

PRODUCT DEVELOPMENT IN RECYCLED PLASTIC

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Abstract

Plastic pollution is featured prominently in the media, and studies indicate that food packaging and water bottles are causing great harm in the oceans. In Denmark, industrial plastic waste is being recycled, but due to the recent implementation of waste sorting in the municipalities, the same does not apply to household waste. We observe an ambiguity around plastic which creates confusion for citizens outside the field, and along with numerous negative stories about plastic in the media, it gives all types of plastic a mutual bad reputation. The challenge is to prevent the plastic from reaching the oceans. Improvements in recycling technologies happen every year, but they will not affect the amount of plastic entering the waste sector relative to what enters the oceans. Concurrently with the growing demand, the pollution will continue to grow. This project concerns the general populations attitude towards plastic. By taking a practical approach and using agile methods, we develop a prototype of a product that will make the user regard plastic waste as a resource.

We take small scale plastic production as starting point, and attack the problem from a Danish perspective, by dealing with the big fractions of plastic waste in Danish households. Through extensive field work, we identify and map the actors and sociotechnical constructions on the development arena. We gain insight into waste handling, chemical concerns and production with recycled plastic, as well as branding of sustainability. We study previous research on consumer behaviour and potential health concerns when recycling post consumer plastic waste.

During a creative process we generate concepts for different solutions. We evaluate the alternatives and choose a suitable product. Through an extensive iterative process, we develop a moulding tool, which we use to produce prototypes. We interview future users, and investigate how a physical prototype can aid the users engage themselves in the problem.

This bachelor end project is conducted in association with the Technical University of Denmark.

Preface

This is the final report of our bachelor end project in relation to B.Sc. Design and Innovation during the Spring semester of 2017. The report is produced in the Institute of Mechanical Engineering at the Technical University of Denmark, DTU. The project is rated at 15 ECTS credits, and is due 4 June 2017.

The documentation of this project consists of two parts; a written report and appendixes in form of worksheets. The report is meant to be readable without the worksheets, but since many of the arguments are substantiated there, we suggest to read the report and have the worksheets on the side, cycling through as you proceed.

The worksheets are referred to as '(WS##)' and the numbering runs chronologically as they are mentioned in the report.

Acknowledgements

We want to thank our supervisor, Associate Professor Torben Anker Lenau, for accepting the task and guiding us during the work with this project.

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We want to thank Nicki van Roon and René Hansen, Roon & Rahn, as well as Benjamin Beckett for competent feedback and collaboration.

Lastly, we thank Lærke Ærenlund, Fors A/S, for offering seats at their conference, giving us further insight in the field.

Initial goals and changes

In the beginning of this project, our focus was on technology development. We wanted to develop a machine, that would allow enthusiasts, artisans and semi-professionals, to process and recycle plastic on a very small scale. From very early on, it was clear to us, that we wanted to affect the current attitude towards plastic. Our ambitious vision was to make these people look upon plastic waste in nature, the same way as a woodworker looks upon a good piece of wood that has fallen of a tree. They should look at it as a material they wanted to take home and use in a new craft or creation, and the feasibility of our machine should enable them to do it. We imagined running a development project with prototyping sessions and early user tests where the users could help shape the machine.

However, early in the research phase, we encountered a project called Precious Plastic, by the Dutch design graduate Dave Hakkens (2017). He had developed and published blueprints of four of these ‘handyman’ versions of plastic producing machines, which people all around the world were already building. Multiple times we attempted to identify parts of this project that we could build upon and improve, but as the project it self were under a rapid development by the time, Hakkens kept launching a new version or addition. In time meant that the only characteristic we thought differentiated our project from his, was an increased focus on aesthetics in the plastic parts.

In the end we chose to change our approach, in order to contribute to find a different way of contributing to the fight against plastic pollution.

We assessed that only very few users would build a machine themselves, and not all builders would be users of the machine and vice versa. Even if users were able to buy one, the amount of potential users would still be very limited.

Due to the larger audience, we considered the potential impact to be a lot bigger, if the message was communicated through commercial products instead of processing machines, and therefore we chose to change the focus of the project to: *“Product development in recycled plastic”*.

During this project we have still been highly inspired by Dave Hakkens’ approach about using plastic waste from household as a local raw material, and use local production to make products for the local society, culture and people.

The change of focus has forced us to make some changes in our project goals. See the original goals on (WS 0.1).

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1 Introduction

1.1 Mission statement

Problem

Plastic pollution is a big problem.

The production of plastic is increasing, and a big part of the plastic migrates to the oceans and enter our ecosystem and food chain.

There are many ways to fight plastic pollution, and one is to recycle the plastic that is already produced.

By recycling plastic, we reduce CO2 emissions from burning it and prevent it from ending up in nature.

To increase the recycling rate, two things are needed:

- Development of sorting and reprocessing technology,
- Sending more plastic to the recycling plants

Vision

To change the way plastic waste is handled, we believe we need to change our attitude towards plastic as a material. We think it is important to make the general population recognize plastic waste as a resource rather than a burden.

Mission

We will create products, which people regard as valuable, made from the plastic waste that surround them in their everyday lives. By showing what potential this material has, we want to make consumers aware of the huge waste, and thereby motivate them to dispose of their plastic in a sensible way and begin to prioritize products from recycled plastic.

1.2 Hypothesis

From the mission statement, we have constructed a hypothesis:

Beautiful and useful products, made of plastic surrounding people in their everyday lives, can help change their attitude towards plastic, because they are regarded as valuable.

1.3 Problem statement

Problems

- How can we make a product from the plastic surrounding people in their everyday lives?
- How can we make people regard the products as valuable?
- Will this affect people's attitude towards plastic?

1.4 Project goals

The goals of this project are to answer the following questions

1. Who are the target users?
2. What types of plastic are present in a Danish household?
3. What product qualifies to making an impact on the populations' handling of plastic?
4. What are the health issues associated with products from recycled plastic?
5. How could the product be produced?
6. How good-looking can we produce the product using plastic waste?
7. How can a safe work environment be ensured when recycling plastic waste?
8. How can plastic waste for a production be sourced?
9. How could a sustainable business be build around the product?
10. What is needed for people to view these products as precious?

By answering all of the above we aim at answering:

11. Will this affect people's attitude towards plastic?

The learning objectives for the project can be found in (WS 1.1)

We attended a conference about “Plastic in a circular economy” hosted by Plastindustrien and Fors A/S with lectures from the plastic industry, waste management companies, NGO’s, and the government. Here we got an essential insight into the current situation and the challenges and obstacles that are hindering recycling of plastic waste.

To investigate the potential of using post-consumer plastic waste from sorting plants, we talked to Martin Tilsted and Jonas Åbo Mortensen (2017) from Copenhagen Municipality. Here we learned that the positive publicity of us using their plastic in our production, would make them give it to us for free. Later in the project we visited their test plant for sorting plastic waste, and got a tour through the process to get a better understanding about the possibility and limitations of the technology today. Also, they gave us two bags of 2.5 kilos of PP and 2.5 kilos of PE, that we have analysed in order to assess the potential of using these sorted fraction for production.

Plastic production and chemical concerns

To learn more about the potential hazards of heating plastic, we talked to polymer researcher, Sokol Ndoni (2017). Here we became aware of the importance of additives, degrading plastic and free radicals, and to learn more about the consequences of the physical contact with these chemicals, we talked to researcher in indoor environments, Gabriel Bekö (2017). This interview emphasized the importance of the matter, and made it clear to us, that health concerns and the missing declaration of additives, are big part of the challenge with recycling plastic today (WS 1.5).

We talked to polymer specialists Henrik Rasmussen (2017) from DTU and Mia Podlech (2017) from Plast Center Danmark, in order to get more knowledge on requirements and regulations regarding documentation and traceability, as well as sparring on our production method. In the interview with Rasmussen, he conjured away some of our health concerns by telling, that the requirements are less than we expected. Also, we built our impression of how the plastic industry views recycling on the basis of his opinion. Podlech confirmed our assumptions about additives in food grade plastic, gave us input for optimization of our production process and sent us a report on health and environmental conditions for plastic materials.

To get knowledge about small scale plastic production we contacted Joe Giddens (2017) from Underbroen and Noe Bhandari (2017) from Space10, who were both building Precious Plastic machines (Precious Plastic 2017). Seeing their machines and learning from their experiences gave us a head start when developing our own tool and process.

For further sparring on the production process, we visited Martin Holm (2017) at Letbæk Plast A/S, who gave us a tour on their factory, showing us how they process recycled PVC and PP using compression moulding.

Product design in recycled plastic

We needed to talk with someone who had experience in product development and design in recycled plastic. Therefore, we visited the experienced industrial designers Aleksej Iskos and Boris Berlin (2016), Julie Skotting and Kajsa Logan Müller (2016), who study industrial design and specialize in plastic design.

Upon choosing the final concept, we talked Nicki van Roon and René Hansen (2017), who founded the interior design startup, Roon & Rahn, and started by using recycled materials, but by now are producing in

other ways. At last, we have talked to owners and employees of interior design stores (Vang, Lightpoint, HAY) for insights on consumer environmental awareness and related purchasing behaviour.

These conversations have given us an insight into the possibilities and the challenges when combining recycled plastic with interior design, as well as valuable feedback and constructive criticism on the project as it proceeds. Through correspondence with Van Roon and Hansen we have learned their experiences concerning consumer behaviour, pricing, business models and branding.

Branding of recycled plastic as a green product

As the story telling through the product has been an essential part of this project, we made contact with Benjamin Beckett (2017), who is experienced in communication and creative marketing. During four meetings with him, he has provided valuable sparring on how to make the story have the most impact on the users. To learn more about consumer behaviour towards recycled plastic, we interviewed Asbjørn Lindsø (2017) from Plastindustrien, who also gave his opinion on our five concepts.

To learn more about the value of a 'green branding' and how to communicate it to consumers, we met with the two founders of DropBucket, Marie Stampe Berggreen and Heiða Gunnarsdóttir Nolsøe (2017), who advised us on how to tell the story and on future perspectives of a potential company.

We attended a workshop as test persons for graduate student Jakob Wulf Andersen (2017), who is developing a guideline for eco-design, to investigate, if some of his methods were relevant to our project.

2 Gathering of knowledge

Before we try to answer these questions we will go through a brief historical introduction to plastic, how plastic is sorted and recycled in Denmark today and the state of the art.

2.1 Attitude towards plastic

“Since their discovery in 1907 by Leo Baekeland, society has had a tumultuous relationship with synthetic polymers (plastics). Once called the “material of 1,000 uses,” the world’s synthetic material has lost popularity over time. Fears of bisphenol A (BPA) leaching have prompted polycarbonate-containing products to be pulled from retail shelves, images of turtles trapped in low-density polyethylene (LDPE) soda rings have circulated the Internet, and plastic bags have been banned in states such as California. News headlines such as “*Nearly every seabird may be eating plastic by 2050*” describe the modern phenomenon of microplastics filling our ocean. Addressing the negative impact of plastics on the environment is not simple, and many have suggested doing away with them completely. However, a universal ban would deleteriously affect quality of life as we know it. Plastic is ubiquitous and comprises everything from disposable medical syringes to running shoes to the body of a Boeing 787. It saves lives and fuel and allows us to live healthy lives.” (Garcia 2016)

In this paragraph Garcia encapsulates the dilemma surrounding plastic. It is a complex mix of environmental, health-related, economic and practical dimensions.

Bisphenol A (BPA) and phthalates like DEHP, are causing growing concerns associated with the exposure to these substances and destructive effects on health and reproduction (North 2013) (WHO 2012) and suggest to be endocrine disruptive chemicals (Meeker 2009). BPA is used in hard plastic like polycarbonate and phthalates are used as plasticizers to soften plastic like PVC, that is a hard resin if no plasticizers are added (resin: plastic type e.g. PP, PE, PVC etc.).

The effect when exposed in smaller quantities have been discussed since then with different waves of EU bans coming over the years as new research is published. A ton of research is still being conducted in this field and hopefully legislation and research will walk hand in hand.

The microplastics leaking into the ocean (Plastic Change 2017) has lately become apparent and it is accumulating in the natural ecosystem with seeming no possibility to degrade. The micro plastic/ beads and also macro plastics accumulate on the ocean floor, in marine life or near the ocean surface. Despite legislative attempts and activist groups, like Surfer Against Sewage (2017), have worked to reduce the amount of plastic going out into the ocean, by raising awareness and doing beach cleanups. However, very few things have actually been done to the accumulating masses of plastic in the ocean, often referred to as *The Plastic Soup* (Plastic Soup Foundation 2017) before the project Ocean Cleanup (2017), which is described in the next chapter.

2.2 Sorting of plastic in Denmark

In Denmark, the 98 municipalities are each responsible for the management of household waste. As a result of this, different waste management strategies are applied throughout the country. This self-rule in waste management has two unfortunate consequences:

1. The different standards for sorting household waste is a source to big confusion among the citizens, as Copenhagen Municipality required citizens to sort 'hard' plastic separately (until 1 May 2017). In Esbjerg Municipality citizens get one container for mixed plastic, glass and metal (Esbjerg Kommune 2017). If a citizen lives and works in two different municipalities, he has to remember when to sort in what way. The confusion results in citizens who do not understand value of their effort, which challenges their motivation for sorting.
2. When the compositions of the sorted fractions are different from every municipality, it is very difficult to create a system that can process waste from more than one source. Due to economies of scale, a bigger amount of plastic waste would make the costs for sorting and reprocessing lower. The current situation makes it hard to create economic value from the plastic waste, and therefore hard to find incentive for development on the area.

At the conference in Nyborg (2017), the Environmental Protection Agency (Bigum 2017), the plastic industry (Drustrup 2017) and the NGO's (Fauerby 2017) all addressed this issue and expressed a demand for a national solution (WS 2.1).

CLEAN Cluster (a cluster organisation of clean tech) and Copenhagen Municipality started a collaboration, with the goal to develop a sorting and reprocessing plant and put it out to tender, for a private company to buy and realize. By combining sorting and processing in the same plant, they claim to be able to make the process more profitable which will allow them to raise the requirements and efficiency of the recycling. The 10th of February 2017, 40 municipalities had signed up for being a part of this collaboration (Ingeniøren 2017).

2.3 Public confusion surrounding plastic

Plastic has a wide range of applications and this can cause some confusion, when talking about plastic. In everyday communication and news media the term "plastic" is used to cover everything from electronic devices and textiles to micro plastic and plastic bags.

In February 2017, a story about a dead whale beached in Norway with a stomach full of plastic bags (DR 2017), received a lot of attention from numerous news media, and revived the debate about plastic in the oceans. At the same time, microplastics and all the negative consequences were much debated topics. While attending a workshop (WS 1.3) and (WS 1.4) on plastic waste in Roskilde Fjord, conducted by Plastic Change, a participant said:

"The invisible plastic is the scary part. It is just like radioactivity" (translated from Danish)

A lot of the attending voiced their expressed their agreement, and another participant added:

"But it is not only dangerous for humans. The animals die too. Just look at the whale in Norway" (translated from Danish)

This is an example of how the plastic can be talked about in unclear terms. Microplastics and plastic bags are dangerous in different ways when left in nature.

Later, another participant said:

"I was so disappointed when we received the new system for waste sorting, and saw that it didn't include plastic, especially when we know all this about microplastics." (translated from Danish)

The confusion among the citizens, makes completely different and unrelated problems magnify each other. It seems like a lot of the citizens only remembered the bad stories and think that they are all about the source, plastic.

We can understand how this could leave to a critical and sterile attitude towards the material, where all plastic could be dangerous, and should be avoided whenever possible. It is our experience that this is a common attitude.

Companies in the industry of paper napkins, toilet paper etc., have invented a term called *brownwashing* (Wall Street Journal 2012). The companies who produces perfectly white paper made from recycled fibres, add a process to the production, using pigment to colour the paper brown. This should allegedly make more consumers perceive the paper as being more sustainable.

In the plastic industry, a similar example is seen when Arla in 2015 launched a new 'green milk carton' for organic milk, which reduces CO₂-emissions by 20 %, compared to the previous edition (See Figure 2.1 Arla's sustainable 'Grøn Karton' (Arla 2015)). According to Arla (2017), the surface coating is made of plastic from renewable sources, which is one of the key factors, but this is hard to understand as a customer, if it looks just like it used to. To compensate for this, Arla now prints brown and grainy texture on the white cartons, most likely inspired by the brownwashing tendency. The fact that the texture is printed, is revealed, as the biggest grains are placed at the exact same spots on all cartons, and since the uppermost part of the cardboard for some reason is left white.



Figure 2.1 Arla's sustainable 'Grøn Karton' (Arla 2015)

Cases like these are interesting of multiple reasons. They show how consumers are heavily influenced by the common perception of recycling being equal to downcycling, and how companies are willing to make

their products look downcycled and of lower quality, only to accommodate the users' misunderstood demands.

When these companies brownwash or print grainy texture on perfectly fine recycled or sustainable material, they are magnifying the existing frames about what recycling is and what it can become. We believe, the confusion it creates, produces negative feedback to the system and slows down development towards a society where recycling is no longer an added feature, but a preferred option.

Both the terms “plastic” and “recycling” act as malfunctioning boundary object, where two actors could be talking about the dangers of plastic and amplify the common concern even if they were talking about different plastic products with different possible dangers. This diversity works as a boundary for efficient communication, and create confusion and reinforces the criticism about plastic.

In an attempt to make the words we use in this report clearer, we have collected some of the terms we are using a lot in this list of definitions, to make it clear what we mean

2.4 States of the art

The last few years has seen rise to projects like the Ocean Cleanup (2017), an ambitious attempt to set up huge static plastic collection systems close to the gyres that attract massive amounts of water carrying plastic waste with it. This new approach is to cleanup the mess that we humans have made. However, it is also clear that this is not a perfect solution to the problem of plastic pollution in the ocean. To solve the problem completely we need to eliminate the source of the pollution.

Another project worth mentioning is the Danish NGO, Plastic Change (2017), who is doing research on the sources and extent of microplastics pollution in the ocean. They are also empowering citizen involvement, doing online campaigns and appealing to the political system to take action on these matters.



