infrastructure and additional features

In order to verify the intended capabilities of the ESP32 and especially surrounding software, multiple additional experiments have been performed. Especially functionality concerning moving data to various cloud services. Research has been done to understand the options for wireless user configuration of the scanner and assessing functionality to perform over-the-air updates.

To test the data transfer options, the ESP32 Wi-Fi capabilities were used to connect to a local Wi-Fi network. From here, the scanner was programmed to transfer the resulting data from a scan to services such as Google Sheets, Firebase, MQTT and Blynk. While the different online services have different advantages and disadvantages, they all performed well.

Some functions were researched to ensure the proposed functionality of the PlasticScanner were possible, but not implemented in this project. This includes the two following.

Utilising the library AutoConnect [92], a Wi-Fi hotspot could be created from the ESP32, where a captive portal and web server would be implemented. This allows for an easy user experience to connect to the scanner and configure settings directly, such as a custom recognition model, location or any other metadata a company could need. It would also allow a companion app to utilise a smartphone cellular connection to send data to an online data store.

Both Blynk and AutoConnect also allows for over-the-air firmware upgrades[93], [94], ensuring the scanner is easy to keep up to date with improved features and recognition models. MQTT is a lightweight protocol, and cannot contain packets large enough to contain a firmware update in one. The Blynk software is a paid proprietary service, with a free tier, where MQTT is an open source protocol. For an initial community system, a MQTT server would be a recommendation, where Blynk could be a future partner for a commercial scanner.

Scanned results

To test the scanner PCB, a series of samples has been scanned. The test data set consist of 77 unique samples spread across 6 types of plastic and 1 Spectralon reference sample. The individual number of the plastic samples can be seen in table 3.2.

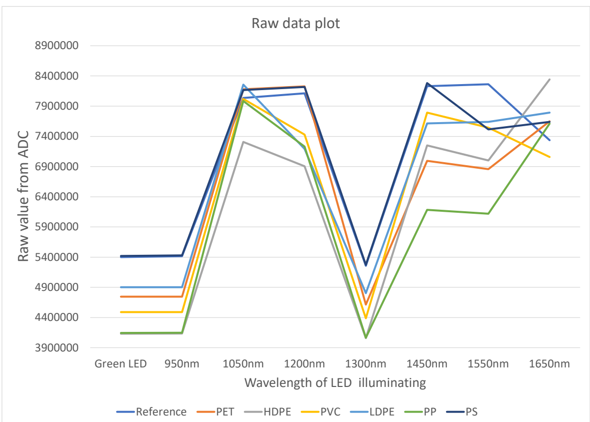
Table 3.2: No. of plastic scan samples

Reference	PET	HDPE	PVC	LDPE	PP	PS
1	7	19	6	7	29	8

The samples have a range of different colours and surface finishes. In order to better compare them graphically, only white samples are used in the plot on figure 3.36. The following two 3D plots use data from all samples, as some plastic types had very few white readings, making it difficult to identify potential patterns The plots look at the primary identification data from the infrared LEDs, where the colour sensor is intended to assist in compensating for the colour of the plastic.

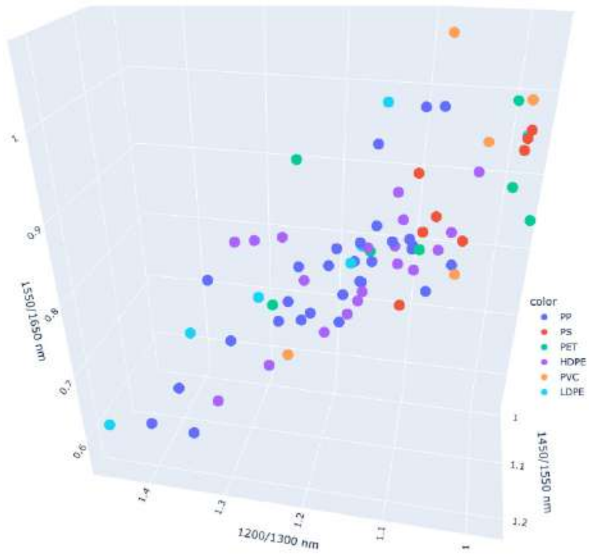
From figure 3.36, some differences between the different samples are noticeable. For example the PP sample being easy to discern from the PS sample, due to the ratio of the 1050 nm and 1200 nm reading, and the ratio of the 1550 nm and 1650 nm reading.

By plotting the ratio between the specific wavelengths as mentioned earlier, the reflectance is expected to differ between



3.36 Comparison of raw scan data for 1 white sample per plastic type

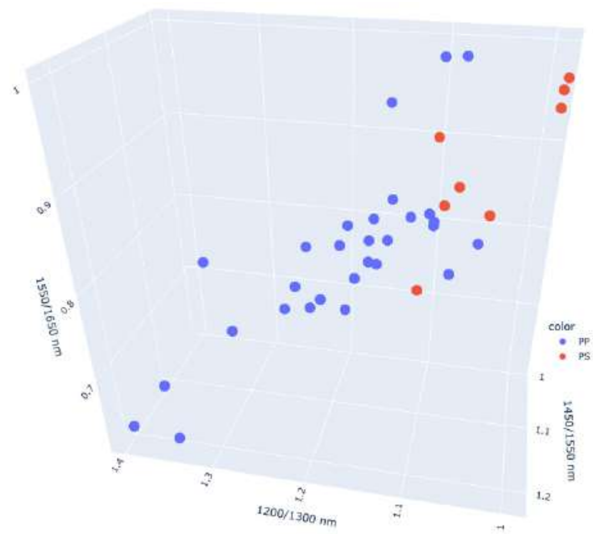
plastics, hence a grouping of the specific plastics would also be expected. When assessing the plot on figure 3.37, the data seem cluttered, with no clear groupings.



3.37 3D plot of all samples in selected ratios

Reducing the displayed samples to PP and PS does indicate a grouping between the individual plastic types. This can be seen on figure 3.38. While the sample size is low, a PP/PS identification model appears possible.

The results of the scans, especially some plastics, vary significantly, indicating that the data quality would benefit from additional noise mitigations in the future and additional verification of scan quality. Further work into the effects of surface finish also needs to be done.



3.38 PP and PS 3D plot

Training the model using TensorFlow

Based on the data from the test scans, a test recognition model is trained using TensorFlow, – a deep learning software library by Google. The normalized data set is split in three parts: 60 % for training, 20 % for testing during training and 20 % for verification of the trained model.

When defining, there are is a series of variables to adjust including:

- Number of layers
- Number of “neurons” in each layer
- Activation function in each layer
- Choice of optimiser
- Number of possible outcomes

A high ratio of outcomes per samples, will potentially introduce noise to the recognition of plastic types [95]. Finding the best balance of the different variables requires a combination of experience, guidelines, and trial and error[96]. As the team is not deeply experienced in machine learning, the training done rely more on experimentation and trial and error, than thorough experience.

The trained model has 4 layers with 30, 30, 15 “neurons” and a output space of 2 to 6, equal to the number of plastic types the model includes. The first three layers use ReLU as their activation function, which is a mathematical operation defining what the neuron should do and is a common activation function for hidden layers [97].

The final layer uses the softmax activation function to give the probability of how likely the input data fits each of plastic types. For example, if the output space is 2, trying to identify PP and PS, the output of the softmax layer could be 0.7 (70 %) for PP and 0.3 (30 %) for PS. The probabilities will always sum to 1. This probability is what is used for determining if the accuracy is high enough and what to tell the user. Increasing the number of layers and the output space typically creates a more powerful model, but at the requirement of additional data to train the model effectively [97]. As the layers increase in number and size, the trained model also increase in size. As the model has to run on an ESP32-S2, the model is limited in size to the amount of 4 MB of memory on the device and just 2 MB of PRAM [98]. To reduce the size of the model, another option is decreasing the number of neurons in the hidden layers. Having too few neurons in each hidden layer reduces the accuracy and success rate. At the same time, a too high number of neurons will likely result in low success rates as well, due to overfitting [99]. Therefore, a compromise between size and accuracy has to be made. The team found that decreasing the number of neurons from 64 to 30 in the two middle layers maintained a success rate of 7/7 with a required 90% accuracy, while decreasing the file size from 172.418 bytes to 64.058 bytes.

Another factor in training a machine learning model is the selected epoch number. An epoch is when all data from the training set has been used once, and the amount of epochs define the number of iterations where the data is used in training the model [100]. Adjusting the epoch rate aims to find the spot where the model has the lowest error, without overfitting as a result of repeating the data too much. The results presented are with a very high epoch rate of 1200 and the model is getting some overfitting, as the validation loss is staring to increase. However, decreasing epochs to 800 decreases the accuracy from 9/9 to 8/9. All tests were done with ***SGD*** as the optimizer, *mse* for loss and *mae* as the metric. Using RMSProp as the optimizer could allow for reducing the amount of epochs, as RMSprop can adapt the learning rate continuously while training. However, in testing the team saw worse results using RMSProp that SGD [101].

The attempt to train a model based on the training method by the PlasticScanner Project, including all six different plastic types, based on a dataset of unique 77 samples, turned out more difficult than anticipated, and the model only reached a success rate of 3/15 with at least 90% probability. The training of models with fewer plastic types samples did result in good results that looks very promising, but require further investigation. One possible reason for the low success rate of the full model, could be the lack of data. As mentioned earlier, the ratio of possible outputs and the number of samples used for training is low, due to the low number of samples. The data plot on figure 3.36 also shows a lack of clear grouping, indicating a need to review the quality of scanning results. Furthermore, the impact of the colour sensor readings should be researched further to see if some readings only add noise to the model.

On-device execution of model

The machine learning model is converted to run on the ESP32-S2 using tf_porter and loaded on the device as a header file. When an item is scanned, the data is prepared the same way as when training the model, thereby allowing the data to run in the model. However, getting the model to function the same way as on a computer has proven difficult, with the model only outputting one number, instead of an array of probabilities. Running the PP/PS model on the ESP32-S2 and piping new readings of either plastic has the results leaning heavily towards just one type of plastic. However, piping a PP and a PS reading from the training data set succesfully returns a value close to 0 or 1, respectively of the plastic, indicating the model recognises these readings. In order to get the PlasticScanner to work as a device, the model needs to return the array of probabilities as with the Python program for the device to effectively tell the user what type of plastic the user is scanning. This is one of the key parts missing for the scanner to work completely.

Noise mitigations

There are several potential options of improving the scan results and reducing external noise factors, through changes to the scanner itself. Physical considerations mainly concerns reducing light bleed and making it easier for the user to correctly place the scanner against the sample. This could be done through ensuring no light is able to penetrate the scanner shell and by improving the material used to seal the interface between the sample and scanner. These are further explored in the physical development section.

How the scanner software is implemented can also help mitigate the effects of light bleed. The first way is to determine the average of a number readings. Currently, a scan has two parts with the first being the infrared readings, which takes 80 milliseconds to complete. Following this is the colour sensor readings, which take 600 milliseconds to complete, resulting in a scan time of around 700 ms. This time does not include data processing or displaying.

Building on the idea of using multiple readings, a self-adapting algorithm could be implemented to continuously take readings, until stable set of values are determined within a specified confidence interval. Using a self adapting algorithm could increase the total scan time if the accuracy requirement is set too high or the gathered data has an unpredictable distribution. In order to ensure the user experience remains great, the total scan time must be kept below a few seconds.

More work should be done to understand the variability of the infrared readings and the colour readings. The LED used to eluminate the sample for the colour sensor is significantly brighter than the infrared LEDs, potentially making the reading more resistant to background light bleed. As the colour sensor reading takes 7.5 times as long as the infrared reading, it would offer increased flexibility for a self adapting algorithm to run under a 2 second max scan time.

Finally, a more controlled approach to adding and handling noise in the data set could be a way to improve the final identification model. By scanning the training samples in a box where all light sources can be controlled, it could be possible to better teach the scanner what different plastics would look like at different levels of surrounding light. The dark reading would further guide the identification model.

The importance of a repeatable data set

While light bleed is a significant noise factor, there are other variables to consider in the design, ranging from the configured ADC gain, distance to the object scanned, layout of LEDs and so on. Changing any of these variables makes the previous data set incompatible with new scans. As a result, the data gathered was performed as late a possible in the development. However, it underlined a need for future development, where the PlasticScanner project should aim to create a large collection of plastic items of different plastic types in order to quickly and consistently be able to recreate the data set when changes are made to any of the variables described. The PlasticScanner project has created a calibration/verification box with a small set of different plastics, that are from the same larger piece. This means a scan of a specific sample should result in very closely the same values between boxes, and thereby allow newly created scanners to be verified against the plastics in the box. This is extremely important in order to ensure data from various scanners can be compared and thereby used in for further recognition model training and to simply help community members know they replicated the scanner successfully. As described in the open source theory section, replicability is key to the success of an open source project, as well as ensuring the community is well taken care of. If community members cannot easily verify their replication of the scanner, the project risks losing the interest of the members very quickly, and thereby ending up worsening the paramount community of the open source project.

While we had the reference box with some plastic samples, we needed a significantly more samples attempt to train a functional recognition model. In order to gather close to the data necessary, we visited hardware stores to scan a range of products. While this served as an easy way to gather data for training a model, replicating the data set with an updated scanner to compare against is not possible as the products in the hardware store keeps changing. The difficulty of reaching 170 samples underlined the importance of creating a repeatable scanning and training setup. For our final model, we had 88 unique sample readings, spread across 6 different plastics, with more than half being either PP or HDPE. For LDPE, PET and PVC, we had between 7-8 readings, it will be difficult to attempt to predict these types of plastics, especially if all the plastic types are in the same model. For PS plastic, we also just had 8 readings. However, PS plastic exhibits very different infrared responses compared to PP, meaning we potentially should be able to separate these two types of plastic. For PP and HDPE which we have the most readings of, we also have a chance, despite these exhibiting closer behaviour than PS/PP. PS

3.6 Deliver

This section covers the deliver phase, focusing on finalising the proposed solution to the problem. The section covers the community engagement, a technical design package and proposes a roadmap for the coming year, pointing towards the “future development” section.

3.6.1 Review of requirements

The requirements described in section 3.4.4 are now evaluated if they have been achieved. Out of the 44 requirements, 32 were fulfilled. 11 were partly fulfilled and 3 were not fulfilled. Only one of the requirements not fulfilled was rated at the highest in importance. This was:

> *Reqmt 45: The system should be able to communicate machine learning models to the sold scanners.*

The primary goal of this project has been the physical and electric design, combined with initial software to verify the electric design. Identification, online infrastructure and more advanced software have been out of scope. This means the prerequisites for functions such as the one described in requirement 45 have been created, allowing for easier development from community members or alike.

Requirement 46 describes the need for good online documentation and guides to replicate the scanner and has been partially fulfilled. This means that while the necessary design files and initial software are available on GitHub, additional surrounding documentation and guides would benefit the replicability and accessibility of the scanner. As the majority of requirements have been fulfilled, the PlasticScanner design is expected to satisfy the usecases of the customers and be ready to be manufactured in a small scale for community developers, allowing for development on the final requirements, especially in software and data science.

3.6.2 Technical design package

This section gives a short overview of the required knowledge to create and manufacture a PlasticScanner with the current design. This includes details regarding both the electric and physical components. This design is at a TRL level 6 and close to 7, meaning the technology is demonstrated in the relevant environment.

The full design and firmware is available on the the PlasticScanner Repository (link).

Electronics and firmware

The schematics of the scanner and controller PCB is included in the appendix, see A.18. On GitHub, the required files are located in the “Hardware” folder, where design files, libraries and bill of materials for both the controller board and scanner PCB can be found. The designs are created in KiCad and it is recommended to use this for viewing and editing the files.

The firmware created for controlling the scanner is found in the folder called “Firmware”. Again, the main program is included with accompanying custom libraries. The remaining libraries required are downloaded through the built-in library manager in either Platform.io or Arduino IDE.

Physical shell CAD model

The full physical design is available in the CAD folder on GitHub. The CAD folder contains the shell designed in SolidWorks for the handheld scanner, as well as a complete assembly with 3D files for all components used in the handheld scanner. STL files for both parts of the shell are available for easy 3D-printing. Finally, the performed injection moulding simulation can be viewed.

Assembly

The whole assembly uses 12 6×2.2mm screw in total. The assembly order is done in main steps. One for the top assembly, one for the bottom assembly and lastly a joining of the two subassemblies.

A: Top shell assembly

Place controller PCB in place.

4. 3x screws for controller fastening
5. Insert and fasten Push button
6. Place Screen o-ring
7. place Screen module
8. 4xScrew to fasten screen module
9. Connect screen to main board

B: Bottom Shell assembly

Place scanner PCB

10. 2x screws to fasten scanner PCB
11. Place scanner glass after removing adhesive protector
12. Place o-ring string in groove

C: Full assembly

Align bottom and top shell assemblies

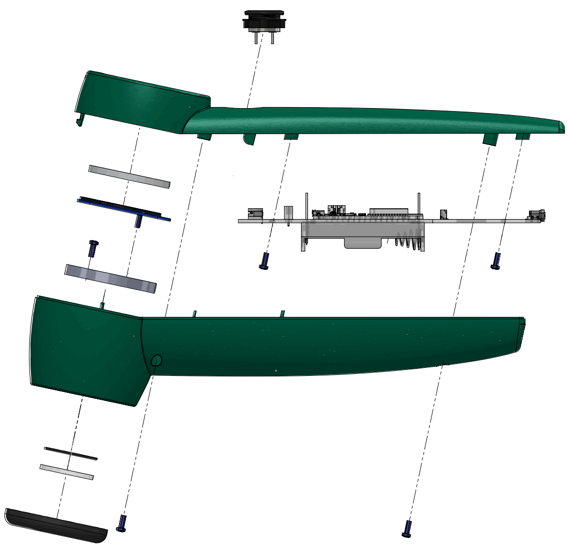
13. Snap parts in place
14. 3x screws for fastening

Based on the teams experience from tests on prototypes, a full assembly and test if everything is placed correct takes less than 5 minutes. Figure 3.42 shows an exploded view of the assembly, with lines for illustrating the line of assembly.

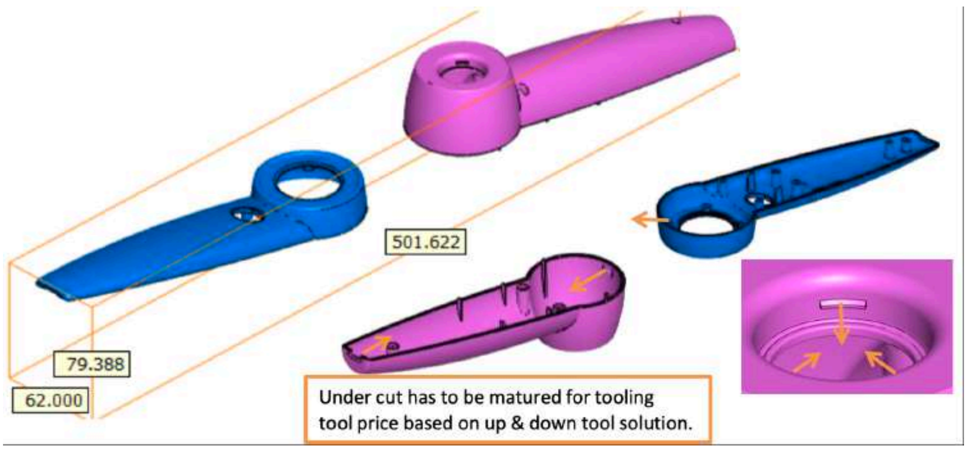
Manufacturing

The design has been sent to Idé-Pro, a manufacturer of plastic and light metal parts. The manufacturer has evaluated the design, and assessed the need for further design for manufacturing. The manufacturer has returned a sketch of the proposed layout of the aluminium mould.

The manufacturer estimates the tool cost to be 77.625,00 DKK, with 3.900,00 DKK needed for further DFM and 2.160,00 DKK for startup costs and a trial run of 20 units for approval by the PlasticScanner team. This adds up to 83.685 DKK or €11.237,44 in tooling, including surface treatment of aesthetic surfaces. Running costs will be €0,67 per top shell and €1,07 per bottom shell, including the Oceanix rPPC material and packaging. The offer is included in appendix A.14. The surface treatment is specified as SPI D2 or D3 and has been chosen to enhance the user experience, and enhance the grip performance for better ergonomics.



3.39 Exploded view of PlasticScanner assembly



3.40 Mould layout sketch from manufacturer, with markings of mould insert andpull-outdirection

3.6.3 Buisness case

A short business case is now described for the PlasticScanner as a commercial company. The total cost of a commercial handheld scanner from a production batch of 1000 units is €223,56, including marketing, distribution, packaging, and labour. The requirements states a minimum of 40% price margin, which results in a scanner price of €312,98, which after VAT is a retail price of minimum €391,22. It should be noted that the numbers are estimates, and thus a margin of error has to be remembered.

The comments from companies like Plastix and BessTrade, regarding a suggested retail price of €2000 excluding VAT as a low price for them, indicates that a retail price of €2500 plus VAT would be a viable business case. This would result in a profit of €1.776,44 per sold scanner, or a profit margin of 795%.

Batch price	1000
Development	€100.000
Material	€88.984
Labour	€3.333
Tooling	€11.237
Marketing	€10.000
Distribution	€10.000
Total	**€223.555**

Unit price	1
Development	€100,00
Material	€88,98
Labour	€3,33
Tooling	€11,24
Marketing	€10,00
Distribution	€10,00
Total	**€223,56**

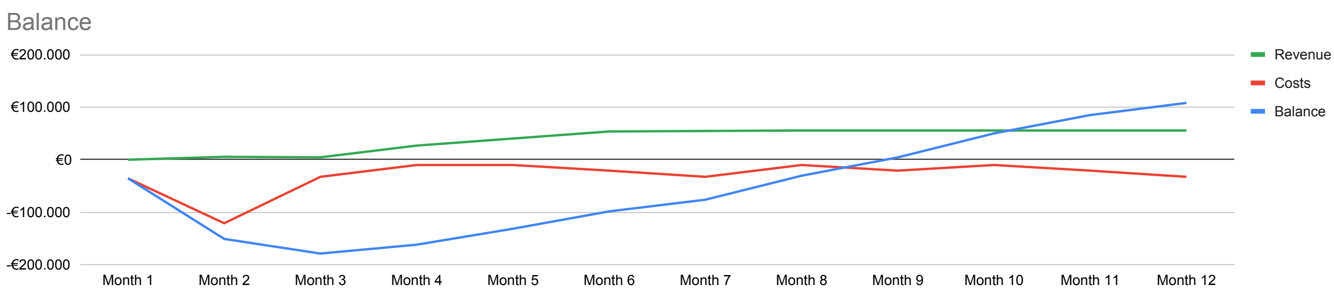
Minimum Retail Price for Scanner	
Cost price	€223,56
Mark up	40%
Net price	€312,98
Vat (25%)	€78,24
Retail price	**€391,22**

Maximium profit	
Cost price	€223,56
Retail price	€2.500,00
Net Price	€2.000,00
Profit	€1.776,44
Profit Margin	**795%**

3.41 Price estimation

Below is a draft of the first 12 months, after the launch of a commercial Plastic scanner. The price estimate is freezing the design in month 1, and order injection moulding during month 2. Since the PCB prices are very high, the team proposes to order smaller batches, resulting in higher prices, but minimises up-front costs, and enables the team to make adjustments along the way.

The sales numbers are rough estimates, based on the length of the list of interested companies the PlasticScanner project currently has, and the type of customers. e.g. large sorting companies might need more than one. Furthermore, the number of commercial ports within the EU is 1200 [102]. In total, this would result in a PlasticScanner business case, that reaches break even after 8 months, but has to find funding to cover the expenses related to future development, tools for injection moulding, and the first batches, for a total of €130.000. The full calculation is added as appendix A.9.



3.42 Draft of yearly balance

3.6.4 Roadmap for 2023

The development of hardware, firmware and physical shape of the PlasticScanner is at a point, where it make sense to spend the money on shipping development kits to active community members. The proposed roadmap for 2023 is displayed in figure 3.43. It is viewed as critical to get hardware into the hands of the other developers in the community, in order to accelerate the development of the manufacturing ready scanner. While the community member nicknamed "LoKi" has assisted the team when challenges arose, he was ultimately limited in some of his contributions by the unavailability of assembled hardware. For open source hardware projects to succeed, accessibility and easy replicability of hardware is key.

The hardware development part of the roadmap is more focused on minor revisions and improvements, while the design is validated in quality and for production. The modular design and ESP32 Feather allows for a more flexible approach to swapping hardware or updating firmware.

Software, data set and machine learning is one of the significant activities in the roadmap. This includes gathering a broad range of samples to compile the data set from, improving the machine learning model and improving the surrounding software. This process is seen as a continuous and iterative process running throughout the year.

Another important activity is ensuring the open source community is cared for, expanded and to facilitate collaboration. Ensuring this is expected to accelerate the overall development.

From Q3, more focus is put on developing and executing a funding strategy to fund full time employees and manufacturing costs. Additionally, this is where focus on creating a commercially viable product is gaining priority. This includes manufacturing, business operations and final end-user feature considerations. The goal is to delivery a handheld scanner from a pilot production at the end for Q4 or beginning of Q1 2024.

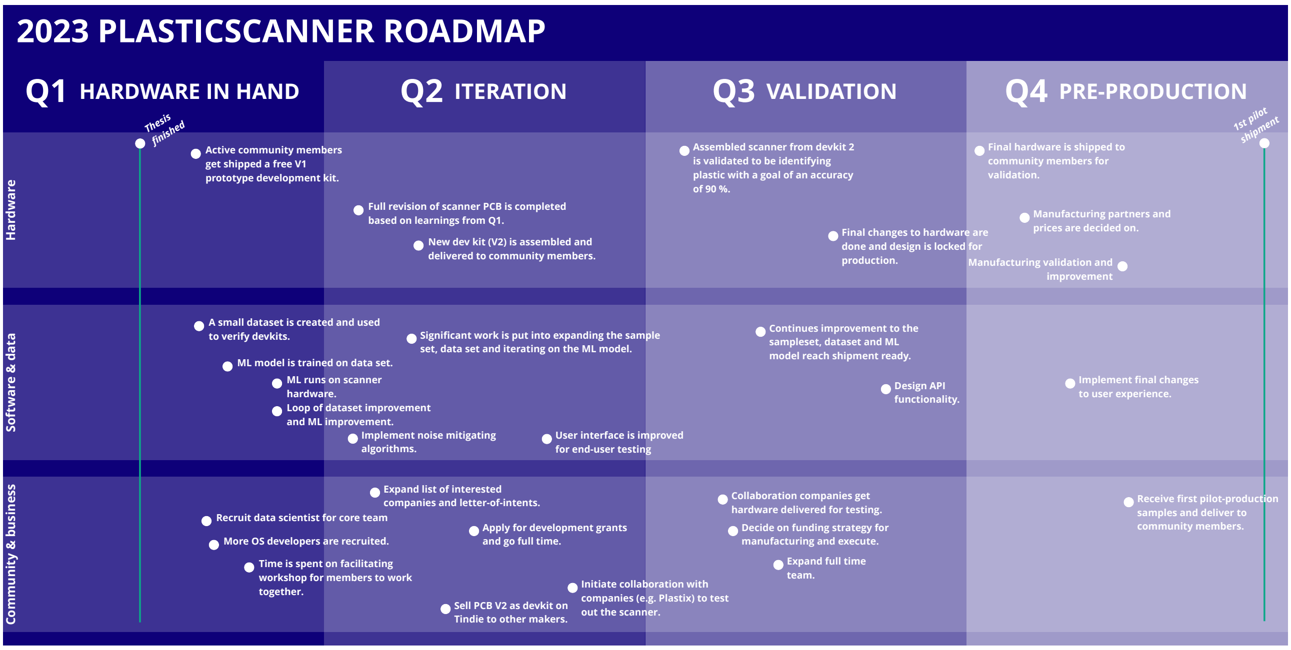


Figure 3.43: PlasticScanner roadmap 2023

4. Discussion

This section will summarise the key findings, decisions, conclusions, and implications of the thesis, along with a critical evaluation of the research methodology and the impact of any limitations encountered during the thesis.

Quality of data

One of the main takeaways from section 3.5.3 on software development is the current challenges with quality of data for machine learning. The issue of data quality is a challenge across several parts of the design, including electronics, software and physical design. The current size of the data set is relatively small and the continuous development of the scanner PCB, in combination with changes from earlier work by the PlasticScanner project, results in a disorganised data arrangement. While the goal of the project was not to perform extensive data analysis and ML training, doing additional data analysis and testing could have better clarified the quality of the data. A better understanding of the data could be used to guide a range of experiments to improve data quality through more optimal designs. However, additional experiments and changes to both physical and electric design would have delayed the primary goals of the project without certainty for a significant change in data performance, and as such were considered more relevant for future work.

Effect of software design

The current machine learning model is based on results from scanning known plas- tics with the developed plastic scanner design. Evaluating the data quality has not been in scope for the project, but comparing the results from the developed scanner with scientific/commercial spectrometer measurements of the same samples could help understand how to tune the design. This would also make it possible to eval- uate the performance of an identification model based on the current eight wave- length measurements to models based on more wavelengths by using subsets of a high precision hypervariate data-set. The scanner currently takes in all eight wave- lengths and uses a model to process the information and guess the type of plastic. Previous work done by D. M. Scott succeeded in separating PET and PVC without the use of machine learning and based only on the difference in the normalised re- flectance of the materials [39]. It might be possible to rule out specific types before applying the ML model, thus narrowing the solution space of the model and then specialise the model on the remaining types of plastics and maybe obtain a higher success rate.

Effect of electronics design

The new electronics design for the scanner introduced a switch from the ADS1258 sensor of the previous generations to a NAU78903 and changed some resistors for the NIR emitter LEDs. This can make it hard to compare the new scanner to the pre- vious designs and their respective datasets. The data gathered during development indicates that the data is compatible and can be used across generations due to the use of normalisation. For further data infrastructure design, a method for identify- ing the scanner board and using that information to tune the model might need to be introduced to gain higher precision. The scanner PCBs developed during this project has implemented a colour sensor which previous work has indicated might help enhance the quality of data and thus enhance the models' ability to identify plastics. A test model has been trained both with and without including the data from the colour sensor. As mentioned in section 3.5.3 on software, the success rate of the two models were not significantly different. This suggests that the use of colour sensor data has not been utilised in an optimal way or that the implemen- tation of a colour sensor is introducing more noise into the dataset than it improves the recognition, thus increasing costs without improving the identification perfor- mance. The full effects of the implementation of the colour sensor are not known and therefore more research is required to assess the impact and opportunities of the colour sensor.

Effect of physical design

The physical shape of the scan head can be a source of noise. The distance from the scanner PCB to the subject can influence the noise from readings, as described in section 3.4.1. Currently, the scan head is made of plastic which can influence the scanner readings of a given material by absorbing other wavelengths than the given sample, thus resulting in a multi material spectroscopy. The design proposed by Reremeter does indicate that a design similar to the proposed design is possible. The team does not have enough test data to compare the designed scan head with designs with a reflector or absorber built in. Furthermore, the choice of protective glass needs to be researched further to ensure that the protective glass has a suffi- cient translucency for the given IR spectrum and that the optical design of the glass is sufficient for the current application. Testing of this has not been within the scope of this project, but it is a running topic within the PlasticScanner community which an upcoming project will work on.

Precision versus price

The current scanner design is limited by the availability of specific NIR emitters for surface mounting, since all the various specific wavelength NIR emitters available from major component resellers, are already in use in the design. The only solu- tion enabling more wavelengths is to change the sensor setup to a broad spectrum light source, in combination with a sensor enabling selective wavelength measure- ments. As described earlier, the price hike from specific wavelength emitters to specific wavelength sensor setups drastically increases prices. The current state of the polymer identification model clearly indicates, that it is possible to obtain promising results for polymer identification based on the reflectance at eight spe- cific wavelengths. The current success rate seems limited by the size of the data set and to some degree the quality of data. Looking at our data plots, it is difficult to discern patterns from just the plots. Previous work done by Straller and Gessler on the ReReMeter [87] suggests that it is possible to have a higher success rate across all the five most common types of plastic. The tests undertaken during this project indicate that it is possible, but it has not been fully tested in this project. Fur- ther- more, it is not known how many types of plastic it is possible to include in the model, and the team has not tested the inclusion of e.g. PLA or PETG in the model. The question is therefore whether the current setup optimally balances price and pre- cision. And can the product have one optimal balance point, covering professional and non-professional users? The CEO of Plastix made it clear that a retail price of €2000 was too low to cause problems for their business case. On the other hand, the PlasticScanner community is full of people who do not dare to start prototyping yet. Community members do not feel certain enough that they can get the scanner working well enough for them to absorb the cost of making one. While the price for the scanner in this project has been accepted by the commercial customers, only limited knowledge on the maximum price for maker spaces has been gained. A bet- ter understanding of their price willingness is needed to price the development PCB correctly. At the same time, users like Plastix and BessTrade are asking to know if the scanner can help detect additives, filler materials or plastic blends. This again indicates that the two user groups share some needs and requirements, but also have further wishes that greatly differ. The proposed 2023 plan is trying to take this duality into account by planning a stepwise rollout, starting with maker ready PCBs that help generate data and verify the design. Afterwards, the PlasticScanner developed in this project should be introduced and later on a "Pro" version which is described further in section 6 on future development. This would enable the PlasticScanner project to work intensively on maturing the hardware and identification software with makers and test how high a precision it is possible to obtain.

Concept and use case

The discussion regarding plastic recycling frequently returns to the need for a large, automated system to sort mixed plastic waste. These systems are huge, costly, and often beyond the reach of many companies. While there are smaller handheld solutions available on the market, they are also expensive and for either solution, it is closed source. The research performed indicate that cheaper and more flex- ible solutions are not a priority by current original equipment manufacturers, but when speaking to the commercial recyclers, the demand for an accessible hand- held scanner is urgent. Recyclers are in huge need of a better tool, which can allow their employees to effectively batch sort plastic. Effective batch sorting is expected to result in a higher sorting rate compared to processing a batch through an auto- mated sorting system, and thereby enable recyclers to continuously supply their customers with recycled material. In addition, the research and comparison of the various sorting strategies indicates that there are several good solutions on the market for large industrial installation, but there are currently no accessible scan- ners on the market—only handheld scanners at an astronomical price level. Lastly, the research indicate that the current NIR spectroscopy strategy used in the Plas- ticScanner, will not be able to outperform industrial setups, due to the limitations on emittance and required size of scan area by the current electronics.

All indications from the PlasticScanner community points towards a desire among makers to make a difference in addressing plastic waste, forming a business case focused on individuals and makers. By providing accessible kits and documentation, the PlasticScanner project can enable communities to create scanners or other custom solutions fitting in their exact context. The open source nature of the project provides an opportunity for communities to create value near them. For companies, an open and affordable product makes it more accessible to identify and document polymer types. For both individuals and companies, the PlasticScanner enables an improved approach to addressing the environmental plastic challenges, which are not offered by the current solutions existing on the market.

Physical design

The proposed design of the PlasticScanner is tested and designed through a series of methods that should help the team obtain a useful outcome of the design process. The PlasticScanner proposed by this project can be seen as an extension of the PlasticScanner proposed by the Delft project [68]. With one team member being a part of both project teams, it is possible that the problem and solution space are being narrowed down by decisions made by the Delft team. A series of steps have been put in place to avoid this, such as performing a fresh individual sketching session, mood boards and CAD designs. The physical design was primarily user tested earlier in the project to determine a good shape and expected placement of key interfaces, such as the button. While both qualitative and quantitative tests were performed, it can be discussed whether the adapted NPS method is fitting for evaluating a physical product as the research for the NPS method is aimed more at overall satisfaction. However, the results from the qualitative user tests fit well with the results of the NPS score. In some cases users first gave a lower rating to the two questions regarding the shape, but then expressed that they preferred that shape. It is reasonable to expect the informants to consider more details in their overall assessment compared to the two specific questions in the NPS method.

Manufacturing and Open Source

To enable makers to create a product that resembles a commercial product as close as possible, the team has chosen to think 3D printing on a FDM printer into the design to make it 3D printable. The finished model is both 3D printable and ready for mass production via injection moulding. This design enables the unique option for the PlasticScanner to be produced in any quantity for two separate user types. It is possible to create a separate variant of the design, more optimised for 3D printing with less overhang, although at the expense of ergonomics. The team has focused on making it possible to 3D print, although the upright printing position described in section 3.5.1 is more difficult for a new user to get perfect. The upright print orientation is necessary to obtain an aesthetic outer surface which a surface with support would not result in, based on our tests. Furthermore, the current print takes about 26 hours to print with 40% support material which is a long print with a large proportion of support material. Creating a new design without overhangs or a bare minimum of overhangs would make it easier and faster to print, thus making it more accessible for makers. But it is not possible to have the same design freedom and it would be harder if not impossible to convey an experience of a sturdy and com- mercial product through FDM 3D print optimised parts. This raises the question whether it makes sense to have a 3D printed plastic scanner design or if it would be more optimal to have a commercial version and an easier 3D printed design for the community version. Doing this would allow the community to have an easily printable shell suited for prototyping, and the commercial version would still have full design freedom (within the limits of mass production).

Open Source

Open source is at the heart of the PlasticScanner Project. The original Plastic scanner concept focused on creating a low cost and open source scanner on the market to be deployed in low-income countries as a socio-economic project. The concept has then grown into an open source community and attracted interest from commer- cial potential customers as well. Along the way from concept to product, challenges have arisen regarding the scan performance while keeping prices at an absolute minimum. Increasing the precision of the scan results would require the scanner PCB to gain more precise and therefore significantly more expensive components. The questions rise: How expensive is an open source project allowed to be while continuing to have a growing community? Will a high price drive community members away? How to run Open source development when the community does not have funding for creating their own artefacts? These questions are important to consider when making future decisions about the technical design and the accompanying impacts.

Replicability

The hardware design proposed in section 3.5.2 uses surface mounted components with the standard 0603 footprints. While this footprint size does enable soldering by hand, it is hard due to the component size of 1.6 mm × 0.8 mm. This change was necessary for the hardware design of the scanner PCB to fit inside the scanner head. The downside of the use of 0603 components is that it makes it harder to make the PCB at home. One discord member stated: “The most intimidating part for me is SMD soldering”[103]. It should be noted that the existing designs are based on SMD components as well. Using smaller SMD components will make the barrier of entry higher, thus only enabling experienced makers to replicate the design. A version based on mostly through-hole or larger SMD components could be devel- oped to help the community better make boards. However, this change will drive up the cost of PCBs and components and might influence the performance of the board. The literature on replicability by Balka, Raasch, and Herstatt indicates that a major influencing factor is the users’ ability to source the necessary components [12]. To implement a design that includes MEMS sensors, or specialised compo- nents not available through major component resellers, will significantly decrease the replicability of the scanner, thus making it harder for the community to grow. Oppositely, the use of specialised components as part of an open hardware development project can make the components accessible if the OSH project acts as a reseller. This could be done by either selling the components as kits for the user to solder on or as finished boards, thus making specialised components available for makers. Another strategy could be to have a low-cost simple scanner for the community and a more specialised version for commercial customers, as described in section 3.6.4.

Documentation

This project could benefit from further implementation guides and thorough online documentation. This is expected to lower the bar to get started on the hardware, although the exact effectiveness has not been evaluated. Replicability is absolutely key [14] for a successful OSH project, and in this project the focus has been on creating a balance between replicability and commercial viability. The community members' understanding of this project has not been thoroughly evaluated, how- ever online meetings and chats indicate an internal community understanding. As a result, new community members might require additional introduction to get started. The full content of the report, including thorough documentation for the electron- ics and software design, is to be published on the official PlasticScanner GitHub repository as a project delivery to the PlasticScanner project. This leaves a solid base for community members to contribute their knowledge to the documentation and further lower the bar of entry. This would make it more accessible to scan and identify plastics for more people, and hopefully make the world a better place, one piece of plastic at a time.

5. Conclusion

In the thesis, a handheld plastic identification tool has been developed to a state, where the physical and electronic hardware is manufacturable and functional. The accompanying software verifies the capability of the hardware and lays the groundwork for future refinements, additional features, and a fully developed polymer recognition model.

Through the thesis, the current state of open source hardware has been described and discussed. It is concluded that there are several factors contributing to the success of open source hardware projects. Several factors that are typically not considered significant for regular development projects, but are considered to have high impact on a OSH project.