Figure 2.2 Adidas x Parley Uncaged, made from ocean waste (Business Insider 2016)

Adidas' collaboration with Parley for the Oceans (Adidas x Parley 2017) is a great example of how waste can be converted into value, while raising awareness at the same time. In this collaboration, the two

organisations are producing sportswear and shoes, seen in Figure 2.2 (Business Insider 2016) from plastic bottles and fishing nets, collected in the sea. Parley's mission and identity is so strongly focused on saving the oceans that the brand itself works as an insurance for the customer, that the Adidas shoe he is buying, is contributing to the cause of cleaning up the oceans. The project is using the convention that most bottles are made in PET and fishing nets are made in nylon to easily get a big homogenous fraction that is easy to recycle in recycling plants already in place for the common PET/ nylon recycling. The perception to the public eye might just be the story of "ocean waste", but for Adidas it is crucial that it is PET and nylon. See (WS 2.2) for elaboration on this.

The way these projects differ from the previous environmental efforts is that these organizations (NGO or for-profit) are not localized around a geographic place but spread out and attack this problem on an international scale, which is needed because this is an international problem.

3 Target users

1. Who are the target users?

Good economy

The target group for this project is defined by the mission statement. Since we are trying to domesticate recycled plastic as a valuable material by using it in valuable products, we narrow the users down to people consumers with a good economy.

Environmentally aware

Our goal is to make them dispose their plastic more sensibly. We want to built upon the willingness to do something good for the planet, and therefore we target the project at users who are environmentally aware.

Politically active

As a result of an increased awareness, we hope to make the users prioritize products made in recycled plastic, why our target users are also politically active.

The target users will be specified further when concept and product is chosen.

4 Types of plastic

2. What types of plastic are present in a Danish household?

There exist two kinds of plastics, thermosets and thermoplastics. Thermoplastics account for around 80% of the plastic being produced (Christensen 2011). The main difference between the two is their thermal characteristics. When thermoplastics are heated they become soft and moldable and when they cool down they become stable again, a feature that makes them easy to recycle. When thermosets are heated, they stay hard until they degrade. Thermosets consists of strong cross bonds that make them resistant to wear and mechanical force and at the same time makes them much harder to recycled.

In 1988 the American Society of Plastics Industry (SPI) introduced a symbol and numbering system of food and non-food packaging consisting of seven categorizations of plastic resin, with each a dedicated number. Japan, Australia and Canada has adopted this system. The use of this identification system has been extended beyond rigid plastic packaging. PlasticsEurope (formerly APME) and The European Committee for Standardization (CEN) have made similar systems Figure 4.1 (Christensen 2011).



Figure 4.1 The SPI Plastic packaging identification system. American use V for the Vinyl in PVC (Christensen 2011)

4.1 Plastic waste fractions

A lot of plastic is being produced and discarded every year. Since 1964, plastic production has increased twentyfold, reaching 311 million tonnes in 2014 (Ellen MacArthur 2016).

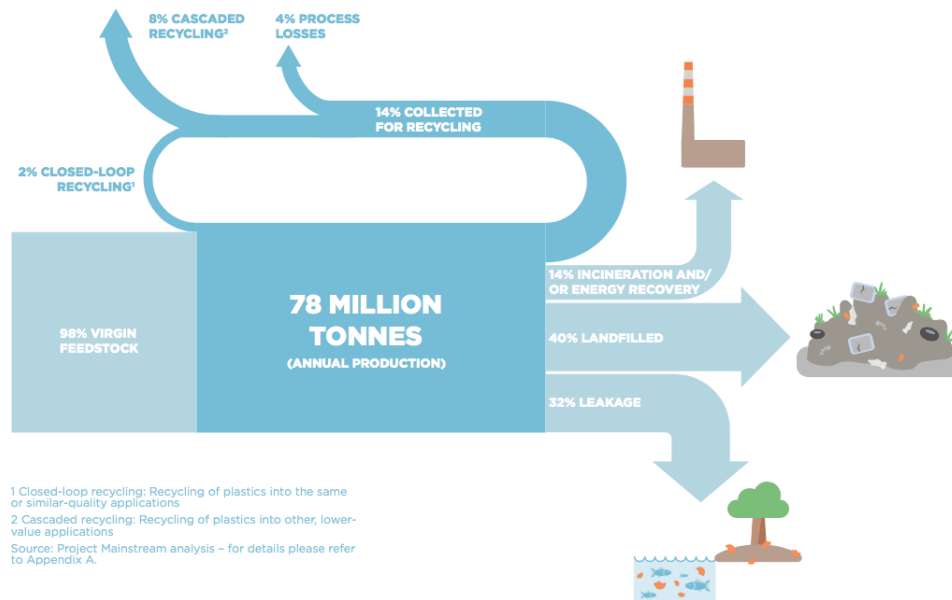


Figure 4.2 Global flows of plastic packaging materials in 2013 (Ellen MacArthur 2016)

When plastic migrates from the waste management system and into nature it causes great harm. United Nations Environment Programme (UNEP 2014) assesses that the natural capital cost of plastic used in the consumer goods industry is estimated to be more than US \$ 75 billion per year (See **Fejl! Henvisningskilden blev ikke fundet.**).

“The cost comes from a range of environmental impacts including those on oceans and the loss of valuable resources when plastic waste is sent to landfill rather than being recycled. The most significant upstream impact is greenhouse gas emissions released from producing plastic feedstock, which is responsible for almost a third of the total natural capital costs. (UNEP 2014, p.7)”

Plastic waste comes in different fractions according to what sector of the society it comes from. Different fractions consist of resins in different amounts, combination and condition.

One part of the industrial waste fraction consists of runners and excess from plastic production and this is usually grinded up at the factory and mixed with virgin material (Schmidt 2006).

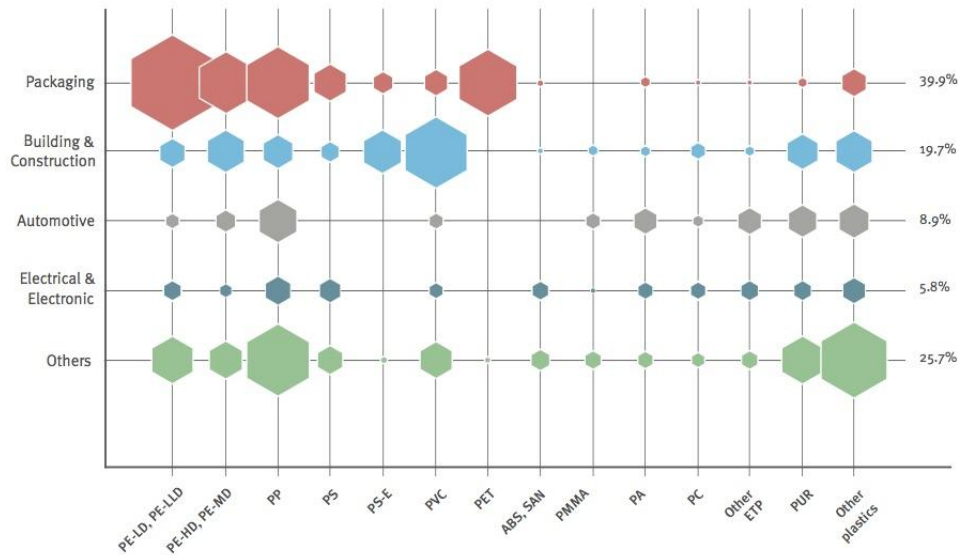


Figure 4.3 European plastics demand by resin type 2015 (Plastics Europe 2016)

Another part consists of wrapping or packaging used for protecting building material and other goods in the transportation industry (Cuculiza 2017). Both of these examples are easy to recycle because of the large amount of homogeneous material (Cuculiza 2017).

The resins are used for different application and so is the resin demands. The European resin demand is shown in **Fejl! Henvisningskilden blev ikke fundet.** (Plastics Europe 2016).

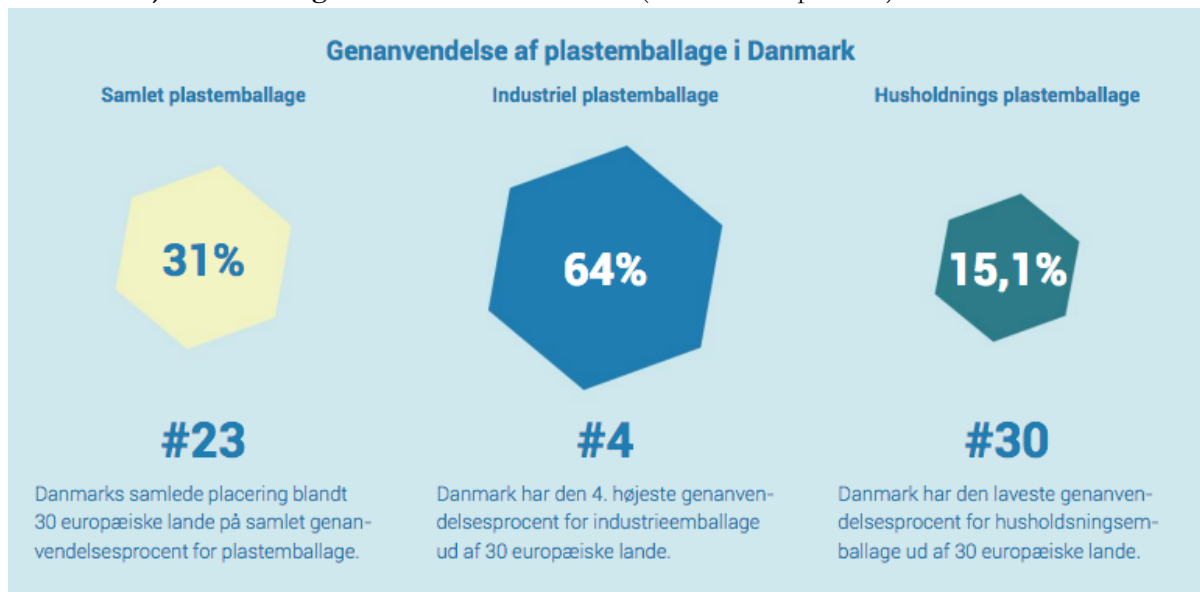


Figure 4.4 Percentage of plastic recycling in DK and position compared to the 30 other EU countries (Plastindustrien 2017). Total packaging recycling (left), Industrial packaging (middle), Household packaging (right).

From **Fejl! Henvisningskilden blev ikke fundet.** (Plastindustrien 2017) it is clear that recycling of plastic packaging waste from households in Denmark is doing far worse than the correspondent industrial recycling.

Only 15.1 % of the plastic is recycled and that is the worst of all the 30 European countries.

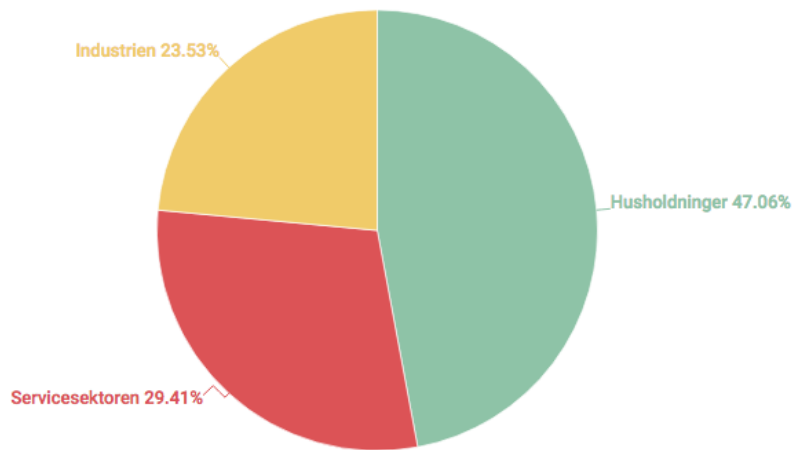


Figure 4.5 Plastic packaging waste fractions in Denmark 2014. Total is 35.000 tonnes (Plastindustrien 2017)

On **Fejl! Henvisningskilden blev ikke fundet.** (Plastindustrien 2017) it is shown that 47 % of plastic packaging used in Denmark in 2014 come from households. This is equivalent to 35.000 tonnes.

4.2 Resin type to focus on

As shown in **Fejl! Henvisningskilden blev ikke fundet.**, packaging from industrial and household are both very big fractions, and we expect it to be easy to get our hands on some of this waste. Within packaging the four largest resin fractions are: LD-PE, PP, PET and HD-PE + MD-PE, in order of size.

LD-PE is usually made into film that have a high surface to mass ratio. That implies a lot of cleaning and a high possibility for degradation from sun and air (Callister 2011).

PET has a high melting temperature, 327 °C (Callister 2011, p. 517), and we had heard that we should try and keep our processes under 300 °C (Almdal 2017) as a rule of thumb to keep the process “safe” and respect the health concerns. When the temperature is risen the substances with lower molecular weights can be broken free and migrate to the air and the risk of reaching hazardous concentrations of substances goes up (Ndoni 2017).

We are going to focus on PP and HD-PE (and MD-PE which is not common) that are two good candidates for this project. Both are polyolefins meaning they consist only of carbon and hydrogen in the resin. Therefore in an idealized situation it would decompose to H₂O and CO₂. That is a good thing compared to resins like PVC, that also contain chlorine, which has the unfortunate ability to develop chlorinated dioxins.

The melting temperature for HD-PE and PP are 137 °C and 175 °C respectively, which is also appropriate to our project. Some of the characteristics and applications of PP and PE is shown in Table 4.1 (Callister 2011).

Material Type ¹	Major Application Characteristics ¹	Virgin Material Applications ¹	Recycled Applications ²

Polyethylenes (HD-PE)	Chemically resistant and electrically insulating; tough and relatively low coefficient of friction; low strength and poor resistance to weathering.	Flexible bottles toys, tumblers, battery parts, ice trays, film wrapping materials, automotive gas tanks	Soft-drink bottle base caps, flower pots, drain pipes, signs, stadium seats, trash cans, recycling bins, traffic-barrier cones, golf-bag liners, detergents bottles, toys.
Polypropylenes (PP)	Resistant to heat distortion; excellent electrical properties and fatigue strength, chemically inert; relatively inexpensive; poor resistance to ultraviolet light.	Sterilizable bottles, packaging film, automotive kick panels, fibres, luggage	Manhole steps, paint buckets, ice scrapers, fast-food trays, lawnmower wheels, automobile battery parts.

Table 4.1 Polypropylene and polyethylene, characteristics and applications (Callister 2011, ¹ p. 521, ² p. 821)

5 Choosing a product

3. What product qualifies to making an impact on the populations' handling of plastic?

We will go through a creative process in order to generate concepts for different products to choose from. Afterwards, we will evaluate the alternatives and choose a product, suitable for this project. At last, we will detail the chosen concept and product.

5.1 Performance Specification

On the basis of the feedback and discussions with the people from our field work, and our literature study, we have compiled all relevant requirements and criteria for a project. These requirements and criteria have been organized into a performance specification (WS 5.1) (Cross 2008, p. 106-119), which will serve as basis of selecting what concept to take further.

We have also included socio-technical aspects based on our personal and subjective impression of what is needed to change the user's perception of the material. Examples are: "The product should have a high sentimental value for the user" and "The product should make the user feel part of a movement".

It is a priority in this project to experiment with plastic in the workshop and get out and interview users with the parts we produce. Since this project runs on a set time frame, we have to set limitation on other part of the process to have time for this priority. We judge that for this project it is not strictly necessary, to develop and identify the very best concept. We want to find a concept that we believe could be a solution. It is then through seeing what we can make it become in the workshop and how people are reacting to it we want to judge if it is a good concept or not. As a result of this we have chosen when exploring the solution space, not to make use of systematic creative methods like morphology charts (Cross 2008).

5.2 Generating ideas

A chronological overview of the full creative process and the used methods is found on (WS 5.2).

After having explored the problem space up until this point in the report, and set the first requirements and criteria for a concept, we entered the ideation phase. With multiple sessions of ideation (WS 5.3 and 5.4), we generated ideas, drew up new criteria and repeated.

We set a goal for ourselves to generate 100 ideas before starting further development, in order to ensure that we had covered enough of the solution space. Only when we noted down the 100th idea, we moved on to the next phase.



Figure 5.1 Bad brainstorming

5.3 From 100 ideas to 5 concepts

During our work with the brainstorming, we developed a model to help ourselves organize our ideas. We have an assumption that we can group products according to the degree involvement of the user has the production of the product. We grouped the different products into five level of involvement.

In the different levels of the models, the amount of sentimental value and potential for scalability are inversely proportional; The higher degree of involvement, the less potential for scalability and the opposite. To make the biggest impact on the biggest group of people, we want to find a product in a sweet spot, which we consider to be in the middle of our model. We have called this model, The WIFI Model, and it is elaborated on (WS 5.5).

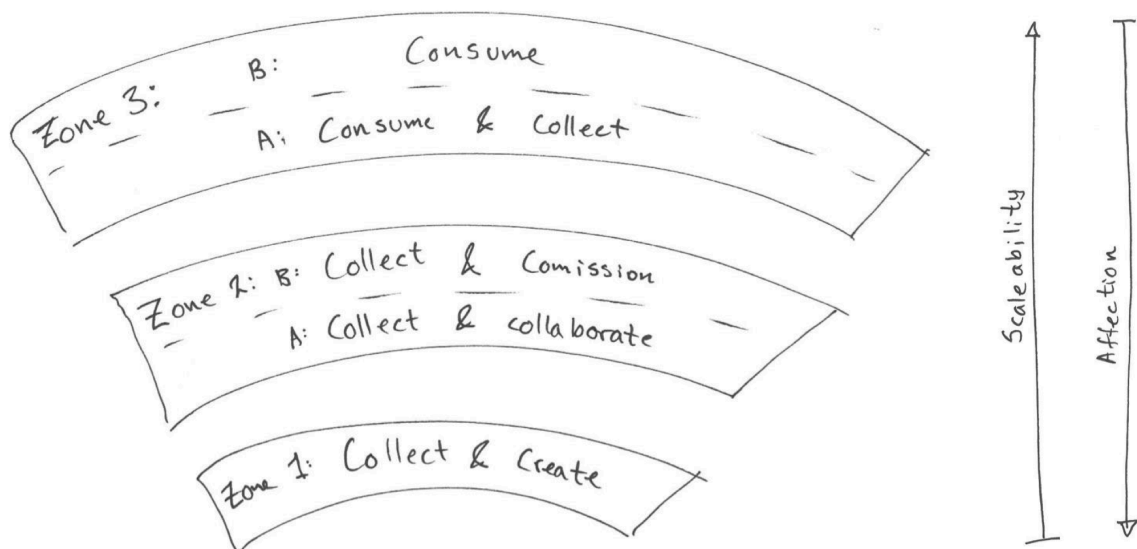


Figure 5.2 The Wi-Fi Model

Based on this and an early iteration of the performance specification, we did a screening and deselected the ideas, we considered to have the least potential.