A major factor for success is the replicability of a project. The research performed indicates that key strategies for enhancing replicability is to create easily understandable documentation for all aspects of the product. Furthermore, the OSH actor needs to be able to source, manufacture and assemble the hardware. The thesis has worked on developing a good compromise between an OSH product that enables the user to easily make it themselves, enhancing the performance of the scanner, and creating good documentation, thereby enhancing the replicability of the project. Based on the research undertaken buy this thesis, this compromise positively contributes to the success of the project, by lowering the bar of entry for the community, while delivering a well performing product.

The thesis also highlights challenges associated with OSH as a business model. A major challenge is the risk of copy-cats. However, OSH benefits of community contributions, free advertising, and instant feedback, which (if properly utilised) can accelerate product development and thus give a competitive advantage.

Furthermore, research indicates that being an open source hardware project has a competitive advantage for some customers due to a reduced risk of vendor bankruptcy or lock-in.

Based on the findings from the research, as well as experience with feedback and development through the online community throughout the project, the team finds the application of OSH an advantage for the development process of this project.

The team has focused on understanding the user, the use cases and the context of the PlasticScanner project.

Two main segments of target users of the PlasticScanner has been identified: Individual makers and commercial recycling companies. These two customer segments largely require the same hardware and software, but the situation and intensity of which the device is used, differs.

The team has identified key requirements based on the necessary requirements for a scanner fitting the more challenging use case of a commercial recycler, such as identification accuracy, use with gloves, price, and recallability. Furthermore, the requirements of a community version for individual makers have been developed. These two main target groups have formed the basis for the development of the plastic scanner.

Based on the use cases and developed design, an appropriate business model has been developed to fit both customer segments. The primary company activities and revenue sources stem from two sources. The first is the development and sale of manufactured development boards and complete PlasticScanners. The second is a data science and software unit, developing the recognition model and selling custom data services and model training. By offering commercial customers cheap and easy access to a scanner, it allows them to rough sort large batches of the same material rapidly. With the goal of increasing recycling rates, this is expected to be where the PlasticScanner has the highest impact, compared to other use cases. Compared to implementing an automated system for individual processing, the PlasticScanner offers a significantly faster and cheaper way to sort batches. The flexibility in software offers further advantages in the specific use cases of both individuals and commercial users.

The design from the TU Delft project has been reviewed, highlighting a functional design with good considerations for the use cases. A range of areas for improvement have also been identified, such as cost of repairability, ergonomic considerations, electronics design, and maturing of the physical design including design for manufacturing and assembly.

The physical design has been redesigned from the ground up to ensure the previous design had not become fixated, and enabled the team to explore new options and ensure a performant design. The design has been tested by the users, and design choices has been made based on user feedback. Through a range of prototyping methods, three major iterations and accompanying tests have been completed to ensure the new scanner design fulfils the necessary requirements.

The design has been optimised for manufacturing by injection moulding, and initial simulations for injection moulding performance has been undertaken. Furthermore, the design has been assessed and verified by three manufacturing companies to be injection moulding ready, with only mould design and minor changes required.

Through these processes, it has been ensured that the design fits e.g.:the required electronics, provides a comfortable and secure grip, is designed for water resistance and displays affordance for gripping correctly.

Based on existing designs from the PlasticScanner project and open source repositories, the electronic design of the scanner has been redesigned to fit a smaller footprint, as well as a modular design with two new separate PCBs has been introduced. The modular design consists of a scanner PCB containing the sensors, ADC and NIR emitting LEDs, and a controller PCB housing the microcontroller, computation and power circuitry.

The modular design allows for easy hardware upgrades or repairs, and it gives the community more options for custom implementation in their specific configuration.

The hardware has been upgraded and adapted to include a spectral colour sensor and use components with wider availability to ensure replicability and volume manufacturing.

The electronic design was undertaken in three major iterations and testing. The open source community members have continuously verified the design and contributed with changes and feedback.

To further develop the scanner and verify that the hardware capabilities can satisfy the requirements, a firmware for the microcontroller was created. The firmware can successfully control all necessary components, read data from these, transfer data via networks and execute a compiled neural network and render images for the display, as well as other smaller functions.

Finally, data from scanning a range of plastic samples are presented and compared through application of Beers Law. The data analysis shows that some plastic types can be partly grouped, while others are difficult to discern. The data is further normalised and used to train a polymer recognition model through machine learning. Testing showed some variation in NIR readings, which it has not been possible to compensate for through software. Therefore, further research on factors impacting the scan, possible compensation or calibration methods for future implantation would benefit the project.

The variation in data quality is expected to have impacted the polymer recognition model. The trained machine learning model does not achieve a 90 % accuracy when training for recognising five main types of plastic. However, the model reaches ~90-100 % accuracy when only testing between two polymers. Increasing the size of the data set and further verifying the data quality is expected to improve the accuracy across multiple polymer types, leading to the full completion of a demanded product.

In conclusion, team behind this master thesis has developed an open source NIR based handheld polymer identification tool, of which the hardware and physical design is tested and ready for pilot production. An accompanying specific use case for the project leads to a presented business case with a future roadmap for the final realisation of the handheld PlasticScanner.

6. Future development

This section covers recommendations for future development, and discusses ideas or directions that could have been taken during this project, and how they could have progressed the project in other directions.

Scanner PCB

The scanner PCB has been developed and tested in several iterations, but there are still more development to be done, if the scanner should be further enhanced. Community members on discord has raised concerns regarding the signal-to-noise ratio of the current scanner. Further test and development should be put into the hardware design of the scanner, in order to minimise noise for optimal scan results. The team has discussed an idea of having the LED's and sensor on a separate board available for purchase, making the rest of the board inexpensive to make. This could also allow multiple LED/sensor setups, and enable the user to swap the LED child board, to gain new scanning opportunities. The LED's and sensor are the most expensive components, and take up 50% of the total cost of the product. Research has also been put into sourcing a custom component, combining the emitters and sensor into one component that is sealed off with protective glass. A custom sensor like this could (if ordered in high enough quantities) be financially feasible, and give a competitive advantage, if specific wavelengths are added, that currently is not available on the "off-the-shelf" market, but only by custom order. Furthermore, competitors would have to source the part first, in order to be able to directly copy the PlasticScanner design, or buy the components through the PlasticScanner project. Lastly, more research and testing of the scanner and machine learning model is required, and a larger dataset is needed. This should be on the top of the list for future development.

MCU PCB

The proposed controller PCB is based on an external ESP feather development board by Adafruit. This allows for easy upgrade of the microcontroller unit for development purposes. The development board by Adafruit is open source, which enabled the PlasticScanner project to produce the boards if Adafruit stopped production. An integrated PCB would allow us to reduce the size of the PCB and create a more tightly integrated design. For a commercial version of the controller unit, a solution with an ESP32 SOC integrated in the design is necessary to keep costs down, and have full control of the design. The integrated solution would enable the use of USB-C port for communication with the ESP, where the current use is limited to power only. The team therefore recommend developing an integrated solution. Another feature to add in a new design of the controller unit, is to enable a larger 18650 battery, and thus significantly increase battery life. Customers like Plastix indicate that data for documentation is what delivers value to them. Hans Axel from Plastix described how data is absolutely key to their business. *"What drives us is data. Data, data, data ... for Transparency, and documentation"*. Future hardware development could include incorporating a small macro camera, GPS and a cellular modem to improve the data delivery capabilities even more. This would make it possible for Plastix to document when and where an item was scanned, and exactly how it looked, and thereby assess if the material they receive match the documentation. Lastly, the current design builds upon an external screen development board, which has very few components, but a large connector. In a future version, the team would recommend developing a better screen design. The team recommends using the same TFT screen component, but integrate the screen connection in the PlasticScanner design. This could be done by integrating it into the controller board, or maintain the modular design by designing a screen board with mounting features optimal for interfacing the top-shell of the PlasticScanner.

Digital infrastructure

The current state of the handheld scanner proposed in this report has the hardware required to connect to Wi-Fi or Bluetooth devices, allowing the scanner to directly submit material data to a database, thereby making the data more available to customers who need it, such as Plastix. But the design lacks the digital infrastructure for centralised data gathering and ML training, as the software side of the PlasticScanner was not in scope for this project. The scanner need a platform for handling plastic scan data generated by the community, and by the PlasticScanner project. Gathering data though a community of plastic scanners pose a dimension of challenges, regarding handling and creation of metadata for the user generated data. Furthermore, user-generated data also poses new legal and privacy related challenges, that need to be dealt with. Finally, a process is needed to verify the quality of data received from community scanners. A centralised training of models would also require the proposed digital platform to enable update of the firmware over-the-air (OTA), thus enabling a plastic scanner to become better over time, by enhancing only the firmware.

The digital User experience of the proposed handheld PlasticScanner, is not fully developed, and require further work to be customer ready. The Delft team proposed a UX design, and it could be ideal to incorporate their findings on UX design into a final design. A UX design should be customisable, meaning that a given scanner can be customised into giving the user feedback like "PP" on a green background or "Not PP" on a red background for easy sorting of a single type of plastic, or "PP → container 3" or customise the colour feedback for the various outputs, thus for making it easy for a sorting worker to perform the job correct. The controller board does enable BLE, Wi-Fi and mesh communication, and a cellular connected board could easily be implemented also. Developing a companion app, controlled either via BLE, Wi-Fi, or the internet via cellular would be an ideal next step for the development, as it would enable the user to control and customise the scanner on the go. Lastly, the digital infrastructure need to enable the user to share and distribute scan data easily. E.g. a harbour need to store scan data for all items sorted in a specific bin, to be able to document that a given sample is scanned to be e.g. 100 % PP.

Product roadmap

A future set of product offerings from PlasticScanner include both physical products and custom data services. The roadmap can be seen on figure 6.1. Four different physical products are proposed with different features:

- **Devkit:** Ensuring a continuously updated and accessible development platform for the OS community and makers is important for development, feedback, and innovation. The devkit can also be used by more traditional companies to integrate in a custom process of theirs.
- **MVP version:** A scanner with an extremely competitive entry price is the focus for this version, which is the version developed in this report. The device has the goal to help sort plastic into the main fractions, while keeping the price low. The platform from the controller board allows for great flexibility in software and an upgrade path.
- **Pro version:** This version aims to offer even greater accuracy in identification and to identify combinations of polymers, for example in fishing nets. Research needs to be done to understand if a MEMS sensor is required to reach these features, or if it can be achieved through additional InGaAs sensors and IR LEDs. Like the MVP model, the Pro model aims to significantly undercut other scanners capable of this, even if a MEMS sensor is required.
- **Specialist version:** This scanner aims to offer an expanded level of recognition features, including specific resins and polymer compositions. A MEMS sensor is expected to be required to offer these features, and potentially additional sensors such as a Raman module. The pitch for this model is to compete with current laboratory processes, such as desktop spectroscopy devices. While this is expected to be the most expensive device offered, it is seen as key to select components strategically and combining with clever software to offer a very competitive price.

Finally, an additional software offering is planned. Companies can have very specific items they need to identify (ML training) or need specific data transferred to a system of theirs. By creating a framework and process for the typical custom requests, the flexible hardware platform allows PlasticScanner to offer a set of additional software services.

Other applications

The applications of NIR spectroscopy can seem endless. So far the team has found applications for sorting of coffee beans, quality assessment of silk, rugs, cigars, fruits, cereals, textiles, and bowling lanes [91]. NIR is widely used because it enables non-intrusive testing [91]. This means that the business case for using the PlasticScanner is not limited to plastic identification, but extends to e.g. textile identification tool. Great amounts of research has gone into NIR spectroscopy of fruit sugar content measurements [91], or determining the type of meat in a sample based on the NIR reflectance of the fat [104]. A last example is the use of NIR for identification of counterfeit medicine [91]. Customising the proposed PlasticScanner to a new purpose would only require the training of a new model to fit a specific purpose, and possibly changing LEDs to fit the specific purpose. The plastic scanner design can easily be adopted for new spectroscopy applications, and thus broadening the use case of the PlasticScanner from plastic only, to a general Open NIR Scanner, enabling makers to apply NIR spectroscopy more easily.

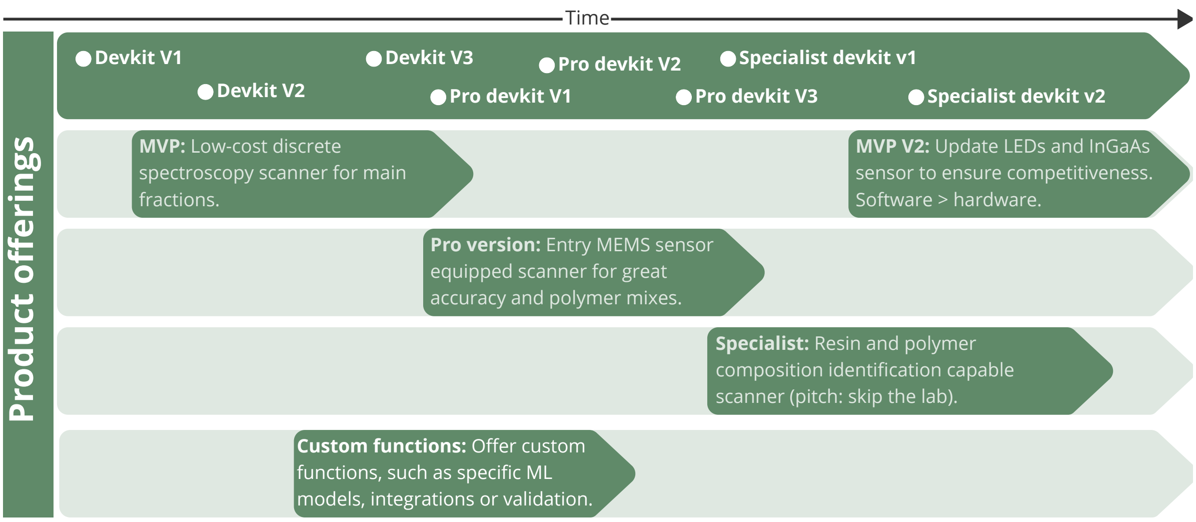
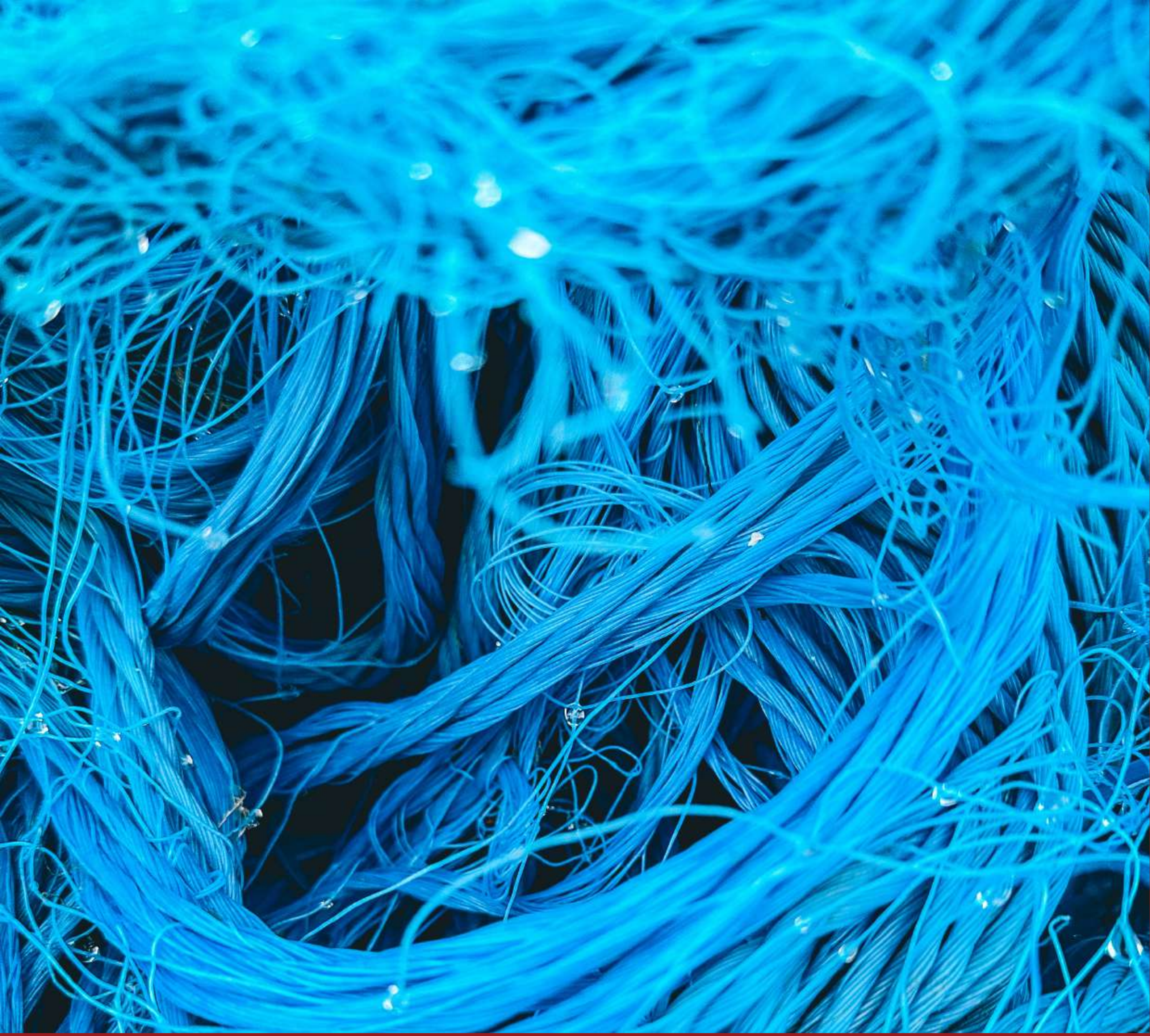


Figure 6.1: Proposed product roadmap



References

[1] F. Hannig and J. Teich, "Open Source Hardware," vol. 54. IEEE Computer Society, pp. 111–115, Oct. 2021. doi: 10.1109/MC.2021.3099046.

[2] Open Hardware academy, "Introduction to Open Hardware." Available: https://hackmd.io/k3uEA4e_SAG1fw5R7p-mGMQ?view#Introduc-tion-to-Open-Hardware

[3] G. Haff, *How open source ate software: Understand the open source movement and so much more*. Apress Media LLC, 2018, pp. 1–180. doi: 10.1007/978-1-4842-3894-3.

[4] C. Peterson, "How I coined the term 'open source' | Opensource.com." 2018. Available: https://opensource.com/article/18/2/coining-term-open-source-software

[5] Wikipedia contributors, "Open source." Available: https://en.wikipedia.org/wiki/Open_source

[6] Jacques Bughin, "wiring the open source enterprise," *McKinsey Quarterly*, vol. January, Jan. 2012.

[7] Opensource.com, "What is open source? | Opensource.com." Available: https://opensource.com/resources/what-open-source

[8] "DIN_SPEC_3105-1."

[9] "DIN_SPEC_3105-2."

[10] Z. Li and W. Seering, "Does open source hardware have a sustainable business model?" *Proceedings of the International Conference on Engineering Design, ICED*, vol. 2019–August, pp. 2239–2248, 2019, doi: 10.1017/dsi.2019.230.

[11] Brian Heater, "Arduino sets its sights on enterprise applications with new funding round." Jul. 2022. Available: https://tcrn.ch/3zo9i1g

[12] K. Balka, C. Raasch, and C. Herstatt, "The effect of selective openness on value creation in user innovation communities," *Journal of Product Innovation Management*, vol. 31, no. 2, pp. 392–407, 2014, doi: 10.1111/jpim.12102.

[13] J. Bonvoisin, R. Mies, and J.-F. Boujut, "Seven observations and research questions about Open Design and Open Source Hardware," doi: 10.1017/dsj.2021.14.

[14] R. Antoniou, R. Pinquié, J. F. Boujut, A. Ezoji, and E. Dekoninck, "Identifying the factors affecting the replicability of open source hardware designs," in *Proceedings of the design society*, 2021, vol. 1, pp. 1817–1826. doi: 10.1017/pds.2021.443.

[15] The Open Next team @ DDC - Danish Design Center, "Show me the damn money!" 2022.

[16] M. Moritz, T. Redlich, and J. Wulfsberg, "Best practices and pitfalls in open source hardware," in *Advances in intelligent systems and computing*, 2018, vol. 721, pp. 200–210. doi: 10.1007/978-3-319-73450-7{_}20.

[17] Marks & Clerk, "How Can Patents Help Your Business - Lexology." Mar. 2019. Available: https://www.lexology.com/library/detail.aspx?g=1d2d622d-d097-43ca-ba53-986699ca4069

[18] RJ Bardsley, "Arduino Empowers Gen Z to Transform the Enterprise World | Business Wire." Jun. 2022. Available: https://www.businesswire.com/news/home/20220607005327/en/Arduino-Empowers-Gen-Z-to-Transform-the-Enterprise-World

[19] J. M. Pearce, "Emerging Business Models for Open Source Hardware," *Journal of Open Hardware*, vol. 1, no. 1, Mar. 2017, doi: 10.5334/joh.4.

[20] M. Cruickshank, "Nest shutdown a key problem for the Internet of Things." Apr. 2016. Available: https://www.themanufacturer.com/articles/nest-product-shutdown-shows-a-key-problem-for-the-internet-of-things/

[21] "Google Graveyard - Killed by Google." Available: https://killedbygoogle.com/

[22] R. Amadeo, "Google's constant product shutdowns are damaging its brand | Ars Technica." Apr. 2019. Available: https://arstechnica.com/gadgets/2019/04/googles-constant-product-shutdowns-are-damaging-its-brand/

[23] C. Dussutour, "CERN, an international

organisation paving the way for the use of open source software in research | Joinup." Sep. 2020. Available: https://joinup.ec.europa.eu/collection/open-source-observatory-osor/document/cern-international-organisation-paving-way-use-open-source-software-research

[24] RepRap contributors, "RepRap - RepRap." Available: https://reprap.org/wiki/RepRap

[25] E. M. Rogers, "Diffusion of Innovations, 5th Edition (Google eBook)," p. 576, 2003, Available: https://books.google.com/books/about/Diffusion_of_Innovations_5th_Edition.html?id=9U1K5LjUOwEC

[26] Danish Design Center, "User guide to the Open Source Ecosystem Toolkit." Available: https://ddc.dk/tools/open-source-hardware/

[27] CCOHS, "Hand Tool Ergonomics - Tool Design : OSH Answers." Available: https://www.ccohs.ca/oshanswers/ergonomics/handtools/tooldesign.html

[28] C.-Y. Wang and D.-C. Cai, "Hand tool handle design based on hand measurements," 2017.

[29] IDF, "What are Affordances? | IxDF." Available: https://www.interaction-design.org/literature/topics/affordances

[30] A. R. Tilley and Henry Dreyfuss Associates., *The measure of man and woman : human factors in design*. 2001.

[31] Steve. Krug, "Rocket surgery made easy : the do-it-yourself guide to finding and fixing usability problems," p. 161, 2010.

[32] F. F. Reichheld, "The One Number You Need to Grow." 2003. Available: https://hbr.org/2003/12/the-one-number-you-need-to-grow

[33] "What Is Net Promoter?" Available: https://www.netpromoter.com/know/

[34] Wikipedia contributors, "Near-infrared spectroscopy." Available: https://en.wikipedia.org/wiki/Near-infrared_spectroscopy

[35] J. WRobinson, E. MSkelly Frame, and G. I. MFrame, "Undergraduate Instrumental Analysis, Sixth Edition," 2005.

[36] D. Aiken, S. Ramsey, T. Mayo, S. G. Lambrakos, and J. Peak, "Beer-Lambert-Law Parametric Model of Reflectance Spectra for Dyed Fabrics," 2016.

[37] H. Masoumi and S. M. Safavi, "Identification and classification of plastic resins using near infrared reflectance spectroscopy." Available: https://www.researchgate.net/publication/285330830

[38] S. Zhu, H. Chen, M. Wang, X. Guo, Y. Lei, and G. Jin, "Plastic solid waste identification system based on near infrared spectroscopy in combination with support vector machine," *Advanced Industrial and Engineering Polymer Research*, vol. 2, no. 2, pp. 77–81, Apr. 2019, doi: 10.1016/J.AIEPR.2019.04.001.

[39] D. M. Scott, "A two-colour near-infrared sensor for sorting recycled plastic waste Comparative Study of the Chemical Compositions of Liquid Fuel from Thermal Cracking of Low and High-Density Polyethylene Plastic Waste," *Meas. Sci. Technol*, vol. 6, p. 156, 1995.

[40] M.K. ALAM, "Near-infrared spectroscopy and neural networks for resin identification," *Spectroscopy*, vol. 9, no. 2, pp. 30–40, Feb. 1994.

[41] W. H. A. M. Van Den Broek, E. P. P. A. Derks, E. W. Van De Ven, D. Wienke, P. Geladi, and L. M. C. Buydens, "Plastic identification by remote sensing spectroscopic NIR imaging using kernel partial least squares (KPLS)," *Chemometrics and Intelligent Laboratory Systems*, vol. 35, no. 2, pp. 187–197, Dec. 1996, doi: 10.1016/S0169-7439(96)00056-1.

[42] Hamed Masoumi, Seyed Mohsen Safavi, and Zahra Khani, "Identification and classification of plastic resins using near infrared reflectance spectroscopy," *International Scholarly and Scientific Research & Innovation*, vol. 6, no. 5, pp. 877–884, 2012.

[43] British Design Council, "Eleven les-

sons: managing design in eleven global brands," *British Design Council*, 2005, Available: www.designcouncil.org.uk

[44] British Design Council, "Framework for Innovation: Design Council's evolved Double Diamond." Available: https://www.designcouncil.org.uk/our-work/skills-learning/tools-frameworks/framework-for-innovation-design-councils-evolved-double-diamond/

[45] European Parliament and Council, "Establishing the identification system for packaging materials," 1997.

[46] ASTM, "Standard Practice for Coding Plastic Manufactured Articles for Resin Identification." Jan. 2022. Available: https://compass.astm.org/document/?contentCode=ASTM%7CD7611_D7611M-21%7Cen-US&proxycl=https%3A%2F%2Fsecure.astm.org&fromLogin=true

[47] R. Geyer, J. R. Jambeck, and K. L. Law, "Production, use, and fate of all plastics ever made," *Science Advances*, vol. 3, no. 7, Jul. 2017, doi: 10.1126/SCIADV.1700782/SUPPL{_}FILE/1700782{_}SM.PDF.

[48] P. T. Tang, "Slutrapport, PolySort og PolySort PLUS Fleksibel sortering af plastaffald," 2018.

[49] Michael Pinkel, Jürgen Deditz, and Renato Sarc, "Study about Plastic Sorting and Recycling," 2019.

[50] Markus Glavind, "PlasticScanner Sensor board – myLists | DigiKey." Available: https://www.digikey.dk/da/mylists/list/Y1S1ANYGRS

[51] C. L. Tan and H. Mohseni, "Emerging technologies for high performance infrared detectors," vol. 7. Walter de Gruyter GmbH, pp. 169–197, Jan. 2018. doi: 10.1515/NANOPH-2017-0061/HTML.

[52] Digikey, "0090-3111-185 Advanced Photonix | Sensorer, transducere | DigiKey." Available: https://www.digikey.dk/da/products/detail/advanced-photonix/0090-3111-185/13165774

[53] Europa-parlementet og rådet, "EU Direktiv 2019/904 - Reduktion af visse plastproduktioners miljøpåvirkning." Europa parlementet og europa rådet, Jun. 2019. Available: http://data.europa.eu/eli/dir/2019/904

[54] Thygesen and Johan, "Udvidet producentansvar på fiskeredskaber Analyse af mulige organiserings-modeller i Danmark," Miljøstyrelsen, Apr. 2020.

[55] Regeringen," Udvidet producentansvar for emballage og engangsplastprodukter." Regeringen, Jan. 2022. Available: https://mim.dk/media/231679/aftale-om-udvidet-producentansvar-for-emballage-og-engangsprodukter.pdf

[56] M. Glavind and J. De Vos, "BessTrade interview and visit." 2022.

[57] M. Glavind and G. Brandt Gregersen, "Plastix visit and interview." Dec. 2022.

[58] Danish Design Center, "Open source: Giving your product away is the best idea you've never had." Sep. 2021. Available: https://ddc.dk/giving-your-product-away-for-free-is-the-best-idea-youve-never-had/

[59] R. Mies, J. Bonvoisin, and R. Jochem, "Harnessing the Synergy Potential of Open Source Hardware Communities," pp. 129–145, 2019, doi: 10.1007/978-3-319-97788-1{_}11.

[60] PlastiX, "How we do it - Plastix." Available: https://plastixglobal.com/howwedoit/

[61] Stanmech, "Plastics Identification Flow Chart - Articles - STANMECH Technologies Inc." Sep. 2019. Available: https://www.stanmech.com/articles/plastics-identification-flow-chart

[62] Sony, "SWIR image sensor Specifications, Device structure Imaging characteristics," 2022. Available: https://www.sony.net/swir-tech

[63] Aage vestergaard Larsen A/S, "What do we buy?" Available: https://avl.dk/en/procurement/hvad-koeber-vi/

[64] D. Buytaert, "Investing in Open Source

startups | Underscore VC." Available: https://underscore.vc/blog/investing-in-open-source-startups/

[65] B. Heater, "Arduino sets its sights on enterprise applications with new funding round | TechCrunch." Available: https://techcrunch.com/2022/06/07/arduino-sets-its-sights-on-enterprise-applications-with-new-funding-round/

[66] Wouter Kets, "How do you design an Audi." 2016.

[67] M. Glavind, J. Piersma, J. Motuzaité, D. Verkerk, and G. Bouman, "Plastic scanner 2.0," TU Delft, Delft, Jun. 2022.

[68] C. M. Hoffman and R. Joan-Arinyo, "CAD and the product master model," 1998.

[69] CAD2M, "The Master Model Technique." Jul. 2017. Available: https://blogs.solidworks.com/tech/2017/07/become-solidworks-master-master-model-technique.html

[70] Hubs, "What's the best SPI surface finish for your injection molded part?" Available: https://www.hubs.com/knowledge-base/injection-molding-spi-surface-finishes/

[71] Erik M. Kjær, *How to select the right plastics material*, 2nd ed. 2006.

[72] Adafruit, "Adafruit AS7341 10-Channel Light / Color Sensor Breakout [STEMMA QT / Qwiic] : ID 4698 : $15.95 : Adafruit Industries, Unique & fun DIY electronics and kits." Available: https://www.adafruit.com/product/4698

[73] Adafruit, "Adafruit NAU7802 24-Bit ADC - STEMMA QT / Qwiic : ID 4538 : $5.95 : Adafruit Industries, Unique & fun DIY electronics and kits." Available: https://www.adafruit.com/product/4538

[74] "Announcing ESP32-S3 for AIoT Applications | Espressif Systems." Dec. 2020. Available: https://www.espressif.com/en/news/ESP32_S3

[75] "ESP32-S2-WROOM-I-N4 Espressif Systems | RF/IF and RFID | DigiKey." Available: https://www.digikey.dk/en/products/detail/espressif-systems/ESP32-S2-WROOM-I-N4/11613167

[76] "ESP32-S3-WROOM-1-N4 Espressif Systems | RF/IF and RFID | DigiKey." Available: https://www.digikey.dk/en/products/detail/espressif-systems/ESP32-S3-WROOM-1-N4/16162639

[77] J.-L. Aufranc, "Leverage ESP32-S3 AI capabilities with the ESP-DL library - CNX Software." Aug. 2021. Available: https://www.cnx-software.com/2021/08/29/esp32-s3-ai-capabilities-esp-dl-library/

[78] A. Voronova, "All About USB-C: Resistors And Emarkers | Hackaday." 2023. Available: https://hackaday.com/2023/01/04/all-about-usb-c-resistors-and-emarkers/

[79] "I2C Bus Range and Electrical Specifications, Freescale 9S12 HCS12 MC9S12 I2C Hardware." Available: http://www.mosaic-industries.com/embedded-systems/sbc-single-board-computers/freescale-hcs12-9s12-c-language/instrument-control/i2c-bus-specifications

[80] J. de Vos, "DB2.x-Firmware/main.cpp at main Plastic-Scanner/DB2.x-Firmware." 2022. Available: https://github.com/Plastic-Scanner/DB2.x-Firmware/blob/main/app/main.cpp

[81] S. Mistry and D. Coleman, "arduino_tinyml_workshop.ipynb - Colaboratory." Available: https://colab.research.google.com/github/arduino/ArduinoTensorFlowLiteTutorials/blob/master/GestureToEmoji/arduino_tinyml_workshop.ipynb

[82] J. De Vos, "Plastic Scanner - Training model.ipynb - Colaboratory." Available: https://colab.research.google.com/drive/1mmC0EGNghU0gmHdPakfaT970cuBZbCdo#scrollTo=-37xTor5cltH

[83] Eugene Dorfman, "How Much Data Is Required for Machine Learning? - PostIndustria." Mar. 2022. Available: https://postindustria.com/how-much-data-is-required-for-machine-learning/

[84] R. S. Geiger *et al.*, "'Garbage in, gar-

bage out' revisited: What do machine learning application papers report about human-labeled training data?" *Quantitative Science Studies*, vol. 2, no. 3, pp. 795–827, Nov. 2021, doi: 10.1162/QSS{_}A{_}00144.

[85] A. Straller and B. Gessler, "Identification of Plastic Types Using Discrete Near Infrared Reflectance Spectroscopy," 2012. Available: https://www.researchgate.net/publication/337868860

[86] PlasticScanner Project, "Training model." Available: https://colab.research.google.com/drive/1mmC0EGNghU0gmHdPakfaT970cuBZbCdo

[87] Armin Straller, "ReReMeter GitHub repository." 2019. Available: https://github.com/arminstr/reremeter

[88] Google Developers, "Normalization." Available: https://developers.google.com/machine-learning/data-prep/transform/normalization

[89] E. W. C. Donald A. Burns, "Handbook of Near-Infrared Analysis, Practical Spectroscopy," p. 836, 2007.

[90] H. Ikasamo, "Hieromon/AutoConnect: An Arduino library for ESP8266/ESP32 WLAN configuration at runtime with the Web interface." 2023. Available: https://github.com/Hieromon/AutoConnect

[91] Blynk, "OTA: Firmware Over-The-Air updates - Blynk Documentation." 2023. Available: https://docs.blynk.io/en/getting-started/updating-devices-firmwares-ota

[92] H. Ikasamo, "OTA Updates - AutoConnect for ESP8266/ESP32." 2023. Available: https://hieromon.github.io/AutoConnect/otaupdate.html

[93] Tensor Flow documentation, "Custom training: walkthrough |." Available: https://www.tensorflow.org/tutorials/customization/custom_training_walkthrough

[94] Adafruit, "Adafruit ESP32-S2 Feather." Available: https://learn.adafruit.com/adafruit-esp32-s2-feather

[95] "Training and Validation Loss in Deep Learning | Baeldung on Computer Science." Nov. 2022. Available: https://www.baeldung.com/cs/training-validation-loss-deep-learning

[96] Simplilearn, "What is Epoch in Machine Learning? | Simplilearn." 2023. Available: https://www.simplilearn.com/tutorials/machine-learning-tutorial/what-is-epoch-in-machine-learning

[97] "CS231n Convolutional Neural Networks for Visual Recognition." Available: https://cs231n.github.io/neural-networks-3/

[98] European Commission, "Europe's Seaports 2030: Challenges Ahead." 2013. Available: https://ec.europa.eu/commission/presscorner/detail/en/MEMO_13_448

[99] N. Prieto, R. Roehe, P. Lavín, G. Batten, and S. Andrés, "Application of near infrared reflectance spectroscopy to predict meat and meat products quality: A review," *Meat Science*, vol. 83, pp. 175–186, doi: 10.1016/j.meatsci.2009.04.016.

[100] Simplilearn, What is Epoch in Machine Learning? | Simplilearn, 2023. [Online]. Available: https://www.simplilearn.com/tutorials/machine-learning-tutorial/what- is-epoch-in-machine-learning.

[101] CS231n Convolutional Neural Networks for Visual Recognition. [Online]. Avail- able: https://cs231n.github.io/neural-networks-3/.

[102] European Commission, Europe's Seaports 2030: Challenges Ahead, 2013. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ MEMO_13_448.

[103] M. Glavind and A. Bryant, Discord: How can we better help each other make working Scanners? 2023.

[104] N. Prieto, R. Roehe, P. Lavín, G. Batten, and S. Andrés, "Application of near infrared reflectance spectroscopy to predict meat and meat products quality: A review," Meat Science, vol. 83, pp. 175–186, DOI: 10.1016/j.meatsci.2009.04. 016.

Appendix

A.1 List of abbreviations

Abbreviation	Description
ADC	Analogue to digital converter
CAD	Computer-aided Design
DIN	German Institute for Standardisation
FDM	fused deposition modelling 3D print
HDPE	High-density Polyethylene
IDE	Integrated Development Environment
IM	Injection Moulding
LDPE	Low-density Polyethylene
MEMS	Micro Electro-Mechanical Systems
MIR	Mid-infrared
NIR	Near-infrared
OS	Open-Source
OSH	Open-Source Hardware
OSS	Open-Source Software
PCB	Printed Circuit board
PE	Polyethylene
PET	Polyethylene terephthalate
PETG	Glycol Modified version of PET for 3D printing
PLA	Poly
PS	Polystyrene
PVC	Polyvinyl chloride
SLA	Stereolithography 3D print
SLS	Selective laser sintering 3D print
SWIR	Short wavelength infrared Light
TPU	Thermoplastic Polyurethane

Table A.1: Abbreviations used in the report

List of Figures

List of Tables

A.2 Customer Exploration

1. Customer Exploration **"Who might benefit from your offering and why?"**

As a ... *[type of customer]*	... I want to ... *[perform some task]*	... so I can *[achieve some goals]*	How can your open-source offering help me achieve this?
Students (as a part of their studies)	implement NIR spectroscopy in prototype/project	To quickly prototype setups that identify materials	Low price, Good & open documentation on functionality, hard- & firmware, high replicability
Plastic Recycler	Identify plastic type	To sell material as commodity	Low price Off the shelf product, Higher flexibility & Customisation. Lifecycle robustness of product through open firmware.
Product developer	get knowledge on previously used materials	To take informed choices that enable better product development	Faster RoI due to lower cost. Open and custom database possible. Lifecycle robustness of product through open firmware.
Production quality manager	Test materials based on known specific materials	To ensure consistent quality	Faster RoI due to lower cost. Open and custom database possible. Enables custom intergration. Lifecycle robustness of product through open firmware.
Maker space / innovation hub	Help and inspire startups and curious individuals to make things.	To create interest and value in the community and create interest in technical problem solving	Open Source documentation for projects, Low price, enables custom integrations.
Maker & enthusiasts (individual)	identify plastic and learn by doing development	Achieve individual goals like: Having succes by developing something by yourself, develop a specific thing to cover an individual need	Open Source documentation for projects, Low price, enables custom integrations.
Recycling startup	implement NIR spectroscopy as a part of a business case	have a sustainable business case	Faster RoI due to lower cost. Open and custom database possible. Enables custom intergration. Lifecycle robustness of product through open firmware.
Recycling community	Identify polymers	Create awareness through data collection and use of collected materials	Open and custom database possible. Enables custom intergration. Lifecycle robustness of product through open firmware.
Cleanup initiatives	Get better data on collected items	Create awareness	Open and custom database possible. Enables custom intergration - add GPS features. Lifecycle robustness of product through open firmware.
Logistics operators	Sort incoming plastic packaging (or similar)	To give trash (wrap/packaging) value, to enable reselling/recycling	Faster RoI due to lower cost.
Internal closed loop recycling	Identify polymers from operations	to sort and reuse in own production	Custom database possible. Enables custom intergration - add features. Lifecycle robustness of product through open firmware.

A.3 Shape development

Concept A: The Salt Grinder

The shape

With the Salt Grinder, the goal was to create a circular shape, that was designed to fit the PCB at the bottom. The circular design is intended to be comfortable to handle and has a slightly continuously increasing circumference. The button is located on the top of the side of the handle, while the display is placed at the top on an angled surface facing the user. At the bottom, the handle smoothly transitions to a wider section, where the scanner module is located. The design takes some inspiration from the design of a handheld immersion blender.