In the remaining ideas, we identified some clear similarities, that allowed us to group them into three main concept categories: Danish interior design, Roskilde Festival and tourists in developing countries.

Having only three concepts, we were concerned our focus could have been too narrow, and to cover a wider part of the solution space, we started a final round of brainstorming on concepts, that would include elements that were not seen in any of the existing, such as big volume plastic consumption, super high-end products and more using electronics to add functionality. This process gave birth to two new concepts, and we now had a total number of five.

Afterwards, we pitched our early stage concepts and received feedback from actors from three backgrounds. Employee of Plastindustrien, Asbjørn Lindsø (2017), relevant actors within the field of small scale plastic processing, Joe Giddens (2017) and Noe Bhandari (2017), and art director Benjamin Beckett (2017).

5.4 The five concepts

Our scope was to identify areas for improvement and to make a difference, either in Denmark or internationally.

We have been developing concepts consisting of stories, products and business models, that we believe can contribute to making the consumers recognize plastic as a resource rather than a burden. We have lined up five concepts for the project, of which we will choose one.

5.4.1 New Danish Design

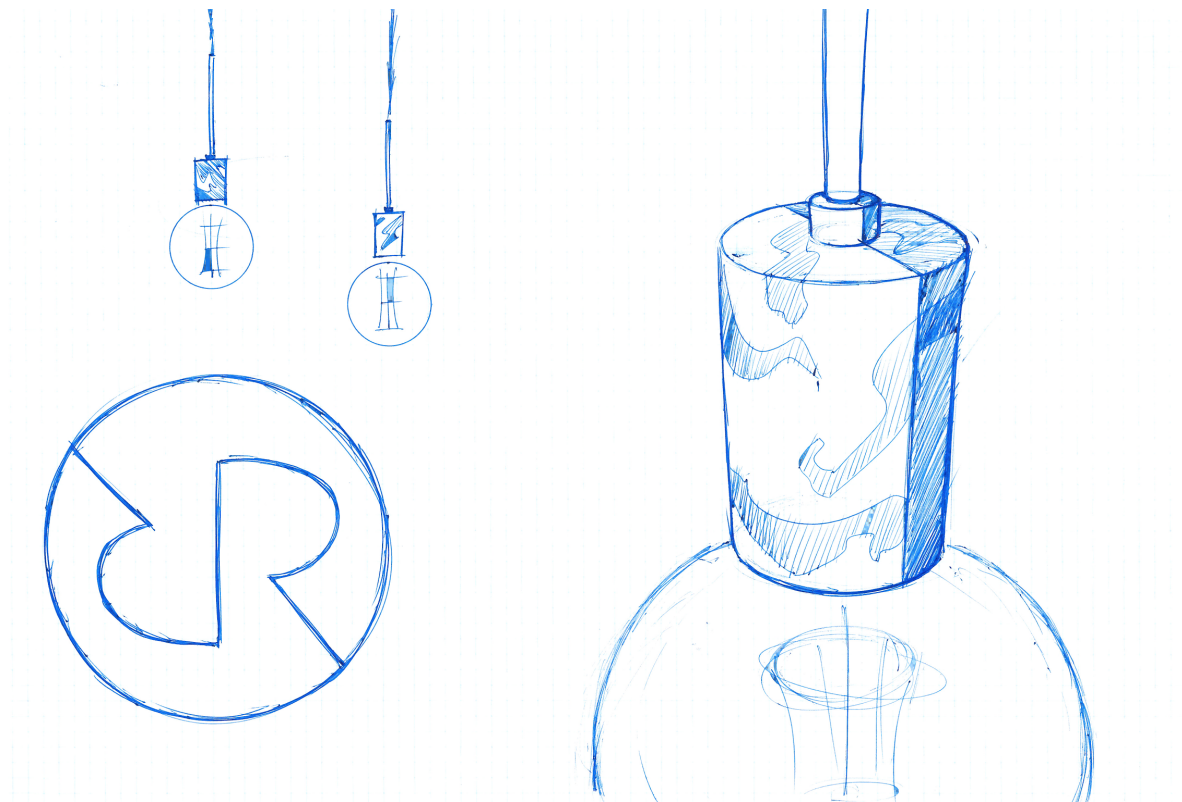


Figure 5.3 Illustration of the concept 'New Danish Design'

Goal

To make the consumers realize the aesthetic potential in recycled plastic by placing the material in a category of product of high sentimental and economic value.

In New Nordic Design (Gundtoft 2016) there is a focus on the raw material, for instance by using untreated wood, or unrefined metal rods. We want to introduce recycled plastic with a rawer look, making the origin of the material clear to the observer.

Our idea is to design a lamp. We have been looking into the Danish design firm Roon & Rahn, and we are very inspired by the idea of uniting recycled plastic with their minimalistic style and form language, which could interact nicely with a textured plastic look. We have been experimenting with renderings showing some of their products in recycled plastics as seen in Figure 5.8 and (WS 5.6). We contacted Roon & Rahn and presented the idea, and they seem interested in a collaboration.

The project

- Investigate the aesthetic qualities in recycled plastic through research and prototyping
- Investigate what is in the literature on environmental consumer choices
- Design a lamp for Roon & Rahn (Expected 2000 pcs/year), to fit into their series
- Work on making it easy to produce
- Work on achieving some degree of homogeneity (in shape and visual expression)
- Develop a business plan and account for the sourcing of the material and production
- Make some prototypes

- Test if we can sell it: show it to and get feedback from possible consumers
- (After deadline: Hopefully start a production with Roon & Rahn)

5.4.2 GoPro Handle

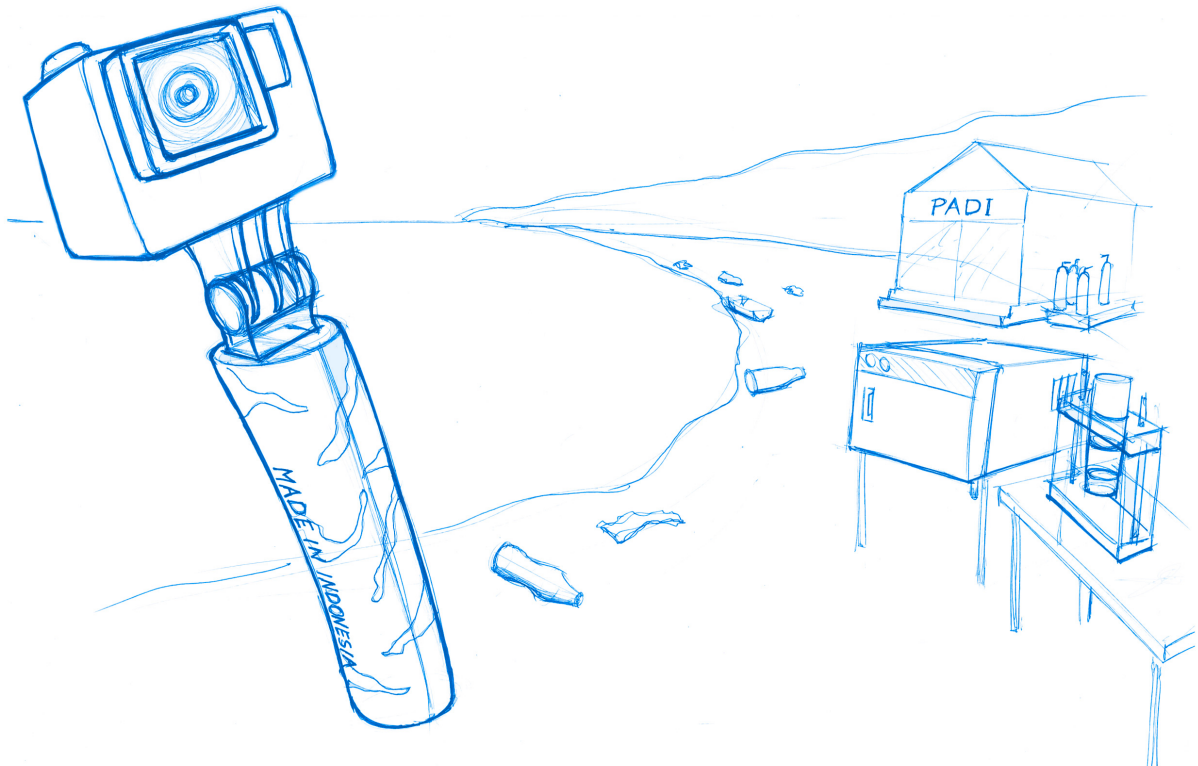


Figure 5.4 Illustration of the concept 'GoPro Handle'

This project is building upon the idea behind the project 'Precious Plastics' by Dave Hakkens about processing plastic on a small scale, potentially using their machines.

Goal

To make use of the frustration over plastic waste pollution that tourists and travellers experience as well as a common motivation to making a difference in the local area they visit. This will be done by setting up locally driven plastic workshops where locals will help tourists transform their collected beach waste into a product to serve as a memory of their effort.

The machines for processing the plastic will be placed on relevant locations (e.g. dive and surf centres in Asia), where locals will be trained in sorting, cleaning and processing the plastic. This project will also take advantage of the general environmental concern in the diving and surfing culture. Therefore, these user groups are the initial focus, but we think it could also be interesting for families and groups of young travellers.

The travellers can only get a product (the GoPro handle or sunglasses, guitar picks etc.) if they have collected x kg of plastic from the beaches. The payment will then consist of both collected plastic and money. The money will pay the salary of the local worker on the machine and will help funding the launch of new centres for plastic processing other places in the world (e.g. through PADI).

The GoPro handles could also be available for purchase online or even in stores in other countries, both for a significantly higher price. The products that the plastic collecting travellers can buy, will be clearly differentiated from the one available online (e.g. with a location tag or different color). Selling it online, should help the project grow in size across national borders.

Branding it under “Made in Indonesia” will also be a valuable gimmick, since it usually refers to big factories with underpaid workers, and here it can a souvenir proving where the customers travelled to and helped.

The project

- Design a handle for at GoPro which is functional, and yet easy the manufacture
- Design the tool for simple production
- Research and design what type of plastic would be most suitable
- Make a prototype using the actual techniques imagined for implementation
- Test prototype (how is it affected by saltwater, sunlight, sand etc.)
- Develop further on the business plan
- Reach out to relevant actors, dive centres, surf centres, municipalities, locals, newcomers, associations
- Maybe work on simplifying or modifying the Precious Plastic machine

5.4.3 Event at Roskilde Festival

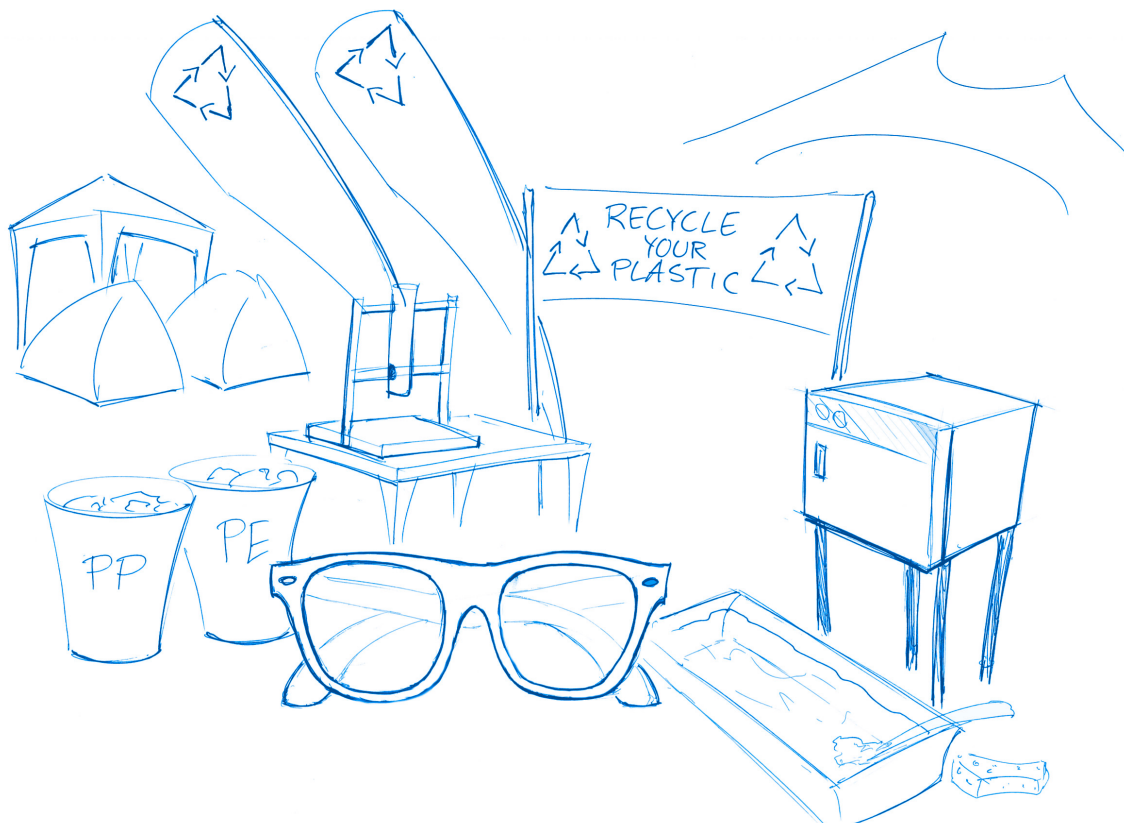


Figure 5.5 Illustration of the concept 'Event at Roskilde Festival'

This project is building upon the idea behind the project ‘Precious Plastics’ by Dave Hakkens about processing plastic on a small scale.

At Roskilde Festival we will make a small workshop, where the visitors of the festival can bring in their plastic waste and through a workshop we will show them how to sort, clean, shred and eventually produce a pair of sunglasses. Meanwhile, we can discuss what plastic really is and how it should be handled.

Maybe we could also give them the possibility to produce other useful things, but regarding spreading the message and showing what plastic can do, we think there is a huge potential in producing sunglasses. Since they are placed right in the middle of your face, everyone you talk to will see them, and if just 1/10 ask you what they are, there is potential for a lot of advertisement for the project.

The project

- Work and experiment with the plastic
- Choose one, two or three products
- Design the product(s) which will have to be super easy to manufacture
- Design the tool
- Simplify the process
- Build or acquire a machine
- Prepare the workshop
- Develop educational literature (flyers, posters etc.)
- Test the work shop (before Roskilde Festival)
- Do the workshop (after Roskilde Festival)

5.4.4 Wetsuit Hanger

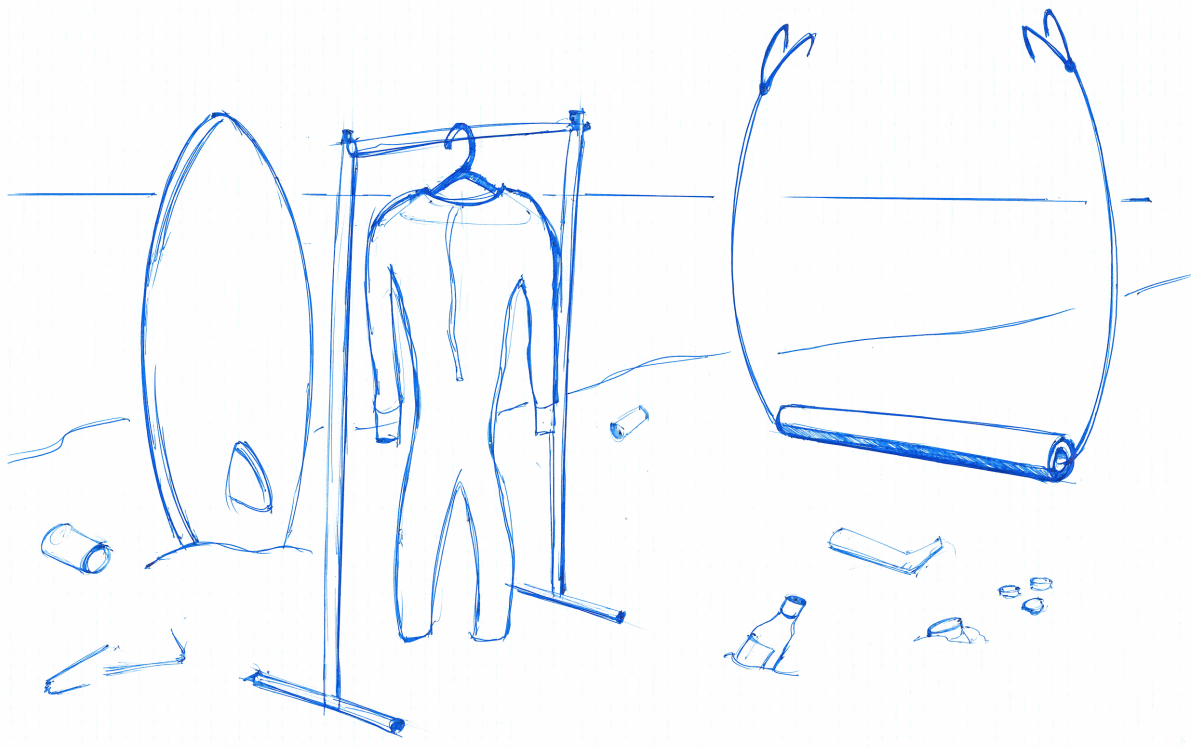


Figure 5.6 Illustration of the concept 'Wetsuit Hanger'

Wetsuits are used all over the world in numerous of water related activities such as surfing or scuba diving. A big issue occurs when drying them, since hanging a wet wetsuit to dry on a hanger like a shirt will stretch

the neoprene on the stress point near the shoulders causing it to lose the important tight fit. The best way to dry them is to fold it over the waist, but this is very hard to do on a regular shirt hanger.

Surfers in Klitmøller and other places all over the world are already hosting beach cleanup events, where plastic and other waste is being collected from the beaches.

We want to use this plastic waste and turn it into a hanger specifically made for drying wetsuit (and maybe including equipment like shoes and gloves).

It is important for the product to have another functionality and branding value (in this case that it is solving an actual problem), leaving the sustainability and the story about beach waste as something extra to amaze the customer.

The project

- Investigate the amount and contents of the beach waste that is being collected in Denmark
- Investigate what beach waste can be used for
- Investigate and iterate on design and functionality of the hanger (user interviews, what needs to dry, how should it be mounted, use, context, users)
- Design for manufacturability, investigate possibility to use different types of plastic to represent the types found in beach waste
- Develop a business model
- Build prototypes
- Test them
- Try to sell them

5.4.5 Plastic Watch

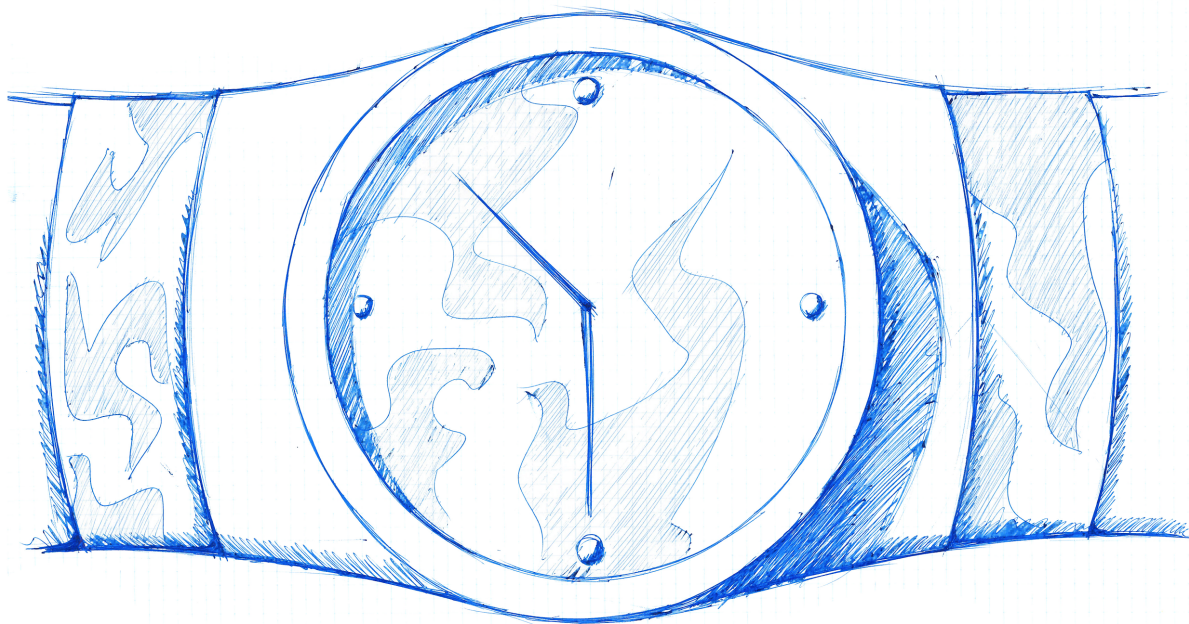


Figure 5.7 Illustration of the concept 'Plastic Watch'

If we should make a product that is super high-end, we consider a watch to be a well suited product, as it is a good place for showcasing the qualities of the material. We imagine making either an electronic or analogue watch, with a casing a wristband made with marbled plastic texture. We could either make our own design for a watch, or try to form a collaboration with an existing watch producer.

The project

- Research on typologies within the product category
- Figure out how to make it (digital or analogue)
- Decide what part(s) of the watch should be made from recycled plastic
- Design the watch
- Build a lot of prototypes
- Design for manufacturing (maybe using CNC)
- Short test phase with target audience

5.5 Evaluation of concepts

For the evaluation of the concepts we have chosen to use the Weighted Objectives Method (WOM) based on an objectives tree (Cross 2008, p. 162 - 164).

5.5.1 WOM: Method

We made sure that all the concepts lived up to the requirements in our Performance Specification (PS) (On the basis of the feedback and discussions with the people from our field work, and our literature study, we have compiled all relevant requirements and criteria for a project. These requirements and criteria have been organized into a performance specification (WS 5.1), and used the criteria as parameters in the WOM.

In our PS the criteria are structured under four categories. These categories are the objectives and the criteria is sub-objectives in our WOM. We perceive both the criteria and the categories to have different magnitude of importance for the concept to complete the mission from our mission statement (Chapter 1.1 above). The hierarchy of importance goes as follows:

- 1. Impact on society**
 - a. We think it is most important to make a change on a society level on how we treat and perceive plastic.
- 2. Product requirements**
 - a. We think it is crucial that recycled plastic can fulfill the requirements of the product. It needs to be realistic to produce the product in recycled plastic and that the plastic stands the use cases of the product. People are buying a product and it needs to be a bonus that it is recycled - not a compromise.
- 3. Impact on user level**
 - a. The product needs to have a personal importance to the user. For instance, could sentimental value be one of the ways to make user feel the the value of plastic.
- 4. Impact on environment**
 - a. We want to make a product and project that creates a good story rather than make a big impact on the environment.

We did not set a specific percentage for each category, but kept this hierarchy in mind when we gave weight to each of the criteria. Over two iterations we found weights for the criteria that balanced the importance

of each criteria within each category and balanced the categories between each others in relation our vision-mission statement.

The weights for each of the criteria can be found in the WOM table (WS 5.7) and the final weights for the four categories are as shown in Table 5.1:

Categories	Weight (%)
Impact on society	35
Product requirements	28
Impact on user level	23
Impact on environment	14

Table 5.1 Categories and weights for WOM

One criteria at a time, all concepts were evaluated and rated with the values 0 - 5. We did the rating ourselves and assigned '5' if the concept fulfilled the criterion completely, and '0' if the concept did not fulfill the criterion at all. It was not a given that any concept would get a '5' for a criterion, as this score would only be given if a concept lived up to the criterion 100 %.

The values were then summed up within each category and a percentage was found of how well the concepts would do with in each category. A total for each concept was then found by summing up the percentage score of each category multiplied by its weight.

5.5.2 WOM: Results

The full WOM table can be found in (The weights for each of the criteria can be found in the WOM table (WS 5.7). Overall results in percentage of the five concepts can be seen in Table 5.2.

Category	Weight of category	New Danish Design	GoPro Handle	Wetsuit Hanger	Plastic watch	Roskilde Event
Impact on society [%]	35	86	86	66	76	55
Product requirements [%]	28	92	60	69	36	69
Impact on user level [%]	23	60	69	79	17	77
Impact on environment [%]	14	75	77	93	59	60
Total [%]		80	74	73	53	49

Table 5.2 Concept evaluated in each category and in total. All values are in %

5.5.3 WOM: Discussion

One concept got the highest score but to verify and get a better understanding of how their score were different, we took a look at their score and highlighted the **highest**, medium and **lowest** score.

Concept	New Danish Design	GoPro Handle	Wetsuit Hanger
Impact on society (%)	86	86	66
Product requirements (%)	92	60	69
Impact on user level (%)	60	69	79
Impact on environment (%)	75	77	93
Total (%)	80	74	73

Table 5.3 Comparison of the three concept that scores the most

Table 5.3 shows a clear picture of how *New Danish Design* is doing best the two highest weighted categories, *Wetsuit Hanger* is doing best in the two lowest weighted categories and *GoPro Handle* is in between.

This indicates that maybe the weight could be higher for the two first categories.

5.5.4 WOM: Conclusion

According to the Weighted Objectives Method we should go with 'New Danish Design'.

5.6 Discussion on 'Choosing a product'

When evaluating the concepts, we consider it a weakness, that it is only done on a hypothetical basis. The true evaluation of the project, will happen through experiences and results from the workshop and how well future users adopt the product.

The results of the Weighted Objectives Method, indicate that 'New Danish Design' is the best concept. However, it is important to mention, that the results of this method should not be taken as a definitive decision, but rather as an argument in the selection process. Other important factors to take into account are how the project suits our qualifications, how far we can get within the time frame of the project.

In Table 5.3 Comparison of the three concept that scores the most is shown how the scores of the three best concepts are distributed in the four categories. This can be used to identify weaknesses for each concept to improve in future work. The concept 'New Danish Design' has the lowest score in *Impact on user level*, which is an indication, that this should be a focus point in the later process.

5.7 Conclusion on 'Searching for Solutions'

The concept chosen for further work in this project is 'New Danish Design', with the goal to *make the consumers realize the aesthetic potential in recycled plastic by placing the material in a category of high value products.*

We consider this concept to have big potential for making an impact on society and at the same time, an indoor lamp as a product, is suited very well for showcasing qualities of a recycled plastic as a material. When developing the concept further, a focus point should be to create a bigger impact on user level.



Figure 5.8 Original RR-1 Pendel in light oak from Roon & Rahn (left) and one of the renderings of a plastic edition, that were sent to Roon & Rahn (right)

5.8 Detailing on the concept



Figure 5.9 Finished prototype of the RR-1 Pendel made of recycled meat trays and yoghurt containers

An interesting finding in our research is that many sincerely want to do an effort in sorting plastic waste in their household (Bigum 2017), but find it very hard to understand what happens to their waste later, and what it can be turned into. This challenges their motivation for waste sorting, and it often makes them question if their waste really is valuable and if their effort makes a difference.

With the marbled texture we want to create a modern look meanwhile we preserve the original colours of the individual recycled plastic products. This, we think, will help the consumers make the connection between their waste and their new product.

5.8.1 Why collaborate with Roon & Rahn?

For the second part of this project, we have chosen to do a case study on a specific product from a specific design company.

We have chosen the lamp, RR-1 Pendel from the Aarhus based design firm, Roon & Rahn. There were several factors that made this specific company relevant for our case study.

Inspired by the business model of Tesla Motors (Figure 5.10), we found it of high importance to introduce recycled plastic in a segment of brands and products, that were associated with high quality.

“If we could have done that [mass marketed] with our first product, we would have, but that was simply impossible to achieve for a startup company that had never built a car and that had one technology iteration and no economies of scale. Our first

product was going to be expensive no matter what it looked like, so we decided to build a sports car, as that seemed like it had the best chance of being competitive with its gasoline alternatives.” (Musk 2013)

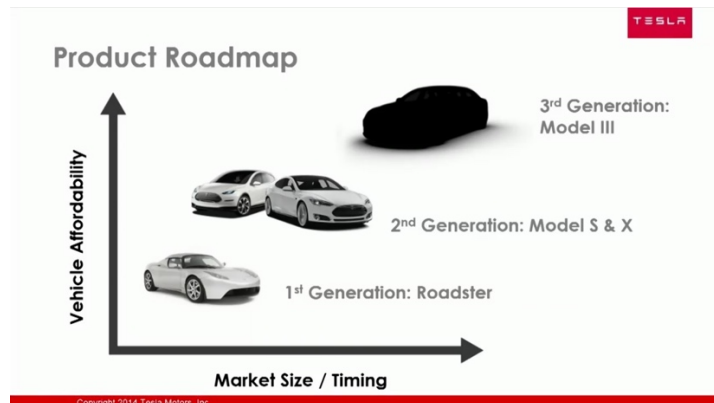


Figure 5.10 Tesla's Product Poadmap (Jay Caplan 2016)

Even though we could be tempted to go directly for landing a deal with IKEA, in order to reach the widest audience possible, we believe, introducing recycled plastic into more high end interior design, will help speed up the domestication process of the material. By placing the material in a high end context, we also hope to make more consumers recognize recycled plastic as a valuable material rather than a cheap one.

This company, Roon & Rahn, was especially suitable, due to its small size. Being a company consisting of only the two founders and a couple of interns, we expected it to be easy to reach the people making decisions. Furthermore, the company is quite successful and has a history of forming collaborations with other companies.

Finally, the company has no experience with recycled plastic, but works mainly with other more traditional materials. Formerly, the company recycled wood from old furniture, but today their sustainability profile is less visible, as it lies in the packaging and transportation. This is important, but invisible to most users.

5.8.2 The target group

The target group for this product can be defined as consumers who are:

- Environmentally aware
- Economically stable
- Middle segment
- Politically engaged

To paint a picture of our future users, we have created three personas (Cross 2008, p.68-73) described in Table 5.4.

Name	Thomas	Lis	Maria
Age	34	45	24
Job	Industrial designer, but works as a consultant in innovation firm	Head of department in a ministry	In her last years of a Psychology- study
Average income	39.000 DKK / month	> 50.000 DKK / month	7.500 DKK/ month
Place of living	Vesterbro -	Værløse	Aarhus
Civil status	Married with two kids	Many former boyfriends, but they do not stay for long. Lives alone.	She is in a relationship for two years now. They just moved together in her apartment.
Hobby	Camping and outdoor trips to Sweden with his two kids (the wife stays home).	Has a lot of friends that she meets for cafe laté or white wine. She recently discovered Instagram and emojis.	Has a lifestyle blog (she wouldn't call it that) with food, fashion and a lot of flowers.
Interests	Checks Indiegogo and Kickstarter once a week to see what stuff people invent	She loves social media. Reads a lot of books, both danish and international.	Travels to South East Asia and other far away destinations at least once a year. Has once volunteered in a kindergarten in Africa.
Political views	Alternativet	Center left (Radikal Venstre)	Enhedslisten
Consumer patterns	He buys organic milk and eggs but never meat. He puts a lot of thought into his purchases. Really enjoys when he get a new phone.	If she has one good reason to buy a product she will do it. She spends a lot of money on food and wine. She likes delicacies.	Can not afford the sustainable life she wants to live. Constantly weighing food, clothes and savings for travels against each other. Is vegetarian.
Transportation patterns	He uses his old bike to get to work everyday but he has a car that he enjoys driving every now and then.	She is proud of having bought a Tesla. Uses it daily.	Bikes mostly everywhere, else she takes the train.
Reason for buying the lamp	He wants to support new, sustainable initiatives. He liked the story and his wife thought it was pretty.	She walked past a local interior design shop, and spotted it in the window. She liked the story but bought it because of the look.	Heard about the lamp on Instagram, but went to a design market at Godsbanen in Aarhus to buy it. Likes the synergy of the story and product.

Table 5.4 Three personas in the target group

6 Health issues associated with products from recycled plastic

4. What are the health issues associated with products from recycled plastic?

6.1 Additives in plastic

In all the journals we have read on health risks with plastics, a lot of the substances in focus is the additives or decomposition product (Meeker 2009) (North 2013) (WHO 2012).

Additives are key ingredients in all plastic products, as they help the production run smoothly and changes some physical and chemical properties of the resin.

This list of additives is based on the report in Danish 'Miljø og Sundhedsforhold for Plastmaterialer' / *Environment and Health Conditions for Plastic Materials* (Schmidt 2006, p. 41-50).

There are eight types of additives in Table 6.1. Under each type of additive, the substances that are possibly used in the production of PP and PE is listed.

1. Stabilizers		
Heat stabilizers		Mostly PVC
Antioxidants	Phenols. Monophenols, bisphenols, thiobis phenols and polyphenols. Amines, phosphites and thioesters.	Almost all resin types, incl. polyolefins
UV-stabilizers	Hindered amines, Benzotriazoles or metal complexes with sulfur compounds such as dialkyldithiocarbamate.	Mostly polyolefins
2. Slip Additives		
Metal salts of fatty acids	Primarily in the shape of aluminum, calcium, lead, calcium, magnesium, sodium and zinc stearate)	Almost all resin types, incl. polyolefins
3. Colourants and pigments		
Insoluble organic pigment	Alizarinderivates, phtalocyanine, benzidine, carbon black og metal-azo compounds	Almost all resin types, incl. polyolefins
Inorganic pigment	Zinc sulphide, zinc oxide, iron oxide, cadmium manganese compounds, chromium and molybdenum compounds, ultramarine and titanium dioxide	
4. Fire retardants		
	Likely no fire retardant in plastic packaging (Ndoni 2017) (Rasmussen (2017)	Unlikely to be used in food packaging.
5. Antistatic agents		
	Ethylated alkylamines and Fatty acid esters	In PE, PP and PS
6. Plasticizers		
	80 % of the plasticizers are used in relation to PVC.	Unlikely to be used in non-film polyolefins.
7. Foaming agents		
	Only for foams	Not i polyolefins
8. Filler		
	The content of filler in plastic can vary from "a little" up to 50 %. It can be hard so always dissecting filler from additives with specific qualities. Clear examples of cheap filler is wood flour, stone flour, clay and chalk. Sometimes glass fibre is add for toughness.	Properly some in polyolefins.

Table 6.1 Additives in plastic production and the substances possibly used in relation to PP and PE. (Schmidt 2006, p. 41-50)

The additives used in PP and PE, according to Schmidt, are stabilizers (antioxidants and UV-stabilizers), slip agents, colourant, antistatic agents and maybe some filler. Specific examples of substances can be found in table x. These are for all PP and PE products and limitation within packaging industry might rule some of these categories of additives out.

6.2 Volatile Organic Chemicals (VOC's)

According to Ndoni (2017) volatile organic chemical, VOCs are one of the types of chemicals that can be hazardous. VOCs are organic chemicals that have a high vapour pressure at room temperature. resulting in a low boiling point, which mean a large amount of molecules will evaporate into the surrounding air.

Due to their high vapour pressure at room temperature, VOCs has a potential to occur in large concentrations indoor, and therefore it makes sense to measure them.

Pezo (2011) describes, the “*method presented adequate selectivity and detection capability for the determination of VOCs in post-consumer PET and HDPE. In addition, the method could easily be used for quality control in the production of recycled PET and HDPE*” (Pezo et al. 2011, p.1329).

The same paper also demonstrated the efficiency of deep cleaning process, like solid state post-condensation. “*The resulting material is expected to be suitable for direct food contact applications*” (Pezo 2011, p.1319). The process was used on PET but it might be interesting to look into the complexity of this process if a product with direct food contact was desired at a later stage or another project.

Lastly the paper conducted laboratory experiments where a multilayer HDPE packaging tainted with VOC’s were put into contact with fatty food simulant and “*These results indicate that VOCs do not migrate to the fatty food simulant under the tested condition employed.*”

A recent scientific opinion (EFSA 2015) from European Food Safety Authority evaluated two processes for recycling used PE bottles into new PE bottles. The conclusion was, if 99 % of the packaging comes from food-grade-plastic and it goes through the cleaning process described in the report, the recycled plastic is safe to use in packaging for fruit, vegetables and mushrooms.