Gained insights:

The test indicates that the circular shape does not communicate an ideal way to grab the product, resulting in the user not intuitively holding the scanner as intended. Test subjects tried to hold the scanner as a torch, instead of the intended way: as a stamper. some users preferred holding the scanner as a torch over the intended way, leaving the screen out of view under the arm. Other informants expressed that the prototype felt like an item for stamping, and experienced it as *"difficult to be precise with"*. Overall the diameter was experienced as okay, but informants suggested including indents to guide fingers and create a steady grip.

Concept B: The Angled Scanner v1

The shape

The idea with the angled scanner is to adjust the angle of the scan head, to the natural angle of the wrist, in order to enable ergonomically correct scanning of an object. On the angled scanner v1, there is a 20-degree angle between the handle and the scanner head. The angled head is made to angle the display towards the top of the head of the user while being ergonomically comfortable. At the bottom of the scanner head is the scanner PCB itself. The handle is rounded on the bottom to give the user a comfortable and natural grip, while the top of the handle is flatter to create a good surface for the button and to fit the sharper angle the hand makes when closing the hand. The button is meant to be operated by the thumb. The handle aims to have an ergonomic circumference for the average hand.

Gained insights

The tests indicated that the handle is too large, and the edges from the top face to the sides are too sharp. informants expressed uncomftability and were struggling to get a firm grip on the scanner. The test informants did respond positively on the angled screen and scan head.

Concept D:

The shape

The idea of the torch prototype is to create a soft transition between the handle and the scanner head. The shape of the scanner head is designed to mimic the way a flashlight is spreading from the source, guiding the user on how to point the scanner. The activation button is placed at the top of the handle, at the transition to the scanner head and is operated by the thumb. Moving further up the scanner head is where the display is located. At the very end of the scanner head is the scanner PCB itself.

Gained insights

The tests indicate that a scanning face angled away from the user is creating unnecessary stress on the wrist while holding the unit. The informant's initial grip on the scanner is as far from the head as possible, making the issue worse.

The tests furthermore indicate that the handle shape is comfortable to hold, but the scanning angle and screen placement are not ideal.

Concept E:

The shape

The flashlight has a circular handle for a comfortable holding experience. At the top is a recessed, flat surface for a display to be, along with a button just before the display. The button is meant to be operated by the thumb. The bottom of the handle has a small flat surface at the full length of the handle to stop the scanner from rolling when putting it down. At the end of the handle is a negative 45-degree angle wherein the scanner module is meant to be placed, creating a scanner head that is part of the handle itself. The goal of incorporating the scanner module into the handle is to reduce the amplification of motion when pressing it against an item to scan, thereby attempting to reduce the use of smaller muscles for fine motor skills.

Gained insights
The tests indicate that the angle between the handle axis and the scan axis, is too large, causing the wrist to be flexed to an extent that is not comfortable. The informants did respond positively to the circular shape of the handle and the indent for thumb placement but experienced the handle diameter as slightly too large.

A.4 Arduino libraries

Library	Function
tlc59208.h	PlasticScanner community library to interface with the TLC59208 LED Controller.
Wire.h	Library by Arduino to enable the use of the I2C protocol for components such as the TLC59208 and NAU7802.
Arduino.h	Defining a range of functionalities for the Arduino development environment.
unity.h	Used for unit testing in C.
SparkFun_Qwiic _Scale_NAU7802 _Arduino_Library.h	Library by SparkFun to take readings from the NAU7802 analogue-to-digital converter.
Adafruit_NeoPixel.h	Used to control the RGB LED on the ESP32 Feather.
SPI.h	Creates support for communicating via SPI for the display.
TFT_eSPI.h	Hardware library for generating and outputting images on SPI-connected displays.
math.h	Library to extend the built-in math capabilities of C++.
WiFi.h	Used to control the WiFi module on the ESP32.
EloquentTinyML.h	Machine learning compatibility library for microcontrollers.
tensorflow.h	TensorFlow machine learning implementation for microcontrollers.
barbie.h	The plastic identification ML model for the ESP32.

A.5 List Of Requirements

List of Requirements

Req. No.	Area	Topic	Need	Importance	Fulfilled
1	Electronics, Software	Performance	Can identify the 5 types of plastic with 90% accuracy when scanning virgin materials	5	Yes
2	Electronics, Software	Performance	Can identify the 5 types of plastic with 75% accuracy when scanning heavily decayed materials	5	Partially
3	Electronics	Performance	Needs to be able to identify plastic samples that are 4 cm or larger	5	Yes
4	Electronics	Performance	Store up to 1000 samples	2	Yes
5	Electronics, Software	Performance	Enable sharing and import of data to device	4	Yes
6	Physical design	Environment	Block 95% of all surrounding light, outside at mid-day at equator	4	Partially
7	Physical design, Electronics	Environment	Needs to work in environments ranging from -20 - 50 *C	4	Partially
8	Physical design	Environment	Needs to withstand water and dust. Have a rating of IP65	4	Yes
9	Physical design	Environment	Needs to withstand drop from 2 meters.	2	No
10	Electronics	Community	Work with full functionality for at least 8 hours before need for charging.	5	Partially
11	Electronics, Software	Performance	Deliver results within 5 seconds	4	Partially
12	Electronics	Performance	Charge from 10%-90% in less than 2 hours	2	Yes
13	Physical design	Performance	Product must have option to be secured to operator and be handheld.	3	No
14	Physical design	Maintenence	The product needs to be disassembled with one widely used screwdriver	2	Yes
15	Physical design	Maintenence	The product must be able to be disassembled by the customer within 5 minutes.	2	Yes
16	Business model	Commercial	The product should have a RRP lower then 2000 euros.	5	Yes
17	Business model	Community	The Community Scanner PCB hould be as cheap as possible	4	Yes
18	Business model	Commercial	The product should have a profit margin of at least 40%	4	Yes
20	Physical design	Commercial	The design is ready for a first pilot production of 100 units.	4	Yes
21	Physical design	Commercial	The design is prepared for a production volume of 2000 units	4	Yes
22	Physical design	Performance	Maximum weight of 1kg	5	Yes
23	User Experience	Design	The product should provided more elborate insights and information when needed	4	Partially
24	User Experience	Design	The product should be made from plastic that can be recycled.	4	Yes
25	User Experience	Design	The product should provide guiding feedback during the process.	4	Partially
26	User Experience	Design	The product should have a multicolour screen.	1	Yes
27	User Experience	Design	Visible parts and features should be integrated with a coherent style in which main product looks as one part.	3	Yes
28	User Experience	Design	The grip should have an NPS score above 50	4	Yes
29	Physical design	Enviroment	The product materials should be as sustainable as possible, create minimal CO2 emissions.	3	Yes
30	Physical design	Enviroment	The material should contain the least amount of toxic materials in electronics and enclosure components.	3	Partially
31	Physical design	Enviroment	At least 60% of the product parts should be able to be recycled at end-of life.	4	Yes
32	Physical design	Enviroment	The enclosure should not be made from black plastic or materials which do not have elaborated recycling streams.	4	Yes
33	Physical design	Enviroment	The use of thermosets and other materials which cannot be recycled should be avoided as much as possible	3	Partially
34	Physical design	Ergonomics	The product should enable use with gloves	5	Yes
35	Physical design	Ergonomics	The product has optimal shape for ergonomic comfort	4	Yes
36	Physical design	Ergonomics	The buttons of the product are in optimal placement that do not create strain on the wrist/hand	4	Yes
37	Physical design	Ergonomics	The product should fit the hand size of the average population	4	Yes
38	Software, Physical design, Electronics	Design	The feedback should be understood in loud factory environments and while wearing gloves.	5	Partially
39	Physical design, Electronics	Design	The scanner should have input controls that can be operated while wearing gloves.	4	Yes
40	Software	Design	The text size of displayed text should be at least 4 mm in height.	2	Yes
41	Physical design	Ergonomics	The product should have a centre of mass that is as close as possible to the wrist joint.	2	Yes
42	Software	Design	The information on the screen should be presented in a clear, not too crowded way.	3	Yes
43	Physical design	Design	The product design should facilitate component repairs.	3	Yes
44	Physical design	Design	The product should be easily recyclable by avoiding glue or permanent joining of two different materials.	5	Yes
45	Software	Design	The system should be able to communicate machine learning models to the sold scanners.	5	No
46	Documentation	Community	Good, easy understandable and thurrough documentation and guidance for creation a scanner PCB available on GitHub	5	Partially
47	Electronics	Comunity	The community scanner pcb should require only parts available online from major component resellers	5	Yes

A.6 Material Selection matrix

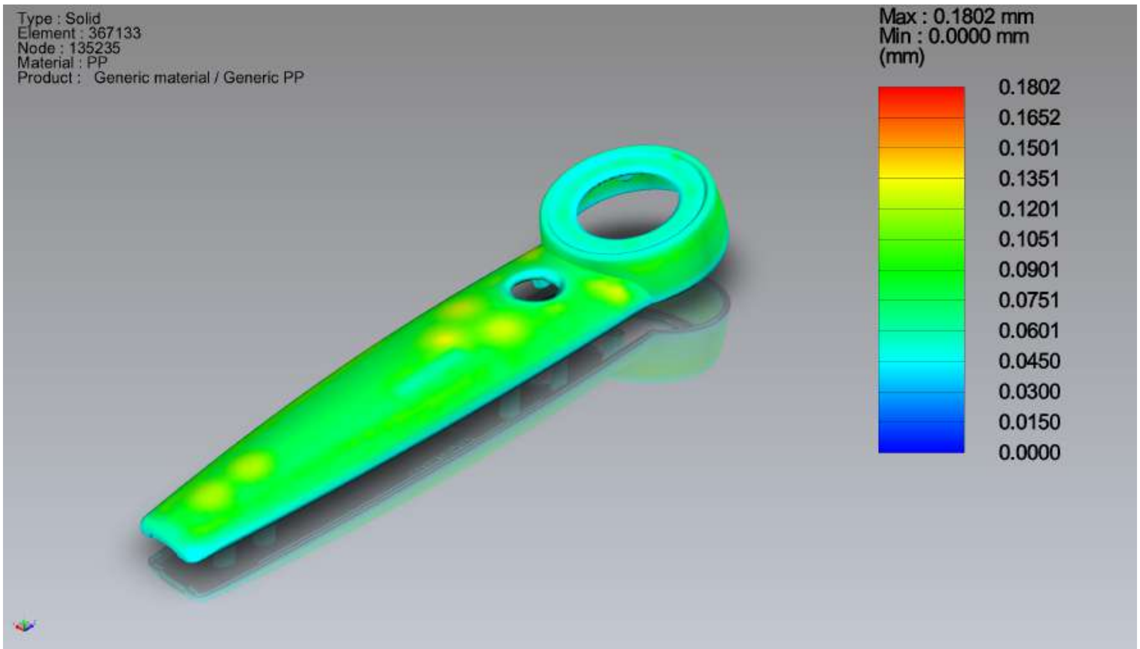
	In design		PS	ABS	SB/SAN	PVC	PMMA	PPO/PS	PC	PE	PP	POM	PA	PBTP	PTFE
Points			2	9	4	9	-1	2	9	9	11	5	7	9	5
Red flags			2	0	1	0	2	2	1	0	0	2	2	1	1
Type	Amorphous	**Weight**	Amorphous	Amorphous	Amorphous	Amorphous	Amorphous	Amorphous	Amorphous	Crystallite	Crystallite	Crystallite	Crystallite	Crystallite	Crystallite
Forming Process															
Injection Moulding	☑	**1**	2	2	2	1	1	1	1	2	2	2	2	1	1
Compression Moulding	☐	**1**	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
Laminating	☐	**1**	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
Extrusion	☐	**1**	1	1	1	2	2	1	1	2	2	1	1	1	1
Blow Moudling	☐	**1**	1	1	1	2	-1	-2	1	2	2	-2	1	-1	-2
Themoforming	☐	**1**	2	2	2	2	1	-2	1	1	1	-2	-2	-2	-2
Assembly															
Snap Conncection	☑	**1**	-1	1	1	1	0	1	1	-1	1	2	2	2	0
Ultrasonic welding	☐	**1**	1	1	1	0	1	0	0	0	0	1	0	1	-1
Hot welding	☐	**1**	0	1	1	1	0	1	1	1	1	1	1	1	0
Friction Welding	☐	**1**	0	1	1	1	0	1	0	1	1	1	1	1	0
Gluing	☐	**1**	2	0	0	0	2	1	2	0	0	0	0	0	-1
Self Cutting Screws	☑	**1**	-1	1	1	0	-1	1	1	0	1	2	2	2	0
Optics and surface															
Crystal Clear	☐	**1**	2	-2	-2	2	2	-2	2	-2	-2	-2	0	0	-2
Transparent	☐	**1**	2	1	1	2	2	-2	2	2	2	1	0	0	2
Bright colors	☐	**1**	2	2	2	2	2	2	2	2	2	2	2	2	2
Electroplating	☐	**1**	-2	2	-2	2	-2	2	-2	2	2	-2	-2	-2	-2
Vapor deposit	☐	**1**	2	2	2	-2	-2	2	2	-2	-2	-2	2	2	2
Lacquer	☐	**1**	2	2	-2	-2	2	2	2	-2	-2	-2	2	2	2
UV Ressistance															
Unstabelized	☐	**1**	-2	-2	-2	-2	2	2	-2	-2	-2	-2	-2	0	2
Stabilized	☐	**1**	0	0	0	0	2	2	0	0	0	0	0	2	2
Physiological															
Contact to foodstuff	☑	**1**	2	2	2	1	1	1	2	2	2	1	2	2	0
Use in medicine	☐	**1**	2	2	2	1	1	1	1	2	2	1	2	1	2
Implantates	☐	**1**	0,5	0,5	0,5	-1	1	1	1	2	2	1	-1	2	2
Floating	☐	**1**	-2	-2	-2	-2	-2	-2	-2	1	2	-2	-2	-2	-2
Relative impact strength	☑		-2	1	0	0	-2	2	2	2	1	0	1	0	2
Chemical ressistance (20C)															
Ketoner (acetone)	☐		-2	-2	-2	-2	-2	-2	-2	2	2	2	2	2	2
Alkoholer	☐		2	2	2	2	0	0	2	2	2	2	2	-2	2
Aromatiske opløsningsmidler	☐		-2	-2	-2	-2	-2	-2	0	-2	2	2	2	2	2
Chlor	☐		-2	-2	-2	-2	-2	-2	-2	-2	-2	2	2	0	2
Eddike (Ethylacetat)	☐		-2	-2	-2	-2	-2	-2	-2	0	0	2	2	2	2
Benzin	☑		-2	0	-2	2	2	-2	2	0	0	2	2	2	2
Vegetabilsk fedt	☐		0	2	2	2	2	2	2	2	2	2	2	2	2
Amoniak	☐		2	2	-2	2	2	2	-2	2	2	2	2	0	2
Natriumhydroxid (10%)	☐		2	2	2	2	2	2	-2	2	2	2	2	0	2
Saltsyre (30%)	☑		2	2	0	2	0	0	2	2	2	-2	-2	2	2
Sulphuric acid (10%)	☐		2	2	2	2	2	2	2	2	2	-2	-2	2	2
Price	☑	**1**	2	0		2	-2	-2	-2	2	2	-2	-2	-2	-2
		A digital tool for plastic selection made by Markus Glavind, based onthe polymer material selection guide, by Erik M. Kjær (2003)													
		"How to select the right polymer," by Erik M. Kjær (2003)													

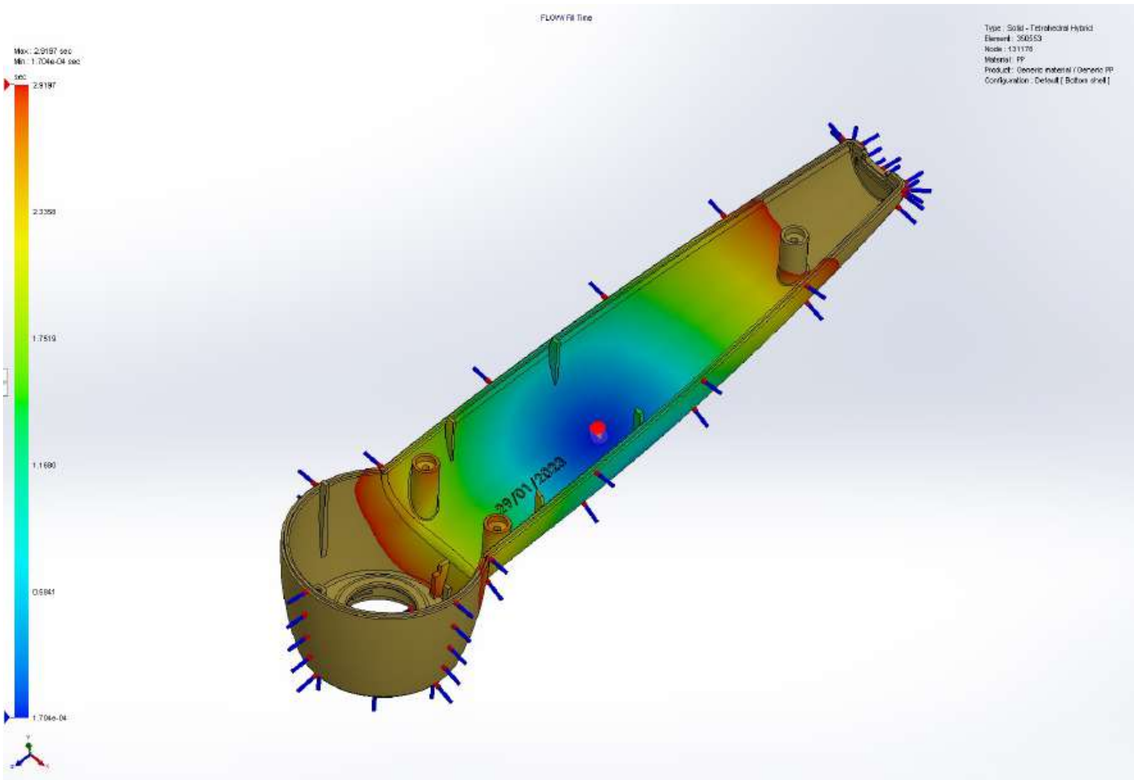
10/02/2023 10.33.20

A.7 Injection moulding results

The results are posted on the public PlaticScanner GitHub for this project, because the files are easier to analyse in a format not compatible with a PDF.