The panel concludes that more data is need before it can be labelled as ‘safe’ to use the process for milk, juice and animal products. They especially point of the misuse contamination scenario, where hazardous substances have been in contact the packaging before it was sent to recycling.

6.3 Traceability for the production of plastic

According to Rasmussen (2017), it should be safe to melt down and reprocess plastic used for food packaging, due to the strict requirements regarding additives in this product category.

Rasmussen told us that to his knowledge the tractability is there because the companies want to be able to go back a trace any error in their production system. He said there would be no extraordinary need for documentation apart from the usual product liability that all producers carry, and the European laws on traceability (EU 135/2012, article 17). That means we would need to specify in what contexts the products can be use e.g. not be put in the mouth or eaten from.

Tilsted (2017) told us that it is the reprocessor, the organisation that turn waste to a material, who carries the responsibility of the cleanliness of the material. To our knowledge this all depends on what guarantees the reprocessor provides. Plastix (2017) make disclaimers that they are not liable for the safety of the use of the pellet as they write:

“risks and liability for results obtained by use of the products or application of the suggestions described are assumed by the user. [...] The user should not assume that toxicity data and safety measures are indicated or that other measures may not be required.” (Plastix 2017)

According to Tilsted (2017), the majority of plastic used for disposable products today, including bottles for detergent, are of a food grade quality, because it is an easy way to avoid any potential problems with their product giving off harmful chemicals in a unfortunate setting.

This is still no insurance, practically or legally, but at least it seems like some the many regulations and guidelines are working in the same direction. Perhaps it shows, that specific packaging products are adequate, and the following approach would then be to sort specifically for these products, and start by

only using them. No matter what, we need to get guidance from someone more experienced with the national and EU law on this subject, to be able to do anything.

6.4 Discussion

We have reach our limit for time and expertise for handling these areas for this project.

In a future production, the incoming waste is certainly contaminated with bacteria following the contact with food and people. This pose a health risk for the workers handling the material until the point where the plastic is heated and the bacteria will die.

A plastic items that is exposed to heat will have an increased possibility to release substances into the air compared to an unheated part. A plastic items that is in contact with fatty foods will have an increased possibility of unwanted substances like VOC's to migrate to the food.

That is the reason why the EU has made directives (Regulation No 1935/2004): to make sure that plastic items in contact with food can be considered *safe*, and hazardous amounts of unwanted substances will not migrate to the food. Three different cleaning processes have been encountered when recycling plastic for new food contact material (EFSA 2015).

By using only food grade items for our production and getting them from sources where we can assess the contamination to be very low, the amount of unwanted substances is likely to be minimal.

In practice, contaminants will not cause any problems, says Rasmussen (2017), as the chemicals that might have been added during use, will be the first to detach and vaporize when heated, due to their relatively low molecular weight. These are the same volatile substances that would have a risk of being released during the use phase of the recycled product (Ndoni 2017). As the lamp is a product with little physical contact, we assess that end product will not be harmful in use. This of course needs to be backed up by emission and migration tests.

If pollutants are bonded in the grease, there is a chance, they might not vaporize, but in return, the plastic needs to be cleaned mechanically, where precisely the grease would be removed. In the event that all pollutants vaporize during heating, they might not be a thread for the user of the product, but it might affect the working environment in the production process.

6.5 Conclusion

We need to make tests to examine if there are any emissions from the plastic part, with and without a LED light bulb in it. We need to examine the PP and PE respectively, and we need to do these tests over time and do them in a laboratory and in a home like environment.

These tests could be done by solid-phase micro extraction and gas chromatography coupled to mass spectrometry detection (Pezo 2011).

Using only food grade waste products might be a way to make sure only small amounts of additives are in the plastic we are recycling.

7 Choice of production method

5. How could the product be produced?

We find it very important to showcase recycled plastic in a beautiful way, and have been inspired by the way Smile Plastics and Carter Zufelt (WS 7.1), succeed in making plastic products where the textures are notably different from new plastic material. We think this texture can be an aid in telling the story about recycling, as user is able to trace the original waste products that went into the production through the different colors.

Asbjørn Lindsø (2017) from Plastindustrien, he says:

"Manufacturers tend to deselect recycled plastic, because it is hard to achieve the same expression as with virgin plastic. Why don't they make it an independent statement and create a special expression from it?" (translated from Danish)

The technologies within recycling of plastic today are of such high quality that the visual quality of the end material is similar to the results when using virgin material. This making it hard to tell whether a plastic product is made from recycled or virgin plastic, causing some of the confusion described in 2.3 Public confusion surrounding plastic.

Aiming for such a texture naturally limits the choice of manufacturing method. Most plastic manufacturing method makes use of a worm to mix and melt the plastic pellet. A technique like this would mix the different colour, so so we need a method without a worm involved.

We compared different plastic manufacturing techniques (Kalpakjian 2014) and chose compression molding (Figure 7.1) which seem to be suitable for our purpose.

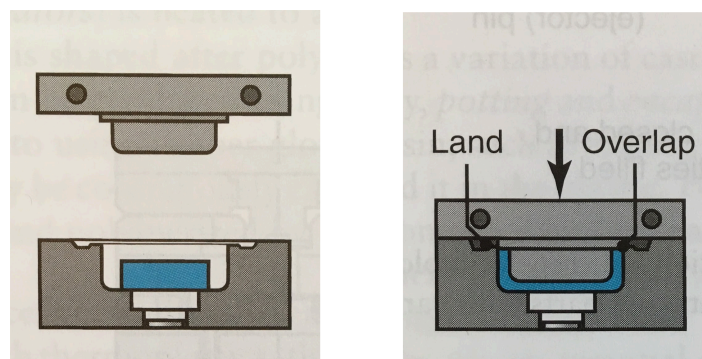


Figure 7.1 Illustration of compression molding (Kalpakjian 2014 pp. 513 - Figure 19.17)

8 Study: Aesthetic potential of recycled plastic

6. How good-looking can we produce the product using plastic waste?

8.1 Introduction

In Spring 2016, prior to the start of this project, we conducted a couple of small and simple tests, where we took plastic from household trash and heated it and tried to make separated pieces bond together. This was an early proof of concept showing that simple manufacturing techniques can be used to re-melting plastics (See Figure 8.1). The setup, tools and results from these tests can be found as *Generation 0* on (WS 8.1).

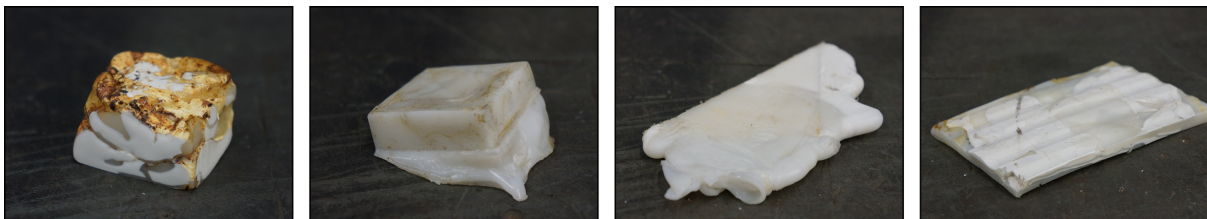


Figure 8.1 Generation 0 of plastic parts

This report is the documentation of a selected stage of our iterative process, trying to manufacture the plastic part for the RR-1 Pendel with compression molding (Kalpakjian 2014 pp. 512-513). The iterative stage described in this report is in the end of our process and during this process, some of the parameters, that were first variable, have been changed to constants following consistency in test results. An example could be the mold it self where we have been through 3 iterations to get to where we are now (WS 8.2).

Nigel Cross expresses:

“The process is heuristic: using previous experience, general guidelines and ‘rules of thumb’ that lead in what the designer hopes to be the right direction, but with no absolute guarantee of success.”

(Cross 2008, p. 29).

We have used our technical knowledge from Material Science, Manufacturing and Thermodynamics as general guidelines in this work. For each iteration our experience grows and new ‘rules of thumb’ can be formulated to make variations and improvements of the experiment.

The requirements and criteria for the plastic part have been put together in a version of a performance specification, which we call a ‘manufacture specification’ (WS 8.3). This document is used to judge whether the produced parts are good enough for the scope of this project.

8.1.1 Aesthetic inspiration

Along with Carter Zufelt and Smile Plastics, we are inspired by tendencies and trends, we have identified in popular products of leading brands within Danish interior design. When looking at HAY and Normann Copenhagen (with target groups very similar to ours), a high amount of their products contain materials with significant textures. In contrast to simple geometries and colors, the naturally occurring grains in the wood or the veins in marble stone are important parts of the visual expression of the products. HAY seem to like marble stone, and a quick look on their website shows multiple examples of how they emphasize the use of texture in the description of the product - also when it is not even made of stone (See Figure 8.2).

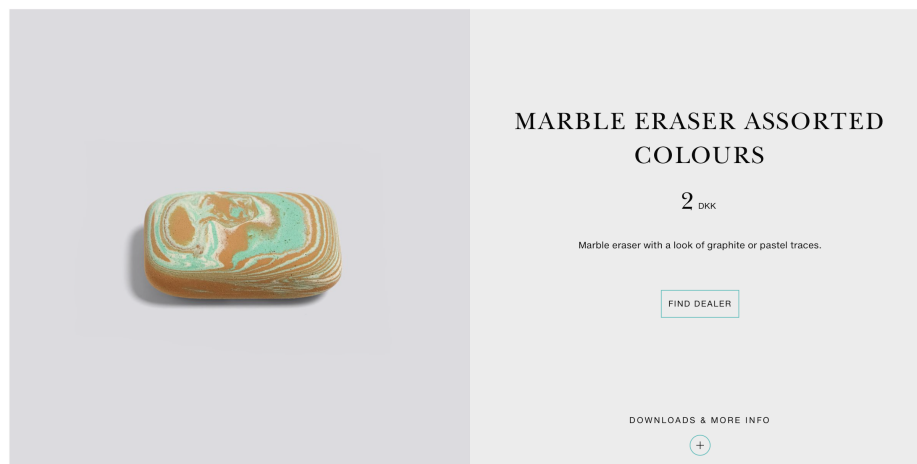


Figure 8.2 HAY Marble Eraser (HAY1 2017)

We have encountered products, which we think communicates the aesthetic potential of recycling plastic in an undesirable way (WS 8.4). Furthermore, the movement of Precious Plastic (WS 8.5), is producing products of varying quality, but the finish and visual expression is often more “do-it-yourself” than “high quality”.

This report serves as a documentation of the production method we are working with and as an insight into our experiences with working with recycled plastic. But most importantly, we are investigating what is possible when processing plastic waste using compression molding and how it is relevant in interior design products.

8.2 Scope

8.2.1 Tool and workshop

We have used a hydraulic shop press, and we have made the mold tools ourselves. This gave us the ability to instantly improve on the mold and other variables in the process.

8.2.2 Three colourways

After talking to Van Roon & Hansen (2017) and by making an examination of competitors on the Danish lamp market (WS 8.6), (WS 8.7), and (WS 8.8), we decided to make a series of three different colourways

the lamp is going to be made in. All colourways have the same marbled or swirled texture with a high degree of randomness or *'lost control'*, a concept discussed with Iskos & Berlin (2016).

During some of the initial iterations we made three different combinations of colours: a mainly white, a mainly black and a green with some transparent as on Figure 8.3.



Figure 8.3 The first three colorways (Prototypes 1.3, 1.5 and 1.7)

The mainly white and mainly black came out in a way we were pleased with. But the green was not swirled enough and needed some more black or white. During this experiment we tried different combinations of colours.

We composed the different colourways by weight ratio (one part takes 60 g of plastic), and the plastic types (PP/PE) of each colourways were chosen on our experience of what colours of trash is available in sufficient quantities.

- Mainly white (PE)
 - 74.5 % white, 25 % transparent, 0.5 % black (extra thin from plastic bags)
- Mainly black (PP)
 - 42 % black, 42 % transparent, 14 % white
- Green (PP)
 - 50 % green, 50 % black
 - 40 % green, 40 % black, 20 % white
 - 33 % green, 33 % black, 17 % white, 17 % transparent
 - 33 % green, 33 % black, 33 % white

8.3 Methodical considerations

8.3.1 Material Science

From Material Science we know that melting temperature for a polymer is not a value that can be looked up in a book. It depends on many factors:

“the melting behavior depends on the history of the specimen, in particular the temperature at which it crystallized [...] Impurities in the polymer and imperfections in the crystal also decrease the melting temperature. Finally, the apparent melting behavior is a function of the rate of heating; increasing the rate results in an elevation of the melting temperature.” (Callister & Rethwisch 2011, p. 516)

“Melting temperature of a polymer also depends on molecular weight. At relatively low molecular weights, increasing M (or chain length) raises T_m . [...] Furthermore, the melting of a polymer takes place over a range of temperatures; thus, there is a range of T_m s rather than a single melting temperature.” (Callister & Rethwisch 2011, p. 518)

The melting temperature is dependant on many different factors, and in these experiments we are using plastic from different sources, which have different molecular weight, have been crystallized at different temperatures and have different amount of impurities. Because of these factors, a precise T_m for, for instance PP will vary from each batch of waste we receive. In these experiments we have chosen to heat the the plastic to a temperature much higher than T_m (oven at 220 °C) to ensure that all the variations of PP will be melted and therefore flow together. We know that this will raise the T_m for some of the PP and most likely make the heating process take longer than needed and cause higher amounts of degradation, but optimization of process is not our main focus. Our focus is to succeed in making parts and mapping the factors that are important.

8.3.2 Manufacturing

Kalpakjian (2014) writes that the pressures ranges from about 10 to 150 MPa, when using compression molding. The whole section is written concerning thermoplastics and thermosets, so it is unclear if these pressures are applicable to our experiment and what pressure is suitable for PP or PE. Our initial tests started at 100 MPa, and step by step we went up to ≈ 230 MPa ($\Rightarrow 5$ tonne), where we got acceptable results. Molds are usually made in tool steel but we use aluminium for prototyping. Industrial molds often have heating element built into the mold, and to simulate that we placed the mold in the oven with the plastic.

8.3.3 Thermodynamics

From thermodynamics we know three different types of heat transfer: conduction, convection and radiation. We know that convection is usually a more efficient heat transfer than conduction. Convection can be obtained in an oven with internal ventilation. During this process we have had access to such an oven. Heating using radiation might be even more effective if the rays can heat through the wall thickness of the plastic. But we do not have access to any equipment with precision heat radiation.

8.4 Materials and methods

This paragraph describes the materials and methods used to produce plastic parts for the case product, the RR-1 Pendel from Roon & Rahn. The part is a cylindrical socket as seen on Figure 8.4 below.



Figure 8.4 The plastic edition of the RR-1 Pendel by Roon & Rahn

8.4.1 Equipment

- Precision oven with internal ventilation, MK Technology, Type: ULE 500, Wattage: 2kW, Maximum Temperature: 240 °C
- Silicone baking mat
- Brass Ø2 mm rod for stirring
- Steel spatula
- Hydraulic press. With a pressing capacity of minimum 5 tonnes.
- Diesella scale, Max load: 15 kg, Precision: 0.5 g
- Molding tools (Figure 8.5). We used a three part mold tool made in aluminium from these technical drawings. (WS 8.9)

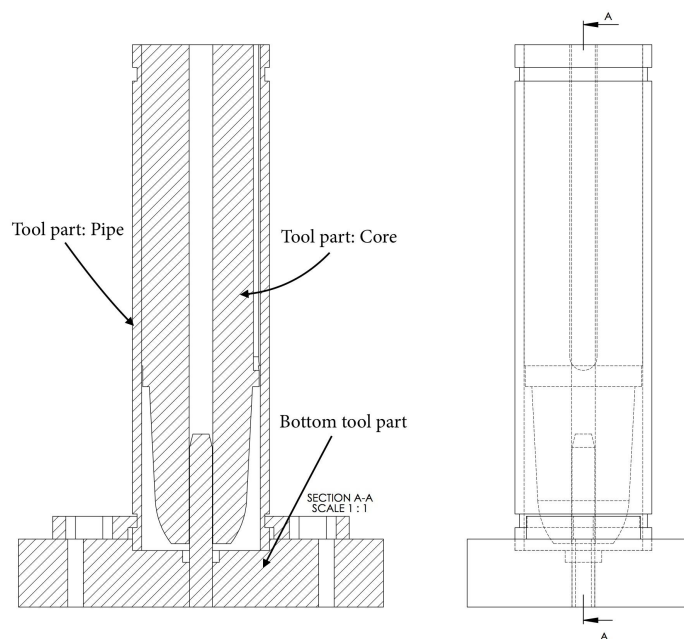


Figure 8.5 Section drawing of final iteration of the mold

8.4.2 Materials

- Plastic: PP and PE (HD-PE) coming from household waste, mainly food packaging with a few detergent products.
- Silicone release agent for the molding tool.

8.4.3 Methods

Below in Table 4.1 is presented an overview of the time consumption for each activity.

(1) The PP or PE is sorted out in colour and plastic type. It is then washed on the outside and inside and the labels are removed. As seen in Figure 8.6, the plastic products are then cut up into approximately 30x30 mm pieces and spread out to air dry if still wet. The exact size and shape is not important. The pieces are then kept in containers according to colour and type.



Figure 8.6 Polypropylene meat trays and disposable cups are being cut up

(2) 60 g of either PP or PE plastic is mixed between different colours to make one of the colourways (Figure 8.7). The bottom tool part and the pipe is assembled. All the tool part is sprayed with silicone release agent (needed once every 5th - 8th run).



Figure 8.7 Prepared material for the 'Mainly black' PP colorway

(3) The plastic is then spread out on a silicone baking mat and put in a preheated oven at 220 °C along with the mold parts (bottom + pipe and the core) for 10-15 min for PP, and 30-50 min for PE, until the plastic softens and has a viscosity like caramel.

(4) The oven is opened and a brass rod is used to mix the molten plastic together and create swirls, like the ones usually made when making ice cream. The plastic cools down a bit during this process and needs to be reheated so the oven is closed and the plastic heated for 5 more minutes.