Link to PlaticScanner GitHub





A.8 Test of shapes

Scale of 0-10 sitting/standing		A		B Angled scanner v1		C Angled scanner v2		D		E		F Angled scanner v3 (v11)		G Angled scanner v4 (v12)				
Test ID		Comfort	Grip security	Comfort	Grip security	Comfort	Grip security	Comfort	Grip security	Comfort	Grip security	Comfort	Grip security	Comfort	Grip security	Ranking	Button placement	Display placement
1		5	6	7	7	9	9	6	6	5	7	7	8	7	7	C+F voted best for most situations,	Prefer thumb for controlling the button on C/F	Depends on if you stand or sit. D,E is angled a bit wrong when standing. Angled Scanner display makes sense, requires it to be a good display to be visible from an angle.
2	Siddende	5	3	8	8	9	9	3	5	4	5	9	9	9	9	G (men lidt smallere)	Prefer thumb for controlling the button on C/F	
2	Stående	7	3	8	8	9	9	7	5	9	8	9	9	9	9	G		
3	Siddende	8	8	5	6	7	9	4	7	8	8	9,5	9,0	9	8	F in the length of G (B has too sharp edges)		
3	Stående	5	6	8	8	9	9	9	7	8	8	9,5	9,0	9	8	F in the length of G (B has too shar	Trigger on front	
4	Siddende	7	9	7	9	10	9	6	7	8	9	10,0	9,5	10,0	9,5	G		
4	Stående	7,0	9,0	7,0	9,0	10,0	9,0	6,0	7,0	8,0	9,0	10,0	9,5	10,0	9,5	G		
5	Siddende	6,5	8,0	2,0	4,0	3,0	6,0	3,0	10,0	3,0	7,0	4,0	8,0	4,0	7,0	F or E	Det er mere intuitivt at trykke med tomlen. Du kan se det du trykker på.	
5	Stående	6,0	7,0	6,0	3,0	9,0	8,0	4,0	10,0	6,0	8,0	9,0	9,0	9,0	9,0	F or E		
10	Siddende	7	9	6	6	9	9	5	8	8	8	8	8	8	8	G		
10	Stående	4	5	8	8	9	9	5	7	9	9	8	8	8	8	G		
11	Siddende	7	7	5	4	7	7	3	7	5	6	6	7	6	6	F, Kan bedre lide længden af G		
11	Stående	7	6	7	5	7	7	5	8	8	8	8	7	8	7	F		
12	Siddende	2	10	5	7	10	10	3	10	4	4	9	10	10	10	G		
12	Stående	2	9	8	7	10	10	10	8	5	4	10	10	10	10	G		
13	Siddende	3	4	5	5	8	8	2	4	2	6	6	8	4	7	F	Foretrækker pegefinger (små hænder)	
13	Stående	1	3	6	4	9	9	4	4	3	5	9	9	10	10	G		
14																		
15																		
16																		
17																		
18																		
19																		
20																		
21																		
22																		
23																		
24																		
Average		5	7	6	6	8	9	5	7	6	7	8	9	8	8			
"Promoters"		0	5	0	2	12	12	2	3	2	3	10	10	10	8			
"Neutral"		7	4	9	7	4	4	1	9	6	8	4	7	4	8			
"Detractors"		9	8	8	8	1	1	14	5	9	6	3	0	3	1			
Total		16	17	17	17	17	17	17	17	17	17	17	17	17	17			
NPS calculation		-56	-18	-47	-35	65	65	-71	-12	-41	-18	41	59	41	41			
Final score		-37		-41		65		-41		-29		50		41				

Det kan være let at få en vinkel hv | Den er for lang. Det smalle skal læ | Den må gerne være lidt smallere

Du har ikke en pejling af hvad vandret er , som man har i de vinklede | Den er for bred

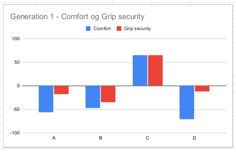
	A	B	C	D	E	F	G
Comfort	-56	-47	65	-71	-41	41	41
Grip security	-18	-35	65	-12	-18	59	41

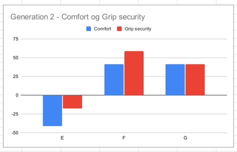
	Comfort	Grip security
A	-56	-18
B	-47	-35
C	65	65
D	-71	-12
E	-41	-18
F	41	59
G	41	41

	Comfort	Grip security
E	-41	-18
F	41	59
G	41	41

	Comfort	Grip security
E	-41,1764705882353	-17,6470588235294
F	41,1764705882353	58,8235294117647
G	41,1764705882353	41,1764705882353

Button placement | Display placement



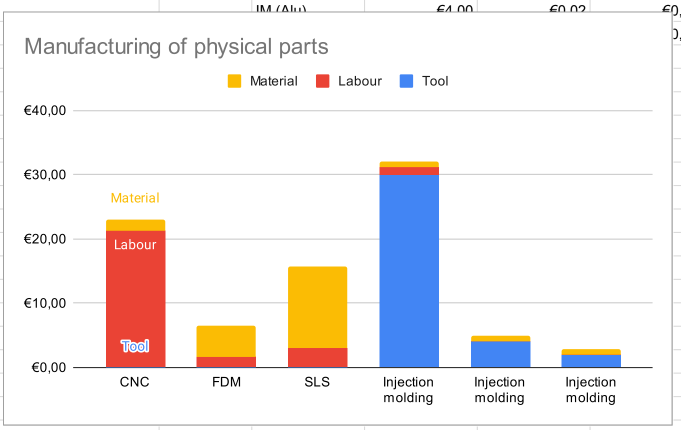


A.9 Manufacturing cost calculation

Method	Units	CNC	FDM	SLS	Injection molding	Injection molding	Injection molding
Tool							
Tool material		None	None	None	SLA	Aluminium	Steel
Production volume	pcs.	1	1	10	100	2500	10000
Number of tools		0	0	0	2	1	1
Tool cost	€	€0,00	€0,00	€0,00	€1.500,00	€10.000,00	€20.000,00
Tool Total	€	€0,00	€0,00	€0,00	€3.000,00	€10.000,00	€20.000,00
Tool p.p.	€	€0,00	€0,00	€0,00	€30,00	€4,00	€2,00
Labour							
Labour cost	€/hr	€20,00	€20,00	€20,00	€20,00	€20,00	€20,00
Labour setup	min	60	2	60	60	120	160
Labour Pre	min/p.p.	2	1	1	1	0	0
Labour Post	min/p.p.	2	2	2	2	0	0
Labour cost Total	€	€21,33	€1,67	€30,00	€120,00	€40,00	€53,33
Labour cost p.p.	€	€21,33	€1,67	€3,00	€1,20	€0,02	€0,01
Material							
Material		POM	PETG	Nylon	PP	PP	PP
Volume	cm3	83,124	83,124	83,124	83,124	83,124	83,124
Support	g		136				
Density	g/cm3	1,4	1,27	1,52	0,9	0,9	0,9
Weight	g	116,3736	241,56748	126,34848	74,8116	74,8116	74,8116
Material cost	€/kg	€15,00	€20,00	€100,00	€12,00	€12,00	€12,00
		€1,75	€4,83	€12,63	€0,90	€0,90	€0,90
	Units	**CNC**	**FDM**	**SLS**	**IM (SLA)**	**IM (Alu)**	**IM (Steel)**
Tool	€	€0,00	€0,00	€0,00	€30,00	€4,00	€2,00
Labour	€	€21,33	€1,67	€3,00	€1,20	€0,02	€0,005
Material	€	€1,75	€4,83	€12,63	€0,90	€0,90	€0,90
Total	€	€23,08	€6,50	€15,63	€32,10	€4,91	€2,90

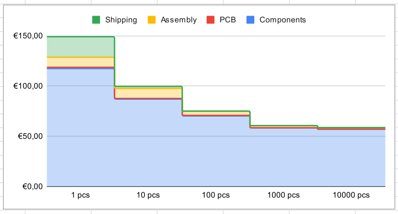
https://blog.prusa3d.com?read-calc=NzQ1NDQ=

	Tool	Labour	Material	Total
Units	€	€	€	€
CNC	€0,00	€21,33	€1,75	€23,08
FDM	€0,00	€1,67	€4,83	€6,50
SLS	€0,00	€3,00	€12,63	€15,63
IM (SLA)	€30,00	€1,20	€0,90	€32,10
IM (Alu)	€4,00	€0,02	€0,90	€4,91
			0,90	€2,90



A.10 Manufacturing cost calculation

Production Volun	1 pcs	10 pcs	100 pcs	1000 pcs	10000 pcs
Scanner					
Components	€117,34	€86,96	€70,20	€58,27	€56,92
PCB	€1,28	€0,64	€0,58	€0,19	€0,15
Assembly	€10,00	€10,00	€4,00	€2,00	€1,50
Shipping	€20,43	€2,04	€0,28	€0,11	€0,05
Total	€149,05	€97,81	€74,79	€60,46	€58,62
	78,72%	88,91%	93,87%	96,38%	97,10%
Controller	1 pcs	10 pcs	100 pcs	1000 pcs	10000 pcs
Components p.b	€30,66	€28,69	€26,56	€24,45	€23,73
PCB	€0,99	€0,62	€0,23	€0,16	€0,15
Assembly p.b	€10,00	€10,00	€4,00	€2,00	€1,50
Shipping p.b.	€20,43	€2,04	€0,38	€0,18	€0,10
Total	€62,08	€41,36	€31,17	€26,79	€25,48



Controller	Components p.b	PCB	Assembly p.b	Shipping p.b.	Total
1 pcs	€30,66	€0,99	€10,00	€20,43	€62,08
10 pcs	€28,69	€0,62	€10,00	€2,04	€41,36
100 pcs	€26,56	€0,23	€4,00	€0,38	€31,17
1000 pcs	€24,45	€0,16	€2,00	€0,18	€26,79
10000 pcs	€23,73	€0,15	€1,50	€0,10	€25,48

A.11 Manufacturing cost calculation

Batch price	1000
Development	€100.000
Material	€88.984
Labour	€3.333
Tooling	€11.237
Marketing	€10.000
Distribution	€10.000
Total	**€223.555**

Unit price	1
Development	€100,00
Material	€88,98
Labour	€3,33
Tooling	€11,24
Marketing	€10,00
Distribution	€10,00
Total	**€223,56**

Minimum Retail Price for Scanner	
Cost price	€223,56
Mark up	40%
Net price	€312,98
Vat (25%)	€78,24
Retail price	**€391,22**

Maximium profit	
Cost price	€223,56
Retail price	€2.500,00
Net Price	€2.000,00
Profit	€1.776,44
Profit Margin	**795%**

A.12 Manufacturing cost calculation

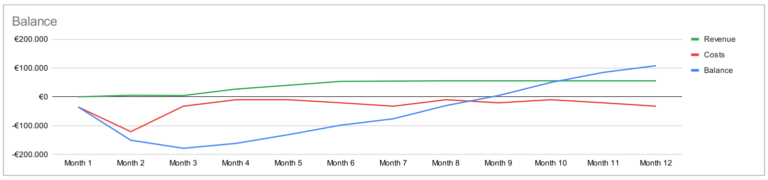
Income	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Total
Scanners sold				10	15	20	20	20	20	20	20	20	165
PCBs sold		30	25	10	15	20	25	30	30	30	30	30	275
Total Revenue	**€0**	**€5.565**	**€4.638**	**€26.855**	**€40.283**	**€53.710**	**€54.638**	**€55.565**	**€55.565**	**€55.565**	**€55.565**	**€55.565**	**€463.513**

Costs	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Total
Development	€30.000	€30.000	€10.000	€10.000	€10.000	€10.000	€10.000	€10.000	€10.000	€10.000	€10.000	€10.000	€160.000
Scanners			100				100					100	300
PCB Kits	50	100				100			100		100		450
Sourcing	€5.300	€10.600	€22.356	€0	€0	€10.600	€22.356	€0	€10.600	€0	€10.600	€22.356	€114.767
tooling		€80.000											€80.000
Total cost	**€35.350**	**€120.700**	**€32.456**	**€10.000**	**€10.000**	**€20.700**	**€32.456**	**€10.000**	**€20.700**	**€10.000**	**€20.700**	**€32.456**	**€355.517**

Balance	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Total
Revenue	€0	€5.565	€4.638	€26.855	€40.283	€53.710	€54.638	€55.565	€55.565	€55.565	€55.565	€55.565	
Costs	-€35.350	-€120.700	-€32.456	-€10.000	-€10.000	-€20.700	-€32.456	-€10.000	-€20.700	-€10.000	-€20.700	-€32.456	
Balance	**-€35.350**	**-€150.485**	**-€178.303**	**-€161.448**	**-€131.166**	**-€98.156**	**-€75.974**	**-€30.409**	**€4.456**	**€50.021**	**€84.886**	**€107.996**	**€107.996**

Inventory													
Scanners	0	0	100	90	75	55	135	115	95	75	55	135	
PCB kits	50	120	95	85	70	150	125	95	165	135	205	175	

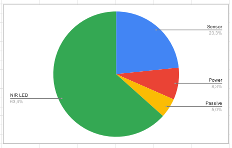
Statics	
PCB Retail price	€185,50
PCB Cost p.b.	€106,00
Scanner retail price	€2.500,00
Scanner Cost	€223,56



A.13 Manufacturing cost calculation

Indeks	Producentens va	Producentens na	Beskrivelse	Tilgængelighed	Stock Status	Enheder	Ønsket mængde	Pakkemængde 1	Pakketype 1	Digi-Keys varenu	Enhedspris 1	Udvidet pris 1	Minimum ordrea	Kundereference	Ønsket varenumm	Referencebetegn	Varestatus	
1	AS7341-DLGT	ams OSRAM	SENSOR AMBIEN	27.56.00	På lager	10	1	10	Cut Tape (CT)	AS7341-DLGTCT-	8,337	€83,37	1	U6	AS7341-DLGTCT-ND		Aktiv	Sensor
2	AP7312-1833W6	Diodes Incorpora	IC REG LINEAR 1.	25.17.00	På lager	10	1	10	Cut Tape (CT)	AP7312-1833W6	0,541	€5,41	1	U7	AP7312-1833W6-7DICT-ND		Aktiv	Power
3	TLC59208FIPWR	Texas Instrument	IC LED DRVR LIN	0	Normally Stockin	10	1	10	Cut Tape (CT)	296-36508-1-ND	1,665	€16,65	1	U5	296-36508-1-ND		Aktiv	Power
4	BSS138DW-7-F	Diodes Incorpora	MOSFET 2N-CH 5	50.35.00	På lager	10	1	10	Cut Tape (CT)	BSS138DW-FDICT	0,367	€3,67	1	Q1	BSS138DW-FDICT-ND		Aktiv	Power
5	EAHC2835WD6	Everlight Electror	LED COOL WHITE	24.28.00	På lager	10	1	10	Cut Tape (CT)	1080-1461-1-ND	0,245	€2,45	1	D3	1080-1461-1-ND		Aktiv	Passive
6	5000	Adafruit Industrie	ESP32-S2 FEATHE	390	På lager	10								Controller	1528-5000-ND		Aktiv	
7	USB4715-GF-A-K	GCT	USB TYPE C HOR	639	På lager	10								Controller	2073-USB4715-GF-A-KIT-ND		Aktiv	
8	CC0603MRX5R8E	YAGEO	CAP CER 10UF 25	29.17.00	På lager	10	3	30	Cut Tape (CT)	311-3494-1-ND	0,47	€14,10	1	C14, C15, C19	CC0603MRX5R8BB106		Aktiv	Passive
9	CC0603MRX5R6E	YAGEO	CAP CER 22UF 10	54.40.00	På lager	10	1	10	Cut Tape (CT)	311-1819-1-ND	0,452	€4,52	1	C17	CC0603MRX5R6BB226		Aktiv	Passive
10	CC0603JRNPO9B	YAGEO	CAP CER 51PF 50	33.02.00	På lager	10	4	40	Cut Tape (CT)	311-3358-1-ND	0,058	€2,32	1	C2, C3, C12, C21	CC0603JRNPO9BN510		Aktiv	Passive
11	CC0603KRX7R9B	YAGEO	CAP CER 0.047UF	549.05.00	På lager	10	2	20	Cut Tape (CT)	311-1427-1-ND	0,043	€0,86	1	C4, C22	CC0603KRX7R9BB473		Aktiv	Passive
12	CC0603JRNPO9B	YAGEO	CAP CER 100PF 5	09.57.23	På lager	10	2	20	Cut Tape (CT)	311-1069-1-ND	0,032	€0,64	1	C5, C23	CC0603JRNPO9BN101		Aktiv	Passive
13	CC0603KRX5R8B	YAGEO	CAP CER 1UF 25V	07.40.53	På lager	10	1	10	Cut Tape (CT)	311-1445-1-ND	0,07	€0,70	1	C6	CC0603KRX5R8BB105		Aktiv	Passive
14	CC0603KRX7R9B	YAGEO	CAP CER 0.1UF 5	11.04.44	På lager	10	10	100	Cut Tape (CT)	311-1344-1-ND	0,0229	€2,29	1	C1, C7, C8, C9, C1	CC0603KRX7R9BB104		Aktiv	Passive
15	LG R971-KN-1	OSRAM Opto (an	LED GREEN DIFFU	225.07.00	På lager	10	1	10	Cut Tape (CT)	475-1410-1-ND	0,155	€1,55	1	D2	475-1410-2-ND		Aktiv	Passive
16	SM04B-SRSS-TB(	JST Sales Americ	CONN HEADER S	186.39.00	På lager	10	2	20	Cut Tape (CT)	455-1804-1-ND	0,487	€9,74	1	J2, J3	SM04B-SRSS-TB(LF)(SN)		Aktiv	Passive
17	RC0603FR-07240	YAGEO	RES 240K OHM 1	270.03.00	På lager	10	4	40	Cut Tape (CT)	311-240KHRCT-N	0,018	€0,72	1	R1, R2, R9, R10	RC0603FR-07240KL		Aktiv	Passive
18	RC0603FR-07150	YAGEO	RES 150 OHM 1%	14.48.30	På lager	10	1	10	Cut Tape (CT)	311-150HRCT-ND	0,018	€0,18	1	R16	RC0603FR-07150RL		Aktiv	Passive
19	RC0603FR-071KL	YAGEO	RES 1K OHM 1%	45.34.54	På lager	10	2	20	Cut Tape (CT)	311-1.00KHRCT-N	0,018	€0,36	1	R18, R24	RC0603FR-071KL		Aktiv	Passive
20	RC0603FR-0756R	YAGEO	RES 56 OHM 1%	315.50.00	På lager	10	1	10	Cut Tape (CT)	311-56.0HRCT-NI	0,018	€0,18	1	R25	RC0603FR-0756RL		Aktiv	Passive
21	RC0603FR-0762R	YAGEO	RES 62 OHM 1%	120.42.00	På lager	10	1	10	Cut Tape (CT)	311-62.0HRCT-NI	0,019	€0,19	1	R26	RC0603FR-0762RL		Aktiv	Passive
22	RC0603FR-0775R	YAGEO	RES 75 OHM 1%	06.55.40	På lager	10	4	40	Cut Tape (CT)	311-75.0HRCT-NI	0,018	€0,72	1	R28, R29, R30, R3	RC0603FR-0775RL		Aktiv	Passive
23	RC0603FR-07301	YAGEO	RES 301 OHM 1%	230.23.00	På lager	10	4	40	Cut Tape (CT)	311-301HRCT-ND	0,018	€0,72	1	R3, R4, R13, R14	RC0603FR-07301RL		Aktiv	Passive
24	RC0603FR-0782R	YAGEO	RES 82 OHM 1%	688.40.00	På lager	10	1	10	Cut Tape (CT)	311-82.0HRCT-NI	0,018	€0,18	1	R32	RC0603FR-0782RL		Aktiv	Passive
25	RC0603FR-0751R	YAGEO	RES 51 OHM 1%	761.54.00	På lager	10	4	40	Cut Tape (CT)	311-51.0HRCT-NI	0,018	€0,72	1	R5, R6, R15, R17	RC0603FR-0751RL		Aktiv	Passive
26	RC0603FR-0710K	YAGEO	RES 10K OHM 1%	50.20.18	På lager	10	4	40	Cut Tape (CT)	311-10.0KHRCT-N	0,018	€0,72	1	R7, R8, R11, R12	RC0603FR-0710KL		Aktiv	Passive
27	NAU7802SGI	Nuvoton Technol	IC ADC 24BIT SIG	119.20.00	På lager	10	1	10	Tube	NAU7802SGI-ND	1,448	€14,48	1	U2	NAU7802SGI-ND		Aktiv	Sensor
28	LM385BD-2.5R2	onsemi	IC VREF SHUNT 1	16.26	På lager	10	1	10	Cut Tape (CT)	LM385BD-2.5R2	0,779	€7,79	1	U3	LM385BD-2.5R2GOSTR-ND		Aktiv	Power
29	MCS-16-NO00A1	SCHURTER Inc.	MCS 16, METAL S	555	På lager	10								Controller	486-MCS-16-NO00A12-Z0NCZ0NC		Aktiv	
30	ECS-2520MVLC-0	ECS Inc.	XTAL OSC XO 4.9	35.03.00	På lager	10	1	10	Cut Tape (CT)	50-ECS-2520MVL	1,202	€12,02	1	Q1	50-ECS-2520MVLC-049-BN-CT-ND		Aktiv	Power
31	0090-3111-185	Advanced Photor	PHOTODIODE 80	13.57	På lager	10	2	20	Cut Tape (CT)	209-0090-3111-1	5,255	€105,10	1	D1, D12	209-0090-3111-185CT-ND		Aktiv	Sensor
32	HIR-C19D-1N90/	Everlight Electror	IR EMITTER 855N	306	På lager	10	1	10	Cut Tape (CT)	1080-HIR-C19D-1	2,915	€29,15	1	D4	1080-HIR-C19D-1N90/L558-P03/C		Aktiv	NIR LED
33	IR26-21C/L110/T	Everlight Electror	EMITTER IR 940N	156.35.00	På lager	10	1	10	Cut Tape (CT)	1080-1357-1-ND	0,284	€2,84	1	D5	1080-1357-1-ND		Aktiv	NIR LED
34	MTSM5010-843-	Marktech Optoel	SWIR EMITTER 1	73	På lager	10	1	10	Bulk	1125-1359-ND	12,681	€126,81	1	D6	1125-1359-ND		Aktiv	NIR LED
35	MTSM0013-844-	Marktech Optoel	SWIR EMITTER 1	507	På lager	10	1	10	Cut Tape (CT)	1125-MTSM0013	8,298	€82,98	1	D7	1125-MTSM0013-844-IRCT-ND		Aktiv	NIR LED
36	MTSM6014-844-	Marktech Optoel	SWIR EMITTER 1	266	På lager	10	1	10	Cut Tape (CT)	1125-MTSM6014	8,298	€82,98	1	D8	1125-MTSM6014-844-IRCT-ND		Aktiv	NIR LED
37	MTSM5016-843-	Marktech Optoel	SWIR EMITTER 1	48	På lager	10	1	10	Bulk	1125-1362-ND	14,33	€143,30	1	D10	1125-1362-ND		Aktiv	NIR LED
38	MTSM5015-194-	Marktech Optoel	SWIR EMITTER 1	761	På lager	10	1	10	Cut Tape (CT)	1125-MTSM501	8,298	€82,98	1	D9	1125-MTSM5015-194-IRCT-ND		Aktiv	NIR LED
39	OPA2376AID	Texas Instrument	IC OPAMP GP 2 C	0	Normally Stockin	10	1	10	Tube	296-26263-5-ND	2,624	€26,24	1	U1, U4	296-26263-5-ND		Aktiv	Power
40	PCA9551PW,118	NXP USA Inc.	IC LED DRVR PS P	27.00.00	På lager	10								Alternative U5	568-11913-1-ND		Aktiv	
41	FDG6301N	onsemi	MOSFET 2N-CH 2	137.58.00	På lager	10								Alternative Q1	FDG6301NCT-ND		Aktiv	
42	TLV2376IDR	Texas Instrument	IC CMOS 2 CIRCU	19.37	På lager	10								Alternative U1, U	296-45053-1-ND		Aktiv	