(5) The oven is opened and a spatula is used to scoop up all the plastic into one charge which is then transferred into the bottom + pipe part. The core is now pressed down into the pipe, first by hand and then using the press when the mold can get into the press.

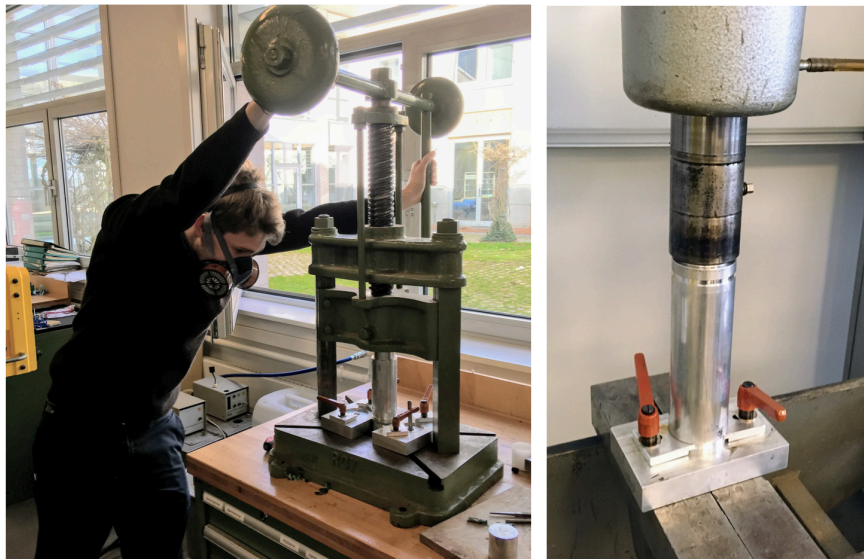


Figure 8.8 First we used the mechanical shop press (left), but to achieve a higher pressure we moved on to using a hydraulic shop press (right)

(6) The press goes down until the the core reaches the end stop, never showing pressure more than 5 tonnes on the pressure gage. At the bottom the pressure is kept for about 2 minutes at 5 tonnes while the plastic cools down (Figure 8.8).

(7) The mold is removed from the press and bottom part of the mold is unhooked from the pipe and then rotated in relation to the rest while being pulled out.

(8) The plastic part and the core can now be pressed through the pipe using the press, with a setup as seen in Figure 8.9.



*Figure 8.9 The part and core is pressed out of the mold (left)
A runner showing the effect of the overflow groove (right)*

(9) Sometimes the part is difficult to separate from the core. Two things can be done:

1. Cutting off flash that runs up between the core and the inner side of the pipe, (this contracts around the core).
2. Placing the core on a hotplate and trying to twist the plastic part every 30 seconds. At one point the plastic on the inside will be soft and the part will release from the core.

Activity	Time (min)	State
Sorting		
Sorting	0.6	Active
Total	0.6	
Cleaning and apportioning		
Mechanical cleaning	2	Active
Drying	1	Active
Label removal	2	Active
Cutting	4	Active
Apportioning	2	Active
Total	11	
Molding		
Cleaning of mold:	5	Active
Assembly of mold	0.5	Active
Heating of plastic (PP / PE)	15 / 40	Passive
Stirring	1	Active
Reheating of plastic	5	Passive
Moving plastic to mold	2	Active
Compression	1	Active
Cooling under compression	3	Active
Removal of part	4	Active
Cutting of flash	2	Active
Total	18.5	
In total		
Passive total (PP / PE)	20 / 40	
Active total	29.5	
Total (PP / PE)	49.5 / 69.5	

Table 8.1 Overview of time consumption pr. activity

8.5 Results

- 11 acceptable plastic parts were produced: 2 white, 3 black and 5 green. See Figure 8.10 below and (WS 8.10).
- 4 sub standard parts were produced (WS 8.11).
 - one was a small part was loose and fell off
 - one was the PE got a discolouration due to heating for too long
 - one with dents
 - one with cavities
- Plastic film and blobs are sticking to the inner side of the pipe and to the cylindrical (upper) part of the core (Figure 8.11).
- Significant difference between how PP and PE was flowing using the same mould at the same temperature and pressure.
- Some of the PP was left in the oven for 40 min. resulting in a grainy texture when molden and a brittle texture when pressed and cooled down. The part fell into piece when gently pressure was applied by holding it in a hand.
- Waste products made in PP had significantly thinner wall thickness that their PE counterparts, resulting in the PE taking longer to heat.
- If plastic is removed from the tool too early, the hot the plastic is soft and still shapeable. Surface and shape becomes rough and undesirable.
- If plastic is removed from the tool too late, the whole tool is too cold, resulting in the pipe to subtract around the part, making it hard to get out.
- A PE part got a surface finish smooth as a mirror when we applied 10 tonnes (normal is 5 ton).
- Producing plastic parts with this technique is very time consuming compared to conventional production methods.



Figure 8.10 Generation 3: 11 successful parts



Figure 8.11 Plastic film and blobs sticking to the inside of the tube

8.6 Discussion on Report: Manufacturing with recycled plastic

8.6.1 Validity

When assessing the validity of our result, it is important to take into consideration, how many variable parameters were in play simultaneously. Our trial-and-error based approach has led us to often changing more than one parameter between two different test. This could result in misleading interpretations of the actual cause for an outcome.

We have been working with PE (T_m : 115 °C) and PP (T_m : 173 °C) (Callister & Rethwisch 2011), at the oven temperature of 220 °C. When moulding, we have also applied the same pressure. Choosing the same working temperature and pressure for the two types of plastic was due to simplification and elimination of variables, reducing complexity of the experiments, but this is definitely a source of error and an area with room for improvement, which should be corrected for further experiments.

8.6.2 Applying pressure during cooling

On a few of the parts, we observed dents and small holes in the surface (4 sub standard parts were produced (WS 8.11)). This could be an effect of not having applied enough pressure during cooling of the plastic. When the plastic cools down, the surface of the plastic will cool faster than the centre, causing the plastic to cure on the outside first. We have had very little control and monitoring of the temperature of both the mold and the curing plastic, so in some cases during cooling, we might have removed the plastic from the mould before having cured completely. When the plastic cools, it contracts, and if no pressure is applied to keep the shape, the contracting plastic on the inside will pull in the surface, creating small cavities and dents. Another possible cause for these could be water vaporizing.

8.6.3 Post-processing on lathe

Getting a proper surface finish has been of high priority during the experiments. We have learnt that the amount of pressure applied, and the surface finish of the mold are crucial factors in achieving this, but in cases where the finish has been at an unsatisfying state, we have experimented with post-processing the parts on the lathe.



Figure 8.12 Post-processing a block of PE on the lathe yields new textures (Prototype 2.1)

Turning the parts have brought interesting results. The achievable surface finish is of high quality, meaning smooth and even, but not as glossy as the best moulded parts. In return, a new surface structure is revealed, having sharper edges between the colour veins and giving the pattern a higher degree of detail.

When the plastic is being moulded, it acts as a fluid flowing up along the walls of the tool, forming a thin boundary layer closest to the pipe with a no-slip condition. In this boundary layer, the caramel-like plastic is stretched, causing it so make more gradient transitions between the colour, but when the surface is cut off, the sharp transitions are revealed as seen in Figure 8.12.

Post-processing on the lathe, allows for new textures, and consistent surface quality, but add a lot of complexity and time needed to the production process. This will inevitably make the cost price go up, but, depending on the shape, this might be worth applying in the production an another product in the future.

8.6.4 Colourways using shredded plastic

One of the first tests we made, was an attempt of making a solid block of white PE. We used a shredder to grind up a couple of completely white bottles into pellet-like flakes (Ø3mm). By accident, a lot of plastic flakes in other colours were caught in the shredder, and got mixed up with our batch. The result is seen below, and it shows how this results in a spotted more terrazzo-like texture as seen in Figure 8.13, rather than marble. Since then, we have been cutting the plastic in flakes of 30x30 mm, resulting in much better textures, but slowing down the process, since it needs to be done by hand (at the moment).



Figure 8.13 Cylindrical part made from shredded plastic

However, it might be worth looking more into the possibility of shredding single colours and mixing them with bigger flakes of plastic in the remaining desired colours of our usual combinations.

8.6.5 Yield and time

An unrelated but very important findings of the experiments is realizing the time needed to produce a part. This process is undoubtedly more time consuming than conventional methods, and will probably never be competitive with e.g. injection moulding. In the future it is therefore very important to emphasize the differences between the two approaches, where our technique is distinguished by having an artisan approach to processing plastic, giving new opportunities in texture and visual impression. It is important to stress this, when comparing the two. Even though competing with injection moulding might not be realistic, reducing the time per part is still highly relevant, which can be done in many ways.

Especially the process of heating and melting the plastic could be optimized with advantage. A reason for the slow heating during our experiments, is the that we heat the plastic and the mold in the same oven. Apart from air being an inefficient medium for transferring heat, the high thermal conductivity of aluminium relative to plastic as well as the heat capacity of the tool, also increases the time needed significantly.

Adding heating to the mold or heating it by other means are obvious upgrades, but the process of melting material also has potential for improvement. In conventional compression moulding, an extruder is used to melt and dispense the charge to the mould, but since the colours would mix completely in the worm, this method is inadequate.

In an interview with Rasmussen (2017), he suggests heating the plastic using heat lamps, and estimates the melting time to be less than 10 seconds. We have not been able to test this yet, but are planning to do it soon.

Four sub-standard parts were produced out of 15 attempts. This is a yield of 73 %, which is also quite low.

To be able to sell products with parts in recycled plastic we need to reach a level in our production where we can ensure the quality of every part.

8.7 Conclusion

Within the limits of the manufacture specification, 11 successful parts were produced, out of 15 attempts.

Flakes in 30x30 mm work well for swirly, marbled textures. Flakes of 5x5 mm results in more terrazzo like textures.

Post processing in lathe adds time and therefore cost, but allows for a different visual expression, worth considering for future products. For this part, it is not recommended.

The heating process has potential for improvement and the effect of using heat lamps should be investigated.

We need to answer the three questions:

- Does the product keep its shape in the use case?
- Do the colours change over time? How will it age and patina? (Especially relevant for PE)
- Is the plastic affected in any way when the lamp is turned on for 100 hours with a LED bulb?

During the experiments we encountered the following challenges:

- Bumps and dents appeared un acceptable parts
- Time per part is too long
- The yield is too low

9 Working environment

7. How can a safe working environment be ensured when recycling plastic waste?

9.1 Work place emission studies

Hoff (1982) did emission measurements in a workplace where different productions of PE were running. The tests were made under normal production conditions with temperatures in the range 140 to 250 °C. **All of the measurements were under the Danish exposure limits, except from aerosols.**

Substance	Exposure limits (mg/m ³) ¹	Concentration (mg/m ³) ²	Standard error of the mean ²	Highest value ²
Total aldehyde	-	2.2	0.6	18.1
Formaldehyde	0.4	0.1	0.02	0.2
Acetaldehyde	45	0.16	0.05	0.4
Acrolein	0.12	<0.02	-	-
Acetone	600	0.78	0.12	1.5
Organic acids	-	15.4	1.4	46.7
Formic acid	9	0.83	0.13	2.1
Acetic acid	25	0.86	0.39	4.9
Aerosol (presumed to be paraffine oil)	2	1.2 - 3.5	0.5	4.6

Table 9.1 Results from workplaces processing polyethylen (different processes)

¹ Values from (Arbejdstilsynet 2012) ² Values from Hoff (1982, p. 35) except the Aerosols (p. 34)

Forrest et al. (1995, p.46) did emission measurements in a workplace where PP tape was extruded. The machine was placed in a big room where other machines were processing PP in other ways. The report only lists these two substances. We have compared them with the exposure limits from Arbejdstilsynet (2012).

Substance	Exposure limits (mg/ m ³) ¹	Concentration (mg/ m ³) ²
Xylen isomere	109	0.22 – 1.65
α-Methylstyren	120	0.14 – 0.16

Table 9.2 Results from workplace extruding PP tape,¹

Limits from (Arbejdstilsynet 2012) ² Values from Forrest et al. (1995, p.46)

Different hydrocarbons were found at different concentrations but the subsequent chemical analysis was not the scope of their report. The conclusion ended up being “none of the situations studied were found to generate a high level of process fume. All the individual chemical species detected, were found to be present at concentrations significantly below the corresponding present occupational exposure limits (where such limits exist)” (Forrest et al. 1995 p. 52).

In laboratory studies Barlow et al. (1996) shows that all emission from extruding PE rise considerably when comparing two process temperatures, 260 °C and 316 °C. To name two differences, the amount of aerosol released are increasing by a factor of 8 and formaldehyde emission is increased by a factor of 80.

The emissions are affected by a lot of different factors: *“Since the type and quantity of emissions are often influenced by operational parameters, the ideal situation is to study each process under the specific operating conditions of concern.”* (Adams et al. 1999, p. 50).

Adams et al. (1999) identified the main parameters influencing on the emissions:

1. Processing type and size
2. Melt temperature and rate
3. Air-exposed surface to volume ration of the heated material
4. Cooling rate
5. Resin type
6. Age of resin
7. Additive package
8. Other material added to the resin prior to extrusion (like composites)
9. For recycled materials, the thermal history is also an important factor

9.2 Discussion

Studies show that emissions from workplaces processing PP and PE generally are lower than the exposure limits. This indicated that PP and PE can be relatively safe to work with.

That being said, additives could have changed since the date of these studies and new research could also have resulted in focus on other substances that are dangerous in small concentrations.

It is mentioned, that the emission vary from process to process, so emission tests need be done at our workplace to assess what substances are released and in what quantity.

Strong ventilation and an active-carbon filter mask has been a minimum requirement when we have worked with plastic so far. A production of recycled PVC-PP plastic is being processed using compression molding in Denmark (Letbæk Plast 2017) where the workers do not use respiratory protective gear and only a fixed extraction device over the outlet of the extruder. On top of that, PVC is generally considered to be a more harmful resin compared to polyolefins (PE and PP) due to the presence of chloride. The industry standards of personal health concerns are considerable lower than what we expected, judging from the norms of this particular company. We might have been overly cautious in our approach, which we think is wise as we are doing experiments and exposing the plastic to all kind of conditions that could result in harmful emissions.

We need to make sure to stay under the current exposure limit (Arbejdstilsynet 2012) but we would rather have much lower emissions, preferably under the measurement limits, to spare the workplace environment as well as the global environment. Lowering the melting temperature might be the first step in this, but other steps might be necessary to take.

We have not looked into the emissions to the environment, as these are usually done in separate studies. The studies we have looked at are focused on the concentration of a substance in the room, indicated in $\mu\text{g}/\text{m}^3$ air. Emission to the environment is given as emission in relation to the material being processed, indicated in $\mu\text{g}/\text{gram}$ plastic. It is not the scope of this report to compare these emissions.

9.3 Conclusion

Emissions from PE and PP processes can be well below the Danish exposure limit for a workplace, but these emissions vary greatly dependant on a lot of different variables. Emission tests of our workplace need to be conducted to ensure safe working environments.

10 Sourcing of material

8. How can plastic waste for a production be sourced?

We have identified three different alternatives and have made small pilot projects, testing each of them. These are:

- Municipalities or waste companies
- Private housings
- Institutions

All three solutions have their pros and cons, which will be described in the following three paragraphs.

10.1 Municipalities or waste companies

If the plastic should come from the Copenhagen Municipality, it would be plastic from household waste, sorted into PP and PE at the new test sorting plant at ARC (2017). Although this is still a small test facility, it is capable of sorting 1 tonne of plastic waste per hour, and if we need to produce 2000 lamps a year, consuming 60 grams each, that would be 120 kg or 0.12 tonne for a year's production. The supply from ARC will definitely be sufficient even if we scale the production up manifold. Copenhagen Municipality (Tilsted 2017) expects to be able to sell sorted plastic at standard European market prices, which at the time of writing is 1890 DKK per tonne (WS 10.1) but as they only have a temporary test plant this is not in action yet.

In a meeting with Martin Tilsted and Jonas Åbo Mortensen, Tilsted (2017) proposed to us an arrangement, implying that Copenhagen Municipality could deliver the needed amount of sorted PP and PE free of charge for a limited time, and in return, the product should serve as a promotion for the municipality, clearly stating the origin of the waste. If the arrangement should be made more permanent a clear legal contract should be formed, price of the plastic should be agreed upon.

For the company, a solution like this is advantageous in many ways. The supplier will be able to deliver plastic very consistently, in very large amounts and at a very low price, if not for free.

However, receiving waste from Copenhagen Municipality will imply challenges concerning the state of the plastic we receive. The plastic collection trucks compress the plastic waste to increase the amount they are able to carry. If some of the waste has leftovers in them, these will be spread all over the batch of plastic waste and the risk of contamination increases (Mortensen 2017). Also, the sorted fractions from this specific plant, have an error percentage of 15 % (Tilsted 2017), which means the plastic would need a secondary manual sorting before production.

Pros: Very large volumes, sorted in plastic types for free, if not for a very low price.

Cons: The waste has been compressed and mixed with food residue, and more intensive cleaning is needed for this waste. Also the waste needs to be sorted manually, adding to the cost per part.

10.2 Private housings

Another approach would be to collect the plastic waste closer to its source; the consumer, before it was collected by the municipality and taken to the sorting plant. This could be accomplished by making agreements with housing cooperatives (andelsforeninger), student housings (kollegier) or other collections of private housing. It is relevant to get in contact with places where people from our user group live, as they might be more understanding and it would help spread the word.

We have tried to introduce sorting arrangements at Nybrogård Kollegiet in Lyngby, where trash is being collected at the common kitchen at each floor. One of the authors, Christoffer, lives there.

We posted on the internal Facebook group with 500 members, asking if anybody would sort PP and PE for us. We attached a A4 poster with examples of PP and PE products (WS 10.2).

Some wrote back, and some also went along and collected some plastic to us.

To make it clear, none of these people knew Christoffer before.

- A. Two kitchens (with 26 residents each) said we were welcome to and go through their trash before it got thrown away. Both have contacted us when their plastic container was full, and we got their plastic.
- B. Two kitchens were collecting PP and PE for us and came by with it when a bag was full.
- C. One person came by with large amounts of uniform plastic pieces from her work: *“Throwing away all this perfectly fine plastic reminded me of your Facebook post”*, she told us.

In situation B and C, the waste had been cleaned thoroughly, and sorted correctly, allowing us to use it in production immediately.

What we take with us from this small pilot project is that some people are willing to sort plastic into smaller fractions when they know, it is going to be used for creating lamps. We can not say for sure what motivated these people, but maybe it is same altruistic motives that Bjørner et al. (2002) described. All of the plastic was cleaned when we received it, even though we did not ask for it.

Pros: There is less chance that the plastic has been in contact with hazardous substances. Maybe we can even get people to sort colour. The trash is the same trash for all consumer, which is good for our storytelling. We are showing the collectors what their trash can become.

Cons: Smaller fractions with a lot of different products in it, and less consistent supply.

10.3 Institutions

A third approach could be to make an agreement with an institution that has a big consumption of plastic articles. We have chosen to take Rigshospitalet as a case, since the mother of one of the authors works in the Fertility Department at the hospital, and thereby have been able to help us conduct small experiments with the employees and the waste.

The disposed plastic we are interested in should obviously be limited to plastic products, that would not imply a risk of transferring diseases. An example could be bottles for demineralised water.

With such an agreement, Rigshospitalet might be able to get hold of datasheets of the specific plastic articles, allowing us to document what additives were present as well as guarantee that the use of the plastic

products has not lead to a contamination of the plastic. Additionally, a high homogeneity within the composition of the PP and PE fractions could be achieved, forming the basis of a more homogenous and stable production.

The incentive for Rigshospitalet to enter a such agreement, should lie in a gain, either as an economic gain or as positive publicity. Usually, institutions like Rigshospitalet are paying private waste management companies, to handle their waste. We could then offer to do it for free, forming a constellation that is beneficial for both parties. In the same way as with Copenhagen Municipality, the story could serve as positive branding for Rigshospitalet. We have not been in contact with the decision makers yet, so we are not sure about what they think.

We have made a pilot project with one department (the fertility clinic) at Rigshospitalet. We have handed out the same printout about PP and PE product like we did at Nybrogård Kollegiet (WS 10.2), the clinic contacted us when they had enough for us to come by and collect.

Pros: Large source of uniform plastic (maybe even datasheets could be supplied). Showing the employees what their trash can become.

Cons: Source of the material is products only people who work in hospitals, have a personal relationship with, which weakens the story.

10.4 Conclusion on 'Sourcing of material'

Three suggestions for sourcing plans have been presented and discussed, but before moving on in the process of implementation, the actual legal requirements within documentation and traceability need to be identified, because this could result in major changes. When this is clarified, the different sourcing plans can be rated.

As it looks now, we would go with sourcing it from private household, but if we develop an automated cleaning system, the waste management companies or municipalities are preferred.

11 Turning it into a business

9. How could a sustainable business be build around the product?

11.1 Optimizing manufacturing for production

All parameters concerning manufacturing are dependant on how big the yearly production is going to be. The strength of this relative simple production method is that it is possible to start a small production with relatively limited investments and then scale up if the product is being sold in sufficient quantities. A start estimate from Roon & Rahn is 2000 pieces a year.

The manufacturing process needs to be optimized to go from prototyping to production.

The process can be broken up into six parts:

1. Cleaning and label removal
2. Cutting the plastic
3. Mixing of Colourways
4. Heating
5. Transfer from oven to press
6. Getting the part out of the tool

They all need to be optimized in some way.

11.2 Cost per prototype part

The plastic we get probably needs a manual secondary sorting when we receive it. According to Ærenlund (2017), an employee is able to sort approximately 80 kilos per hour of unsorted plastic waste from households in types, and according to Ærenlund's experiments, the percentage of PP is 12 % and PE is 17 %. If we assume that it takes as long to sort the plastic in the desired colour fractions, and that 50 % of the PP and PE has the desired colours, one hour of work will produce 5.8 kilos of usable raw material. With a plastic consumption of 60 grams per part, this is equal to 96 parts, and with an hourly wage of 118.35 DKK/hour (Jobpatruljen 2017) the cost of sorting will be 1.22 DKK/part. Below is shown the calculations.

$$\text{Usable plastic per hour} = \frac{\text{Sorting speed} \cdot (\text{Percentage of PP} + \text{Percentage of PE}) \cdot \text{Percentage of desired color}}{\text{Sorting sequences}}$$

$$\text{Usable plastic per hour} = \frac{80 \frac{\text{kg}}{\text{h}} \cdot (0.12 + 0.17) \cdot 0.5}{2} = 5.8 \frac{\text{kg}}{\text{h}}$$

$$\text{Sorting expense per part} = \frac{\text{Hourly wage} \cdot \text{Plastic per part}}{\text{Usable raw material}}$$

$$\text{Sorting expense per part} = \frac{118.35 \frac{\text{DKK}}{\text{h}} \cdot 60 \frac{\text{g}}{\text{part}}}{5800 \frac{\text{g}}{\text{h}}} = 1.22 \frac{\text{DKK}}{\text{part}}$$

In Table 11.1, an overview of the time consumption of cleaning, apportioning and molding is presented. In Table 11.2 below is presented an overview of the whole process. Adding the cost of each process results in a total cost of 59.4 DKK/part.

Activity	Time (min)	Rate (DKK/hour)	Expense (DKK)
Sorting	0.6	118.35	1.2
Cleaning and apportioning	11	118.35	21.7
Molding	18.5	118.35	36.5
Total	30.1	-	59.4

Table 11.1 "Active time" and expense per part

11.3 Breakdown of the value chain

At the moment, Roon & Rahn (2017) is paying their subcontractor 25 DKK for the wooden socket. In order to match this price, and make it profitable, we estimate that the plastic part should not cost more than 15 DKK to produce. With an hourly wage of 118.35 DKK, the time consumption per part needs to be reduced to 7.6 minutes, which is by a factor of four.

$$\text{Time per part} = \frac{\text{Cost per part}}{\text{Hourly wage}}$$

$$\text{Time per part} = \frac{15 \text{ DKK}}{118.35 \frac{\text{DKK}}{\text{hour}}} = 0.127 \text{ hour} \approx 7.6 \text{ min}$$

So far, our process is very inefficient, so speeding it up four times will be challenging but not impossible. Also, as discussed in 12.6.6 Pricing, we think we will be able to sell it at a 10-20 % higher price, giving us more economic latitude.

	Expenses (DKK)	Profit (DKK)	Turnover (DKK)
Plastic part	15	10	25
Roon & Rahn (plastic part + wire, socket, brass tube)	103	97	200
Retail	200	200	400
+ VAT			500

Table 11.2 Expense, profit and turnover for a collaboration with Roon & Rahn

11.4 Business plan

To realize the project, we have worked out the following business plan, with input from Pål Fernwall (2017), Rune Rex (2017) and Benjamin Beckett (2017).

We will advise companies in launching products in recycled plastic: re-launching old and making limited editions or permanent new products. We are offering consultancy in the process of designing or adjusting products to be suitable and robust enough for production in recycled plastic. In addition, we will handle development of the mould and the production of the plastic parts.

Companies receive “green branding” and a more visible sustainability profile, as it is displayed directly through their products. By collaborating with us, the companies join the movement with recycled plastic, creating good publicity and a reputation that portrays them as companies that take responsibility. The green profile could open up for a new target group of potential customers.

Likewise, the collaboration between Adidas and Parley (described in 2.4 States of the art), ensuring that a product is made completely from recycled post-consumer waste is costly, which makes it reasonable to charge a fee on top of the payment per part.

We will make it easy for the consumers to make the right choice by creating aesthetic, meaningful products in recycled plastic without compromising functionality. The products have a clear message, works as a statement on environmental awareness and creates a feeling of making a difference.

The first collaboration might not be profitable for the company, but only serve as a mean for getting the name out to relevant future collaborators, and in case it proves to be a success, an argument in signing a bigger, more profitable deal later on.

An alternative business model could be to handle both designs and production. The production of the plastic parts still needs to be affordable, but the company would have more freedom in setting limits for how expensive it can accept the part to be.

11.5 Discussion

The cleaning and label removal needs to be optimized in terms of time consumption and quality, and hopefully they can be combined into one process. Regardless of the size of the cut-up of the plastic, some kind of shredding machine is preferred.

The mixing of colourways could quite easily be automated with a feedback loop between a scale and containers with the different colours of either PP or PE. Using a heat source that creates thermal radiation might be able to speed up the heating process, because the heat is no longer transferred through the air which is inefficient to transfer heat.

An oven or heating device should be dimensioned in such a way that multiple portions can be heated at the same time. The process from here on could be conducted in parallel. Getting the part out of the tool could be simplified by using a more standardized two-piece part mold with ejectors. Lastly heating and cooling could be integrated into the mold, to reduce cycle time.

11.6 Conclusion

We have proposed a business plan with collaborations and an alternative option with our own design.

We need to be certain about what we are doing, before we can expect companies to pay for a collaboration. We might need to complete one or more successful collaborations before being able to land a profitable deal. There is a chance, still no companies are interested, but we have to give it a try.

12 Study: User responses to product

10. What is needed for people to view these products as valuable?

To be able to investigate this, we are dividing the problem statements in two:

- Investigate how the plastic edition of the RR-1 Pendel works as a communication media in addition to verbally telling the story about plastic waste as a resource
- Investigate which parts of the story about plastic waste as a resource, the user will talk about when confronted with the physical prototype.

12.1 Introduction

With the following report on user interviews, we seek to communicate our experiences with interviewing potential users from the target group, good ones as well as bad ones, to the reader.

We attempt to document and communicate what we did, what experienced, and how we interpret our findings, in relation to the case.

12.1.1 Problem background

The mission for this project is to make consumers recognize recycled plastic as a resource rather than a burden, as stated in our mission statement. The story about what plastic waste can become, is a key component in the concept. Therefore, proper communication is essential. We believe, the physical product can be an essential tool in telling the story. We need to make the consumers realize this potential, and in this process the lamp is tested as a communication media.

With this user study we seek to find out, if it makes sense to combine story and product to back up an environmental cause.

12.2 Scope

We have defined the target group for the concept as consumers who are environmentally and politically aware and are interested in interior decoration (See 0

The target group for personas). For that reason, the majority of the users, we have interviewed have been from this segment, and in some sense related to us.

12.3 Methodical considerations



Figure 12.1 Mads (left) is interviewing Jørn (right) about the possibilities in plastic

When talking to users, we chose to conduct semi-structured interviews, where we have tried to stay in the background, and let the interviewees speak their mind, without influencing their statements. Statements and opinions are of much higher value, when they are given unsolicited, but at the same time, it is important to get statements on specific subjects. Therefore, we have been forced to ask about certain topics, if the interviewees did not speak about them themselves.

We chose to take a qualitative approach to the interviews, as our aim was to receive their individual opinions, and the details and reasons behind them. However, from the qualitative interviews, we have tried to make quantitative conclusions. The interviews have taken place in various different settings, ranging between meetings, talks over lunch in a cantina and in the users' living rooms. Equivalently for all the interviews, we have tried to keep the setting relaxed and informal, in order to get a conversation flowing and obtain honest opinions.

Our approach to this research was inspired by the prototyping phase from Design Thinking (Plattner, Meinel, Leifer 2011). We have strived towards quickly producing early-stage prototypes, which would work as “communication media” (Plattner, Meinel, Leifer 2011, p. xv), and give the users a starting point in the interviews. Having a prototype of the actual product in their hands during the interview should help the user understand the context, and demand less from their imagination. Also, it should allow them to give very specific feedback on what they like or dislike.

12.4 Materials and methods

12.4.1 Users and Materials

For this user test, we have talked to 73 potential users, who we consider to be inside our target group. All interviews have been without recording of sound or video. They have been casual conversations, where few notes were taken during the talk, and most notes were written down afterwards.

In all interviews, the presented parts have been 1.3, 1.5 and 1.7 as seen in Figure 12.2 and (WS 12.1), as shown below. We have not shown the assembled lamp, but in most cases a picture of the wooden edition has been shown afterwards.



Figure 12.2 The prototypes used for interviews: (Prototypes 1.3, 1.5 and 1.7)

Interview structure

1. Introduction of project, problem and idea (Interviewer talks)
2. Dialogue (Interviewee and interviewer talk)
- Presentation of product -----
3. Interviewee's monologue (Active listening, first hand impression)
4. Dialogue (Interviewee and interviewer talk)

A more detailed description can be found in (WS 12.2).

12.5 Results

Below is a list of all statements and reactions observed with two or more interviewees. The full list of quotes from each interview can be found in (WS 12.3), (WS 12.4), (WS 12.5), and (WS 12.6).

- #1. The interviewed users are generally interested in the subject.
- #2. The majority of the users in our target group are familiar with the issues associated with plastic pollution.
- #3. We experience a significant shift in the conversation, when the physical product is presented, as the users talk about the problem with more commitment, are more action oriented and relate the problems and solution to their own lives.

- #4. The users are surprised that plastic waste can be recycled into a product at this aesthetic level, and 9.5 % said the colors and texture are modern.
- #5. 37 % of the interviewees use associations from their everyday life to describe the texture.
- #6. 27 % mentioned that they think it looks like marble stone.
- #7. 31 % of the interviewees start suggesting alternative applications for the material.
- #8. 5.4 % say they expect the product to be cheap, since it is made from waste.
- #9. 14 % asked critical question about health, safety and the production process.
- #10. 14 % were interested in the production process, and the challenges.
- #11. 23 % asked what kind of plastic the lamps are made of, and 6.7 % asked if we can use specific waste products.
- #12. 6.7 % asked if their own trash can be used, and if they can decide their own colour.
- #13. 18 % asked and talked about the story and the project behind the lamp.
- #14. 8.1 % offered to help collecting plastic for us.
- #15. 20 % of the users stated that they want to have one or two lamps.

12.6 Discussion

12.6.1 Validity

When assessing the validity of our findings, a concern could be that, all of our quotes and statements come from interviews conducted by our selves. Especially regarding the identified high interest for handling of plastic waste (Result #1), this is important. Since we are probably more interested in plastic than the average consumer in our target group, there is a risk, that we have affected the interviewees with our enthusiasm.

On the other hand, we might have received more positive feedback, if we had presented the fully assembled lamp, instead of only the plastic parts.

Also, many of the findings are based on our subjective impressions and memory of the interviews. When documenting reactions and assessing an interviewees excitement, there is a high risk of cherry picking, meaning only notices what we want to see. It has been difficult to document the change in enthusiasm, and a video recording would have been preferable. At last, the majority of the interviewees are people in our circle of acquaintances, which might have influenced their attitude towards the project.

12.6.2 Product as communication media

The interviews were conducted in two parts, before and after showing the prototypes of the actual product, in order to assess the effect of the product in the story telling.

We saw a general tendency that, before presenting the prototype, the conversations were characterised by ethical considerations and a sense of obligation for us all for to make a greater effort for taking care of the planet. The possible initiatives that were discussed, were mainly of a very superficial character, and not very action oriented or concrete.

Upon presenting the product, we have observed a significant change in the interviewees' behaviour (Result #3). Almost all of the interviewees suddenly get much more interested in the topic. The conversation changes from being very superficial to being detailed, and regarding what we as consumers can actually do, to make a difference in the whole. Most of the interviewees wanted to touch the plastic parts and some even smelled them.

It would be an advantage to have video recording of the observed reactions, in terms of documenting and subsequently analysing the changes in behaviour and excitement (Result #4). The feedback is often difficult to document only by writing notes, as the majority of the feedback happens through facial expressions and gestures.

We can conclude that we experience a tendency that most users give the product and visual expression a good reception (It is not certain the same responses will be found in other groups of interviewees).

12.6.3 Cover the target group

Upon talking to 73 people, they started to repeat what the previous interviews had already taught us. We then concluded that we were close to having determined our target group, and decided that we had interviewed an adequate amount of users. This was especially clear, as a big part of the interviewees compared the texture in the material with marble (Result #5).

12.6.4 Play on with the concept

Without us asking for it, a lot of the interviewees suggested other products and new systems, the material could enter (Result #7). An example of a system, that many have suggested, is to allow users to bring in their own plastic waste, and have a lamp produced from it (Result #12).

12.6.5 Consumer contribution and customization

In 5.6 Discussion on ‘Choosing a product’ the results of the Weighted Objectives Method indicated that the weakest point of the concept “New Danish Design” was the lack of impact on user level. This was due to an estimation of it having little potential for creating strong sentimental value for the user. In order to strengthen the concept, this is a relevant focus point.

A way to create more sentimental value for the consumers is to let them become part of the manufacturing process. The users could collect and sort their own plastic waste, and hand it in at the store as part of the payment, as described in the GoPro concept. This way, sourcing material could be cheap and the quality of the plastic would probably be clean. In addition, we believe, sourcing the material directly from the user will convey the message even better, as the user will be able to follow the entire road from waste to new product. However, this might add some logistics to the production process.

If the customers hand in the plastic waste, that will be used in the production of their lamp, there is a big opportunity for adding product customization to the business. An employee from Rigshospitalet once returned to us and said:

“I was in the shower and had just finished my shampoo, as I realised how beautifully coloured plastic the bottle was made of. And then I could not throw it away.” (our translation) (WS 12.7)

With the possibility to customize their own lamps, we think once again this will enhance the message of the plastic waste being a resource, as it will encourage the users to consider how the colours of all their plastic products would look, if melted into a lamp.

Using the users’ own waste and adding customization are ideas, that were earlier deselected due to four reasons.

1. We considered the concept to have very low potential for scalability.

2. We did not think the interest from the consumers would be high.
3. In a meeting with Roon & Rahn, they advised us to be careful with demanding too much from our customers, as their experience was that many would just buy from another brand, that was easier for them.
4. Offering customization requires a more complex infrastructure, as we need to keep track of what material batch goes into every specific lamp, which will affect the cost per part, and eventually the retail price (more about this in next paragraph).



Figure 12.3 Meeting with Roon & Rahn, showing them our first prototypes of the RR-1 Pendel

However, receiving the many suggestions about taking in plastic waste from customers and adding customization, have made us reconsider the option. Obviously there is a big difference between what people say and what they do, so Roon & Rahn's experience in consumer behaviour should not be underestimated. An argument that this model could succeed, is that our target group consists of more environmentally aware consumers, who might be more motivated to making an effort, compared to Roon & Rahn's usual customers.