Sensor	23%	202,95	23,33/Sensor
Power	8%	71,78	8,25/Power
Passive	5%	43,86	5,04/Passive
NIR LED	63%	551,04	63,36/NIR LED
		0	
		0	
		0	
		0	0
		869,63	23,33
			8,25
			5,04
			63,36
			0
			0
			99,98



A.14 Manufacturing offer from IdePro

Idé-Pro Skive A/S
Skyttevej 15
DK-7800 Skive
T: +45 9615 3200
ide-pro@ide-pro.dk
www.ide-pro.dk

Plastic Scanner

Att.: Markus Glavind

Skive den 9.februar 2023

Tilbud på: **Prototypeværktøj**

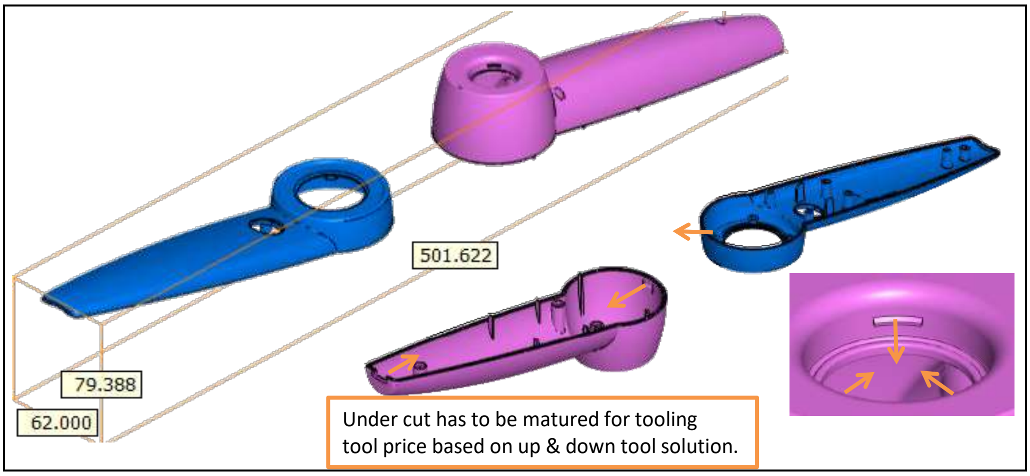
Til: **Top Shell+Bottom Shell**

I henhold til Deres forespørgsel fremsendes hermed tilbud.

Generelt vedr. aluminiumsværktøjer/prototypeværktøjer-
Værktøjet består af indsatse fremstillet i en velegnet aluminiumslegering.
Tolerancer og placering i tolerancer aftales mellem kunde og Idé-Pro Skive A/S.
Værktøjsindsatsene fremstilles i henhold til godkendt 3D dokumentation med en tolerance på plus/minus 0,1 mm.
Vejledende støbetolerance Din 16 742.
Hvis ikke andet er aftalt, er kvaliteten baseret på visuel kontrol samt kundens godkendelse af udfaldsemne.
Evt. specialmateriale faktureres særskilt ved indkøb.

A.15 Manufacturing offer from IdePro

Idé-Pro Skive A/S
Skyttevej 15
DK-7800 Skive
T: +45 9615 3200
ide-pro@ide-pro.dk
www.ide-pro.dk



Top Shell+Bottom Shell

DFM emnemodning		DKK	3.900,00		
Værktøjspris:		DKK	77.625,00	1+1	kavitet værktøj
Antal udfaldsprøver:	20 sæt	DKK	2.160,00	Inkl. opstartsomkostning	

Emnepris:

Top Shell		DKK	5,00	Inkl. Materiale
Bottom Shell		DKK	8,00	Inkl. Materiale
Emnepriserne tillægges 3,5% i energitillæg ved fakturering.				
Opstartsomkostninger:		DKK	1.900,00	pr. serie

Emnevolumen:	83,0	cm3	Emnevægt:	77,2	gram
Materiale:	PP - OceanIX rPPC 210-001 green				
Synlig overflade:	Glasblæst IP 27				
Indløb type:	Direkte indløb			Indløb-	Klippes af

Emballering: Pakkes med foam og mellemlægspap

VAT no. DK17607839
Sydbank A/S
Account no.: 7118 000 1067 761
IBAN no.: DK69 7118 000 1067 761
BIC-kode: SYBKDK22

Side 2/4

A.16 Manufacturing offer from IdePro

Idé-Pro Skive A/S
Skyttevej 15
DK-7800 Skive
T: +45 9615 3200
ide-pro@ide-pro.dk
www.ide-pro.dk

Betalings- og leveringsbetingelser:

Betalingsbetingelser værktøj/udfaldsprøver:	50 % ved ordre og 50 % ved levering af udfaldsprøver. 14 dage netto kontant.
Betalingsbetingelser produktionsemner:	Ved levering af emner - 14 dage netto kontant
Vejledende leveringstid konstruktion:	1 arbejdsuger fra ordre.
Vejledende Leveringstid værktøjer:	5 arbejdsuger fra ordre og levering af godkendt 3D CAD-dokumentation med slip og radier.
Generelt vedr. DFM emnekonstruktion.	Kunden godkender konstruktionen før opstart af værktøjer, og evt. ændringer af konstruktion, og deraf følgende ændring af værktøjet foretages for kundes regning.

Alle priser er ekskl. moms, fragt og emballage.

Vi håber, at ovenstående tilbud har Deres interesse, og vi ser frem til at høre fra Dem.

Med venlig hilsen
Idé-Pro Skive A/S

Morten K. Frandsen
+(45) 96 15 32 16
mkf@ide-pro.dk

A.17 Manufacturing offer from IdePro

Idé-Pro Skive A/S
Skyttevej 15
DK-7800 Skive
T: +45 9615 3200
ide-pro@ide-pro.dk
www.ide-pro.dk

Salgs- og leveringsbetingelser

Levering og leveringstid.
Forsendelsen er ab fabrik, og ordren betragtes leveret fra det øjeblik, varen er overgivet til fremmed fragtfører.
Enhver bestilling udføres under forbehold af strejke, lockout, force majeure eller uheld ved støbning eller under transport, som på indgribende måde bevirker en standsning i arbejdet, hindrer erhvervelsen af det nødvendige materiale eller forsinker forsendelsen af leverancer eller materialer til denne. Disse forhold gælder såvel vor egen fabrik som leverandøren. Vi er dog forpligtet til så hurtigt som muligt at gøre køberen bekendt med sådanne forholds indtræden.
Leverancer omfatter kun de i tilbud og ordrebekræftelse nævnte dele og præstationer. De opgivne leveringstider gælder kun tilnærmelsesvis, når der ikke foreligger særlige aftaler. Alle indgående ordrer ekspederes så vidt muligt i rækkefølge. Vi er ikke forpligtet til at erstatte tab som følge af overskredet leveringstid.

Pris.
Prisen er kun bindende for os, såfremt vi ved modtagelsen af endelig specificeret ordre har eller kan fremskaffe varerne til de priser, kurser, leveringstider og andre betingelser, som vi har kalkuleret med og lagt til grund for tilbudet, respektive salget. I øvrigt er de nævnte priser kun gældende, såfremt fremstillingsomkostningerne ikke forøges væsentligt inden leveringen, også ved forsinkelser, der hidrører fra ovennævnte forbehold.

Antal og vægt.
Af hensyn til fabrikationen forbeholder vi os ret til ved levering af det beordrede stykantal at forøge eller formindske dette med indtil 10%. Skulle en kunde reklamere over stk.- eller vægtopgivelser, må partiet optælles, når repræsentanter for begge parter er til stede, eller vejes på autoriseret vægt, og den tabende part betaler alle udgifter herved.

Betalingsvilkår.
Betaling må finde sted til den i tilbud eller ordrebekræftelse fastsatte tid. Vekselomkostninger betales af køberen.

Emballage.
Emballagen faktureres, og tages ikke retur, med mindre særlig aftale foreligger.

Reklamationer.
Eventuelle reklamationer må finde sted senest 8 dage efter modtagelse af vare eller faktura. Varer, der på grund af fabrikationsfejl skulle vise sig ubrugelige, bringes i orden eller ombyttes uden beregning, når de defekte dele straks returneres. Yderligere erstatning for udgifter i forbindelse med reklamation kan vi ikke påtage os.

Værktøj.
Værktøjer, der helt eller delvist debiteres, henligger på Idé-Pro Skive's lager og udleveres ikke, men anvendes kun til kundens ordrer.

Produktion vil først finde sted når værktøjet er fuldt betalt af kunden.

Produktansvar.
Af hensyn til udvidelse af vor produktansvarsforsikring vil vi fra dags dato supplere vore generelle salgs- og leveringsbetingelser med §36 i "Almindelige leveringsbetingelser NL92", hvis ordlyd er som følger:

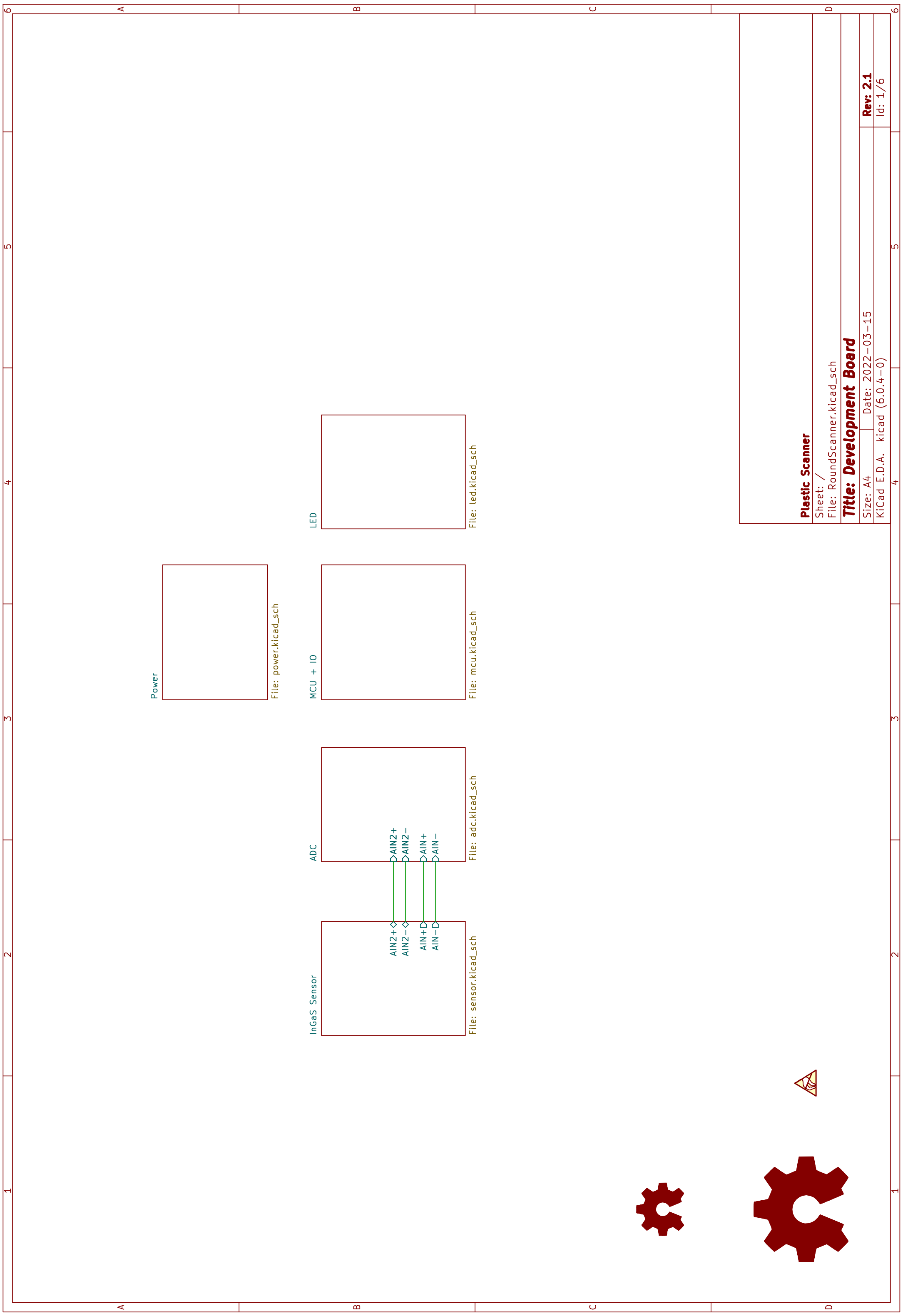
Ansvar for tingskade, forvoldt af materiellet (produktansvar).
Køberen skal holde sælgeren skadesløs i den udstrækning, sælgeren pålægges ansvar overfor tredjemand for sådan skade og sådant tab, som sælgeren efter dette punkts andet og tredje afsnit ikke er ansvarlig for overfor køber.

Sælgeren er ikke ansvarlig for skade, forvoldt af materiellet:
a. på fast ejendom eller løsøre, som indtræder, medens materiellet er i køberens besiddelse.
b. på produkter, der er fremstillet af køberen, eller på produkter, hvori disse indgår, eller for skade på fast ejendom eller løsøre, som disse produkter som følge af materiellet forårsager.

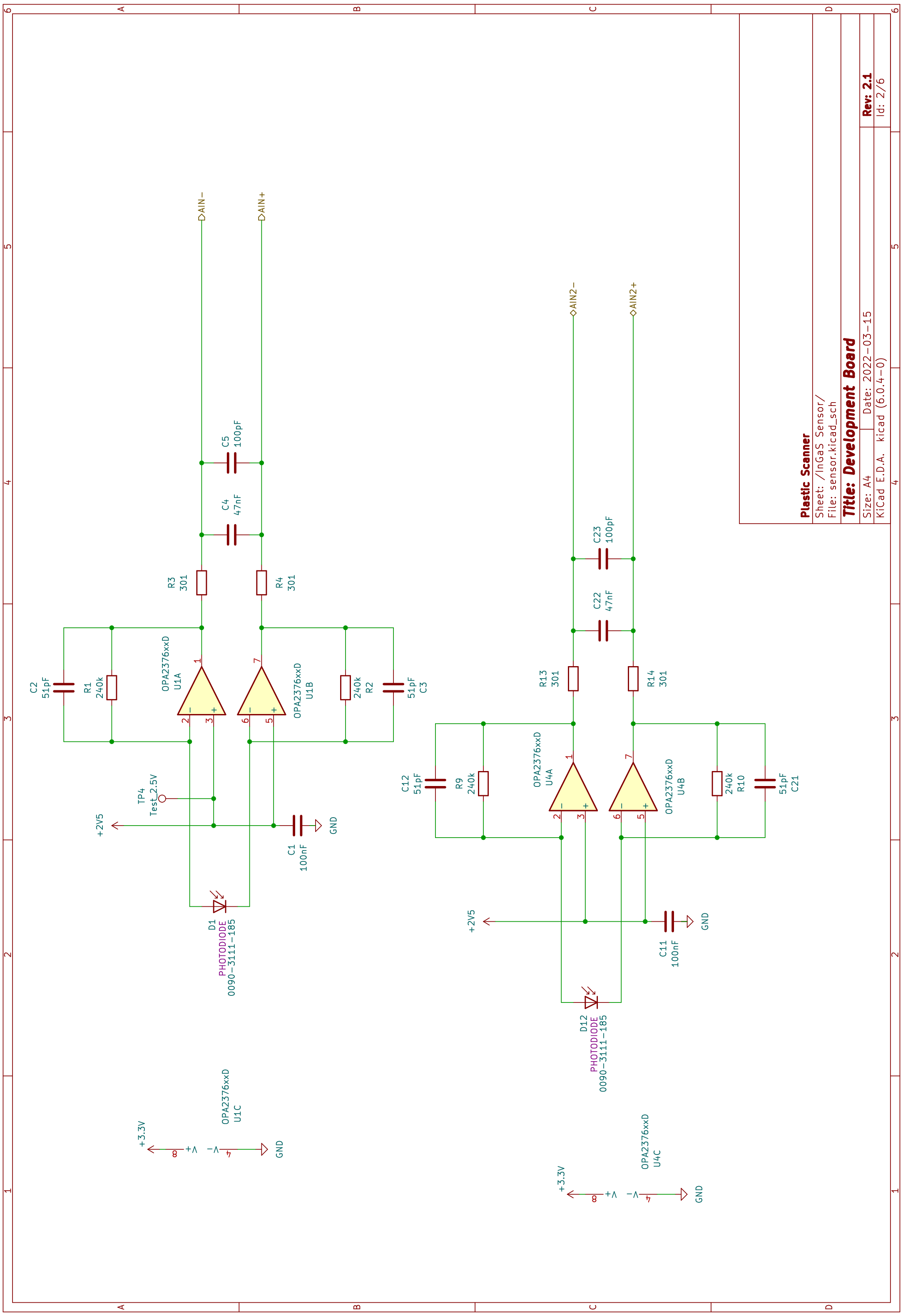
I intet tilfælde er sælgeren ansvarlig for driftstab, tabt fortjeneste eller andre økonomiske konsekvenstab. De nævnte begrænsninger i sælgerens ansvar gælder ikke, hvis han har gjort sig skyldig i grov uagtsomhed. Hvis tredjemand fremsætter krav mod en af parterne om erstatningsansvar i henhold til dette punkt, skal denne part straks underrette den anden herom.

Sælger og køber er gensidigt forpligtet til at lade sig sagsøge ved den domstol eller voldgiftsret, som behandler erstatningskrav, der er rejst mod en af dem på grundlag af en skade eller et tab, som påstås forårsaget af materiellet. Det indbyrdes forhold mellem køber og sælger skal dog altid afgøres ved voldgift i henhold til punkt 40.