12.6.6 Pricing

*"If it is made from waste, I suppose you sell it cheaper. You get the material for free, after all."
(Quote from interviewee, Result #8)*

We find statements like this of high importance, and believe this view bound in an overall perception of recycling being equal to down cycling, i.e. the material will always be reintroduced into a product of lower

value, than the previous. This is an attitude, we would really like to challenge, and therefore we might need a higher price.

Today, recycling plastic is in no way cheaper than using virgin material, due to the sorting and cleaning, but there is a need for it to be done, and by purchasing our product, the consumer can contribute to supporting this development.

An analogy worth mentioning is the introduction of the Nordic Swan Label in Denmark. The purpose of the eco label is to make it easy for the consumers to choose the environmentally best products and services as well as reduce the total environmental impact of the consumption (Miljømærkning Danmark 2017). Bjørner et al. (2002) has done a study of toilet paper, paper towels and detergent with and without the label. The study was conducted in the transition period, where only a limited number of brands had gotten the label. The products that had received the label were 10-17 % more expensive than similar products, but were still selling more. In the conclusion it is stated:

“The fact that (Danish) consumers are willing to act on an environmental label, even though this does not yield any direct benefit to the users indicates the presence of altruistic motives of some kind” (Bjørner et al. 2002, pp. 65)

It is these altruistic motives we want to appeal to by presenting recycling as a similar environmental action that the consumer can support by buying these lamps.

Furthermore, we see a tendency that people often perceive plastic products, as being cheap, which is likely to be caused by the low cost of modern and conventional production methods like injection moulding. When introducing recycled plastic as a high value material, it is therefore important to consider what elements to use in the branding, to justify its higher price. To have an effect, we believe these elements needs to create value for the end user. The notion of the sustainability as an added feature, is a good example, but user involvement in the manufacturing and design process, could also be beneficial for this.

Flynn & Vencat (2012) states that “consumers *are willing* to pay a premium for custom goods, especially from high-end established brands” and that “most customers are happy to spend around 25 % more to get goods built specifically to their needs, although the premium varies widely depending on the product and the type of customization”. We can now substantiate that more involvement yields more sentimental value, and therefore more willingness to pay. A last argument, for charging a higher price is the added ‘feel-good’ factor.

Based on the above, we believe that the lamps too can be sold at 10-20 % higher price than similar lamps.

12.6.7 The story and the first impression

The storytelling is key is making this product sell.

In an interview about his book “StoryBranding: Creating Stand-Out Brands Through the Power of Story”, Jim Signorelli explains:

“I call them that [StoryBrands] because they function the way stories do. Stories don’t push influence on us, they pull us into becoming influenced. They inspire rather than force identification. And they create resonance to the extent that we share the underlying belief that is espoused.” (Signorelli, J. 2012)

In our user tests we have started every interview by telling the story about the project and then showing the plastic part. Our collaborator Roon & Rahn did the opposite, and tried to present the RR-1 Pendel with our plastic part at a fair where it was presented next to lamps with wooden parts and other interior design products (WS 12.8).

Most of the conversations with users started with the user seeing the lamps, and expressing a certain confusion about the choice of making products in plastic. Only at this point, would the user be told that it was made from recycled plastic waste, and according to Roon & Rahn, this changed the user's perception of the lamp significantly. According to Van Roon & Hansen (2017), one user said that *"It is now worth four times as much"*, which was obviously not meant literally. Van Roon & Hansen have told us that they are willing to pay up to two times as much for a part in recycled plastic than for the current wooden one.

The drastic change in how the user perceives the lamp is indicating how important the story is for the user to regard the product and material as being valuable. Once again, this proves the importance of implementing it as an essential part in advertisement, presentation, branding and packaging of the product. At Godsbanen, the consumers did not understand the story from the presentation material, so in the future this should be a part of the first impression.

12.6.8 Created value

Last but not least, we have experienced that 20 % of the interviewed users wanted to *'have a lamp'*. Most users have said: *"I would like to have two lamps for my living room"*. Often, we have had to ask what they mean by *'have'*, before they told us that they would be willing to pay the price of 500 DKK (as for the wooden edition). Unfortunately, we cannot draw any conclusions on pricing, but the many statements of consumers wanting a lamp in their homes is a clear indication, that we have succeeded in creating value from the material.

12.7 Conclusion on user tests

We have conducted 73 of interviews following a semi structured composition.

When the plastic parts were presented, we often saw a significant change in the conversation from eg. ethical considerations to subjects much closer to their own everyday lives.

The opportunity for adding customization to the product has been discussed, and we believe it has potential worth exploring further.

Different studies render it possible to sell at a higher price, both for increased income but more importantly to help spread the notion of recycled plastic as valuable material. Due to storytelling, environmental aspects and customisation, we estimate the price could be 10-20 % higher than the original wooden edition.

21 % of the interviewees express a wish to get one lamp themselves, which means we have succeeded in taking something that the users first think of as being worthless and wanting to get rid of, and turned it into a product, that they value and want to take into their homes.

15 % talked about health concerns, an aspect we still need to investigate.

13 Effect over time

By answering all of the above we want to be able to

11. Will this affect people's attitude towards plastic?

13.1 Important experiences so far

During the second study: 'User responses to product' we experienced shifts in the conversations when the plastic part in introduced.

We interpret this to be due to the fact that something does not match the users' common view of the material.

Two times employees at Rigshospitalet told us something extraordinary. One employee was very excited when we got a batch of plastic waste from them, she sorted through the whole black plastic bags to find a specific blue bottle, and showed it to us like it was a precious stone. She took it in her hands and put it on a table where the light came in from the windows and looked at it. A pretty remarkable moment in an absurd way.

We were told that another employee had been standing in the shower, used the last hair product and suddenly realized what beautiful coloured plastic it was made of.

This is the effect we were hoping to inflict on people buying the finished product, so it surprising to us that this was happening in connection to people collecting and sorting waste for us. This indicates there might be potential to showcase the aesthetics of plastic in both ends when people have an impression that is going to be used for something aesthetic

13.2 Affecting the actors in the development arena

With our company, we want to place ourselves in the centre of it all. We want to bridge the gap between the social worlds around the plastic manufacturers and the consumers, whose supply and demand, do not fit in terms of recycled plastic. As a processor and manufacturer of recycled plastic we want to accommodate the customers' demands for sustainability by offering an honest product and a transparent story. We will make the customers aware of the recycling by telling them the true story in their eye level, by showing what the material really is, and work for a better understanding of the fact that recycling not necessarily produce lower visual quality.

CLEAN Cluster (2017) is described 2.2 Sorting of plastic in Denmark. An important purpose of this plant is that it should improve on the current standards so that recycled plastic can be recycled at a price, quality and in a quantity that is actually attractive to companies that use recycled plastic in their production.

CLEAN's assessments are 3% of household waste and 40 % of industrial waste is sorted and recycled today.

CLEAN is definitely going to make a big difference in the Danish industry of recycling plastic, but there is still a big problem that should not be forgotten. With CLEAN, the sorted post-consumer waste will be

handled in a more responsible efficient way, but this is not going to affect the users' personal perception of the material.

Boyan Slat, founder of The Ocean Cleanup, a large scale attempt to clean the oceans from Plastic waste using nets close to the big gyres where the plastic accumulates, was during an interview with web media Inhabitat (2014) asked:

INHABITAT: "In one of your talks, you mention how using nets is ineffective against garbage patches such as the one in the Pacific. What do you think people could do in their daily lives to make an impact, apart from use less plastic bags?"

SLAT: "In short: making sure no more plastic enters the oceans in the first place."

The demand for plastic is growing, and in the future the consumption and production for plastic will grow accordingly (MacArthur 2016). Therefore, the problem with plastic in the oceans that Slaat and many other are trying to solve, will only be bigger and more challenging.

CLEAN Cluster and similar system solutions will make sure, that more of the sorted post-consumer waste will be recycled rather than being burned or deposited, but the amount of plastic ending up in nature or the oceans, can still grow unaffected, concurrently with the growing plastic consumption.

Again, communication is essential, and we predict that the organizational changes and improvements that happen out of the consumers' sight, will not affect their habits. If no habits are changed, the percentage of plastic entering the waste sector will stay the same, and likewise will the percentage reaching the oceans.

If we only recycle plastic into products like garbage bags and feet for traffic cones, recycled plastic will stay equal to downcycling, and the consumers are never going to realise the potential of the material. With large scale recycling we might get better at recycling the amount of plastic the citizens sort and throw in their plastic waste containers, but it is not necessarily going to work against plastic pollution.

We need a mental change to seriously work against plastic pollution. We believe it is not a question of getting rid of all the plastic. We believe we should appreciate plastic more and value it.

13.3 Different approach, different impact

We have had a different approach to plastic recycling and circular economy, avoiding the central recycling plant. We are trying to create small loops, by prioritizing local production, aesthetics over quantity and uniqueness over homogeneity. With the design approach to recycling plastics, the big focus on the properties of the material rather than requirements for an application we create the right setting for sustainable product development (Podlech 2017).

We are designing a product where the consumer can easily identify with the whole lifecycle, serving as a tangible example of what the effort can lead to. Using the products as communication media in spreading the message, will hopefully boost the domestication of plastic waste as a valuable resource in our society, for consumers as well as companies.

We will affect some companies directly by collaborating on new products, but hopefully the biggest impact will happen as show that a business can be built on the demand for sustainability, and thereby inspire them to follow. With an increased awareness about recycling and the related challenges, a pressure will build up

on the politicians and decision makers, demanding initiatives and regulations that promote recycling of plastic.

The presence of our company will therefore not necessarily disrupt the system, but simply fit into a gap in the existing market, and working on achieving our vision, product by product.

13.4 Discussion

In our research we have identified several strong frames about recycled plastic. One that limiting is how the plastic industry looks upon recycling. When plastic waste is recycled today, the aim is to create pellets to go into the same method of production as virgin material and the criteria for the products coming out of it is a similar homogeneity and visual quality.

We experienced this framing first hand in an interview with Rasmussen (2017) who did not hesitate with calling our molded parts ugly and unacceptable, due to the swirly texture and the not perfect surface finish. Another actor

13.5 Conclusion

We have not yet launched a product, so we do not know whether it is going to affect the general population's attitude towards plastic or not, but we know that we have affected some. The actual effect show, will only show after a certain amount of time has passed. We see a potential, and will continue to work on this case.

14 Further work

When analysing the concept using the Product Idea Model seen in Figure 14.1 (Hansen & Andreasen 2005), three areas still need to be worked out more thoroughly, before realizing the concept.



Figure 14.1 Product idea model (Hansen & Andreasen 2017)

Regarding *Technology*, the production process needs optimization, which means the production costs and thereby also the end retail price remains unknown.

For both the end-users who buy the lamp, and the companies that we want to collaborate with, the actual *Need* is still of high complexity. Even though we are certain, that consumers value the product, the decision to actually pay for the product is always going to be a personal balancing of whether the story, the product and the good deed weigh up the price. Since the retail price is still unknown, the outcome is difficult to predict, and tests of the saleability are needed.

The missing clarification of the above, makes it difficult to estimate the economic potential of the *Business*, but much can be optimized, so we are optimistic.

14.1 Structure of an organization

During this project, we have tried to get a broad understanding of the many different aspects of the field and challenges of recycling post-consumer plastic waste. Some of them, we have worked with, but some are still left untouched. In a long term future perspective, we find it beneficial to imagine an expansion of the organisation, engaging in five areas of expertise, with the purpose of seeking answers and solutions to the different problems with plastic.

The *product development* with recycled plastic would continue, reaching out to more companies in interior design and seeking integration in other relevant product fields. As the name of the company spreads and we gather experience, we could start launching our own products as well.

Regarding *health and safety*, there is still no clear answer to the question: How can post-consumer plastic waste be recycled in way that is safe for end-users as well as manufacturers? To answer this question definitively, experiments need to be conducted. Some are already done, but still it has been difficult to find. Testing, researching and gathering information about the health concerns is needed.

In parallel, there would be a focus on *optimizing compression molding*. This processing method has not been developed for many years, and with its low startup costs, an optimized process could be well suited for producing smaller series of parts, where investments in injection moulding are too costly.

In continuation of the wish to reach out and collaborate with other persons and organisations who want to produce with plastic waste. We aim to inspire other companies, to start working with recycled plastic, we could create a *forum* and offer sparring for people who want to start up their own business or join the movement. In Dave Hakkens' project Precious Plastic (Hakkens 2017), he has built a similar platform, so potentially, we could collaborate with him.

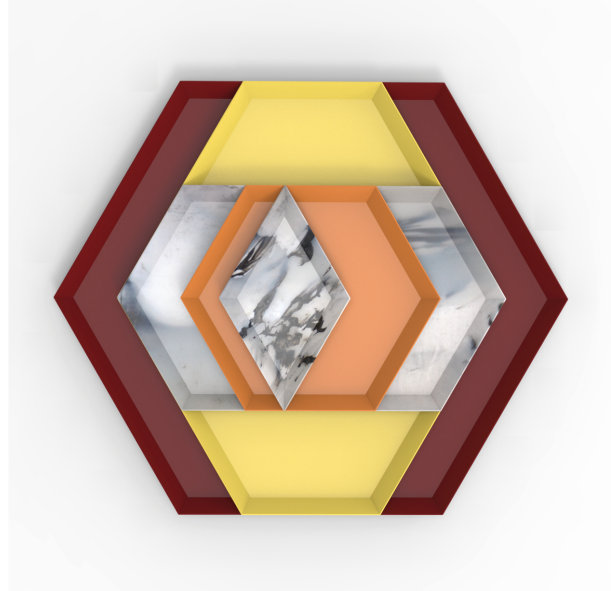
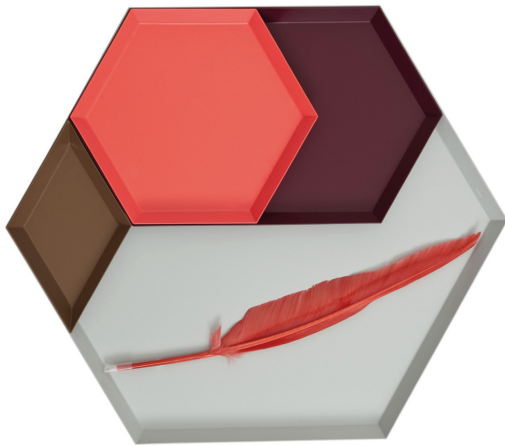
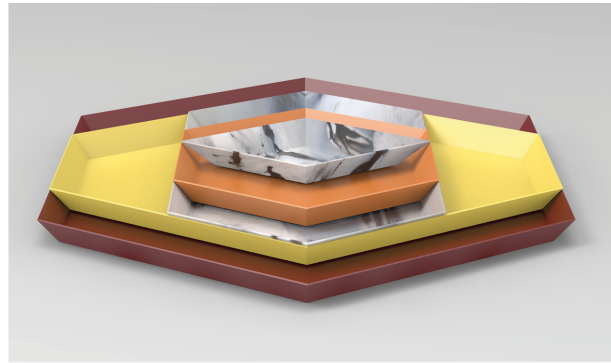
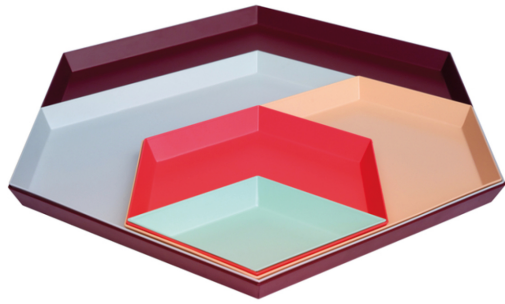
Finally, the low startup costs also make it a great technology, for setting up recycling plants in *developing countries*. A department could work on ways to create jobs and welfare in rural areas, meanwhile cleaning up the beaches and rivers.

With a structure like this, we expand our business to an organization working on different levels, to solve the same problem. To achieve this, we obviously need to expand our team with competent staff, like machine engineers and chemists, but this might take a couple of years.

14.2 Next collaborative product

For the next product in recycled plastic, we assess a brand like HAY to be suitable. Interior design low human contact, no food.

A HAY product with potential for making a special edition, is the Kaleido series of stackable trays. In Figure 14.2 below is a digital rendering showing how it would fit into the already existing collection.



*Figure 14.2 Kaleido by Hay (left) and rendering showing how a special edition would fit into the collection (right)
(Pictures: Ambient Direct 2017)*

The modularity of the product is interesting, as it creates an opportunity to produce special edition to be added to the already existing product series. When the recycled plastic trays are added directly to a design object like the Kaleido, we believe it helps the user associate the plastic part with high quality, maybe even more than if it was introduced as a new product.

This product would be relatively easy to produce and we would like to try out the model where the customers collect and hand in their own plastic and have a product produced from that.

15 Conclusion

We will not be able to confirm nor deny our hypothesis in the time constraint of this thesis.

However, we did expect this to be possible as it is overly ambitious to change 'people's attitude towards plastic' (Project goal #3) over a couple of months.

We have succeeded in making plastic parts in 100 % recycled polypropylene and polyethylene with simple methods and without major investments. The result were really good.

We have talked to 73 potential users and gotten generally good responses and reactions when revealing the plastic part. However, reacting with excitement does not necessarily mean that they will act on it. What people say and how they act in one instance, are not guarantees for how they will act in a future context.

We need to test if people want to buy it, and if it is possible to charge a higher price for recycled product. It is our clear conviction that a high price would be beneficial in propagating plastic waste as a resource.

Some questions still remain:

- How intensive a cleaning method is needed to secure the safety in use of the end product?
- What product requirements are set by law in this product category?

These are questions out of our expertise and we need to consult with authorities or experts to get closer to answers.

In this project we have shown the advantages of taking a design approach to product development. By putting more emphasis on different properties of the materials it allows us to look beyond the mechanical requirements of the application.

With starting point in recycled plastic, the 'soft' qualities such as storytelling, sustainability and visual expression, has a value. This is a contrast to comparing the more 'hard' qualities like strength and durability, where recycled plastic will seldom be the best choice.

We estimate that the gain in the story and the visual expression weighs up for the added costs and complexity when using recycled plastic. It is our assessment that this alternative to the conventional production with virgin material is legitimate.

Danish interior design is a well-suitable context and industry for showcasing and exploring the qualities and potential in recycled plastic, and there is great potential for expanding to other products.

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