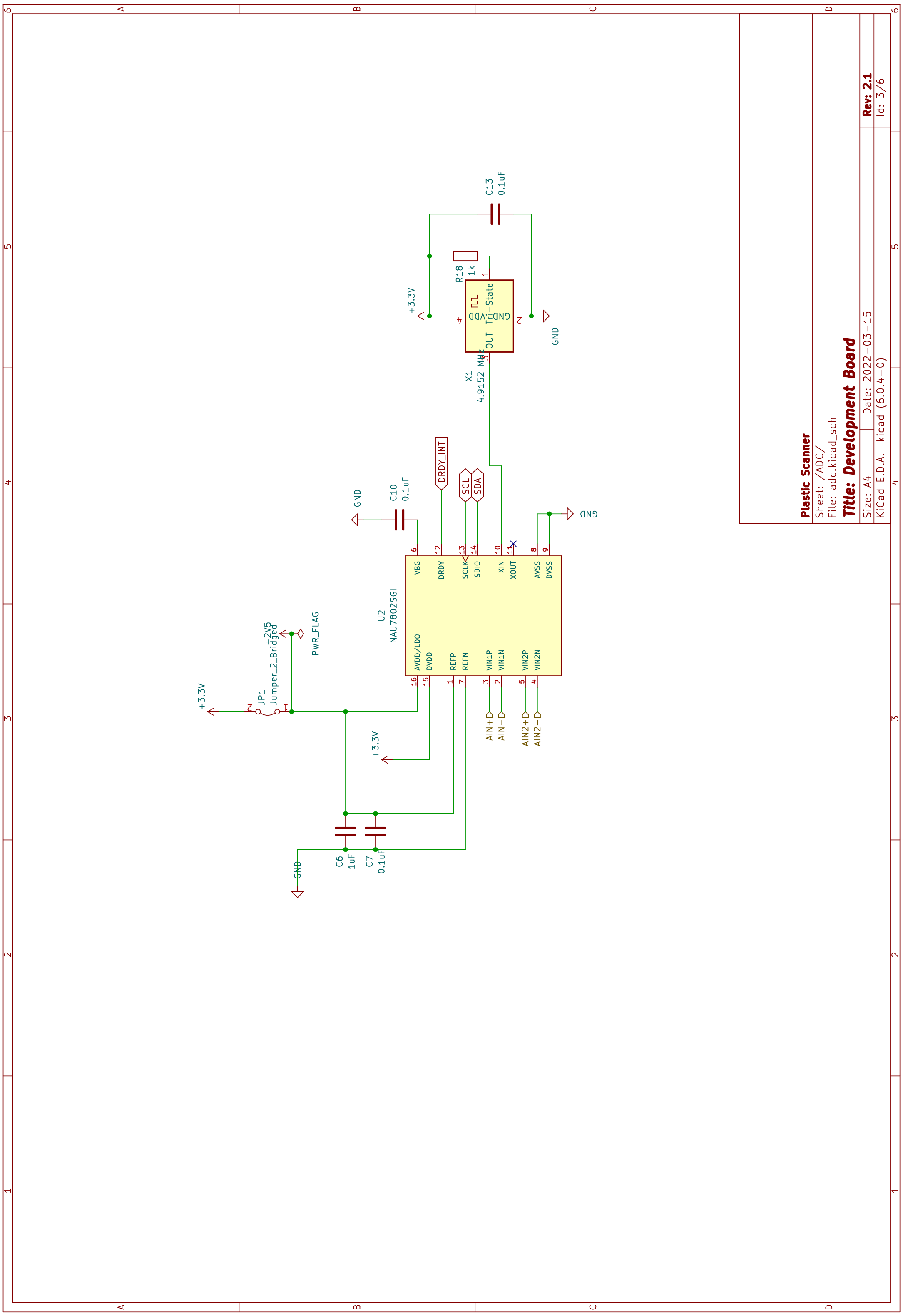
A.18 Schematics of the Scanner PCB



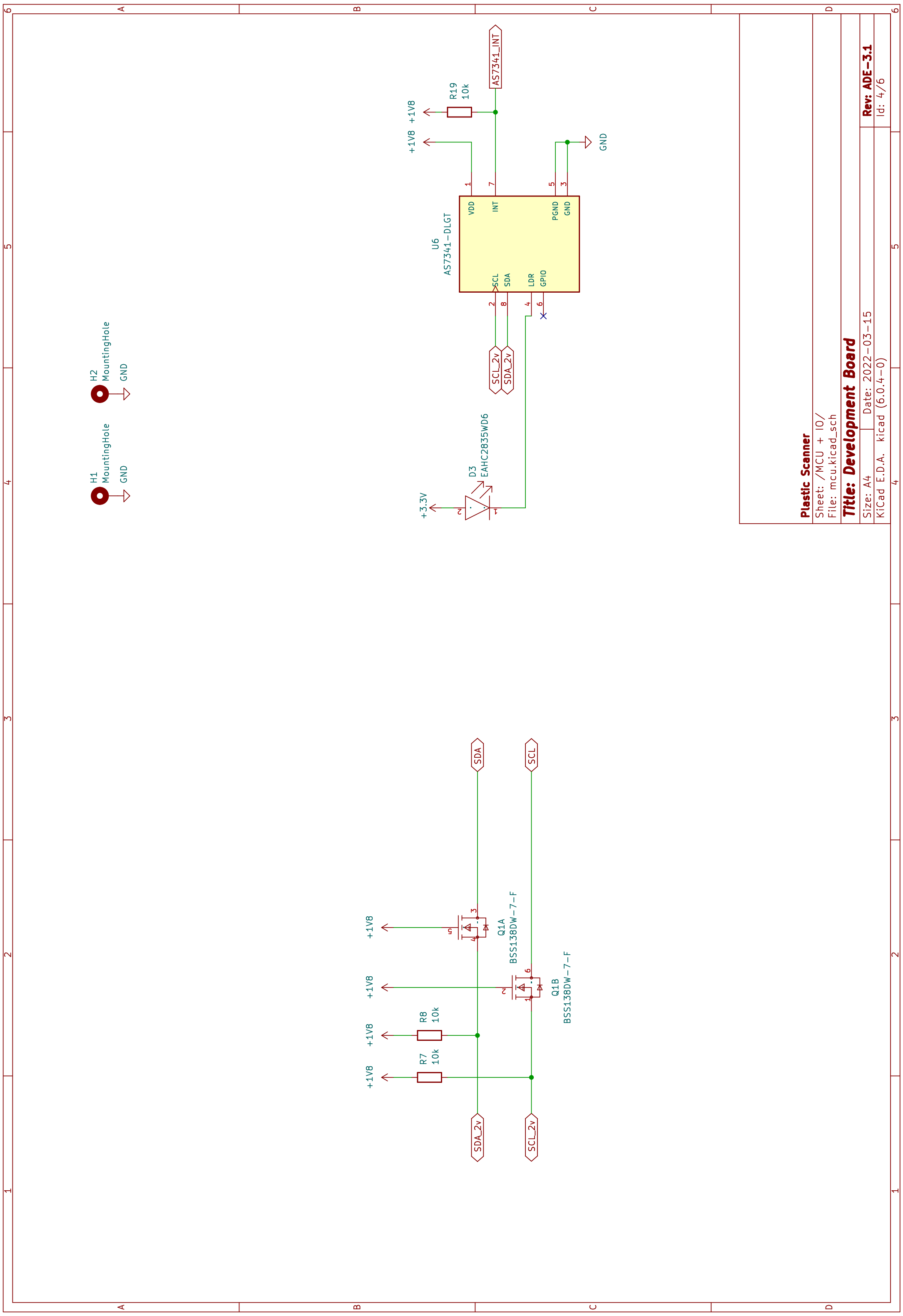
A.19 Schematics of the Scanner PCB



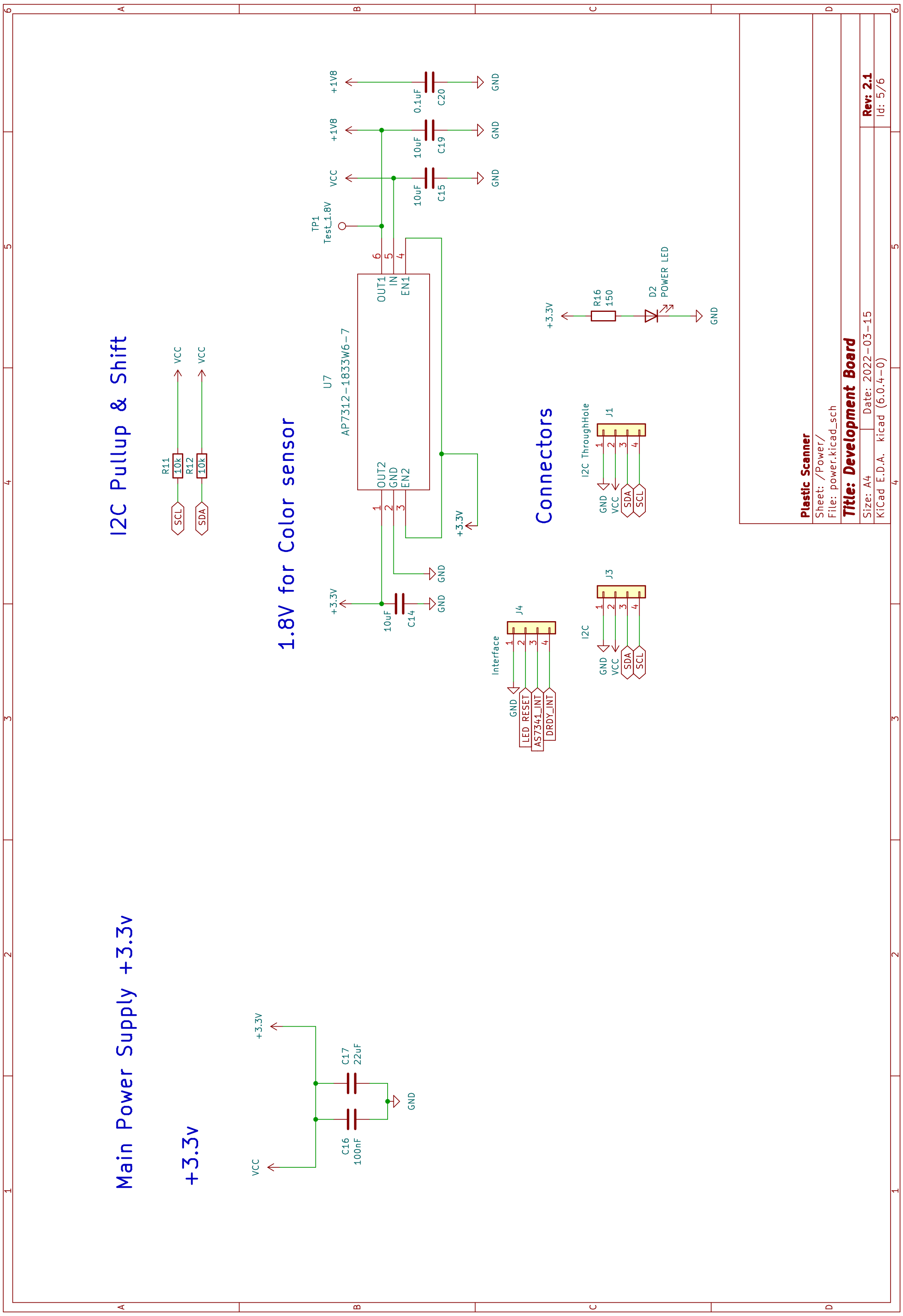
A.20 Schematics of the Scanner PCB



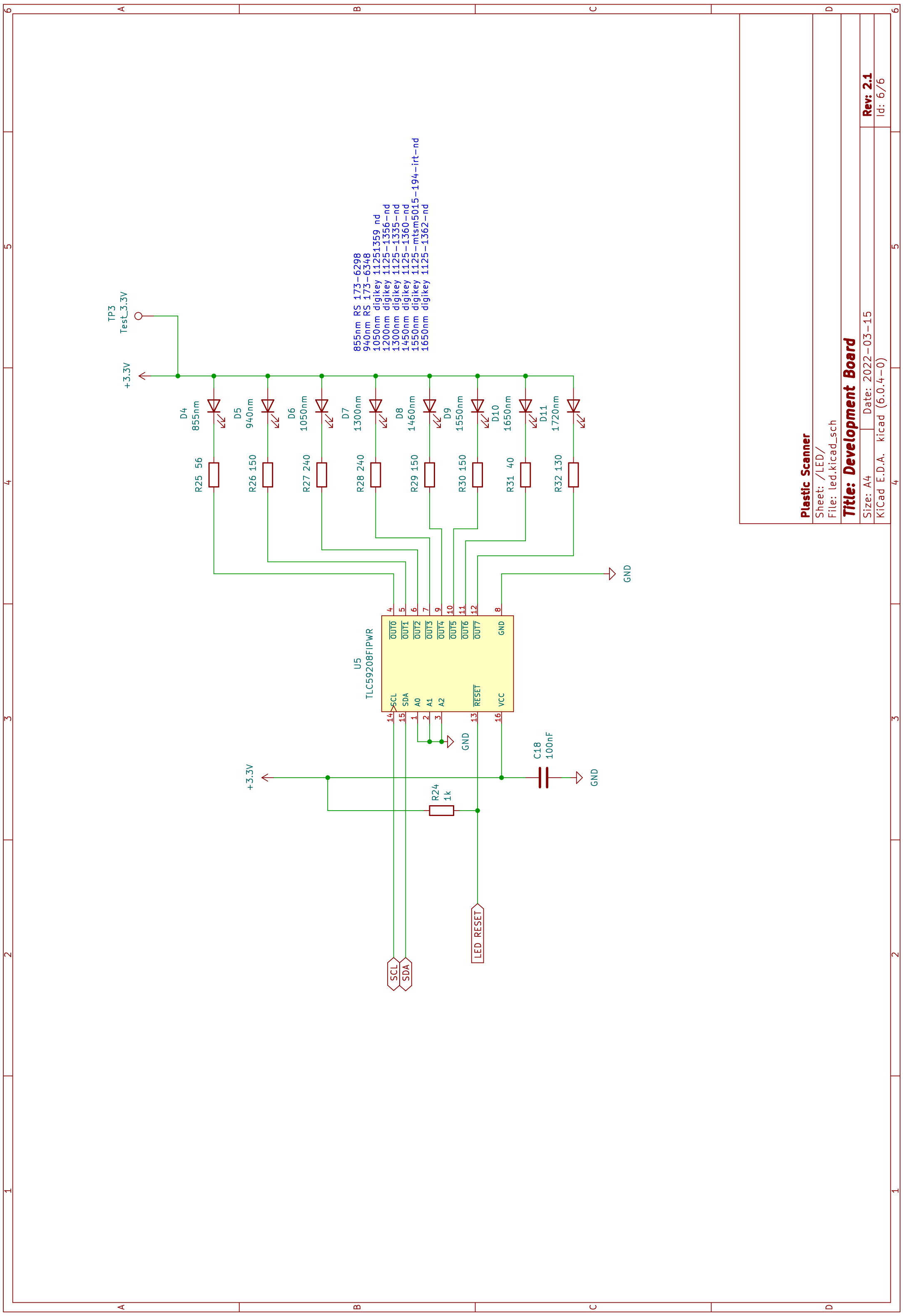
A.21 Schematics of the Scanner PCB



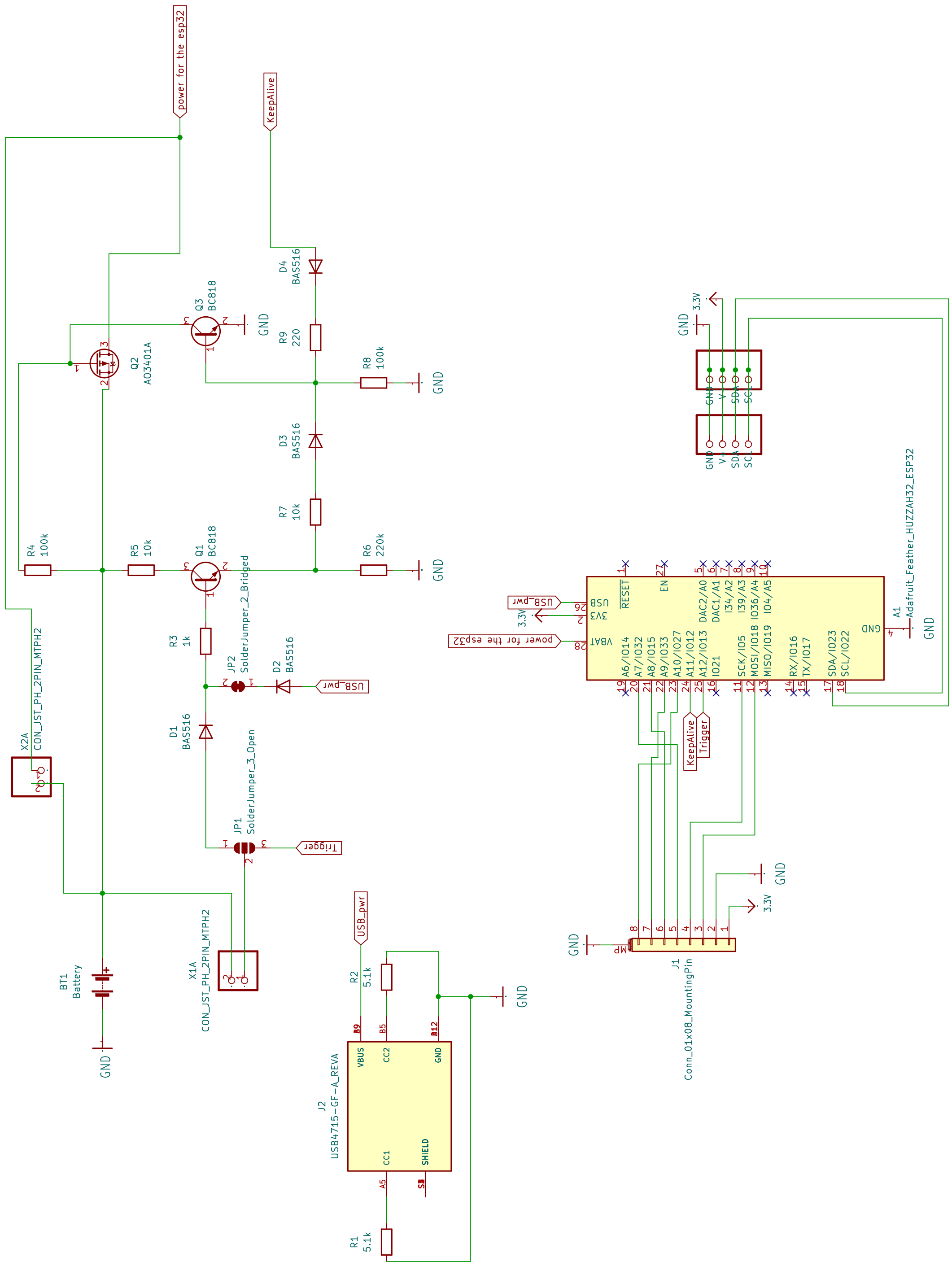
A.22 Schematics of the Scanner PCB



A.23 Schematics of the Scanner PCB



A.24 Schematics of the controller PCB



A.25 Evaluation of design from Delft report

The project has made an evaluation of the design proposed by the student team at TU Delft

The goal was to identify and describe key aspects of current design that needs to be redesigned in order to have a better product. The assessment is based on the following points:

- Usability
- Ergonomic experience
- User experience
- Repairability
- Durability (harsh environments)
- Upgradeability
- Manufacturability
- Functionality
- Cost
- Aesthetics

The full review with subpages for the Firmware, PCB, Screen and physical design can be found via the following line: Link to evaluation.

Shout-out to ChatGPT for this masterpiece! Verse 1:
With a light so bright and a sample in sight
We shine it through, what a beautiful sight
Every wavelength, every vibration
We gather data with precision

Chorus:
NIR spectroscopy, NIR spectroscopy
Identifying plastic types, so easily
No more guessing, no more lies
NIR spectroscopy, our ultimate prize

Verse 2:
Polyethylene, polypropylene
PET and PVC, we can tell them apart
From packaging to bottles and more
NIR helps us keep track of the store

Chorus:
NIR spectroscopy, NIR spectroscopy
Identifying plastic types, so easily
No more guessing, no more lies
NIR spectroscopy, our ultimate prize

Bridge:
It’s quick, it’s accurate, it’s eco-friendly too
Making sure that our planet stays blue
With NIR, we can make a change
Reducing waste, it’s a win-win game

Chorus:
NIR spectroscopy, NIR spectroscopy
Identifying plastic types, so easily
No more guessing, no more lies
NIR spectroscopy, our ultimate prize

Outro:
NIR, NIR, our hero
Making our world a better zero
Spectroscopy, the way to go
Saving the planet, don’t you know?

Technical
University of
Denmark

Akademivej, Building 358
2800 Kgs. Lyngby
Tlf. 4525 1700

www.dtu.dk