Researching possibilities for the leftover mix fraction of domestic plastic waste using rotation moulding

Midwaste

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Abstract

A summary of the project

The Netherlands aims for a circular economy by 2050. One of the major challenges is using waste as a resource. Midwaste, a cooperative association that manages waste streams and covers around 130 municipalities for the plastic waste dossier, is contributing in working towards a circular economy. As the client of this project, it requested looking into creating a valuable product out of the leftover mix fraction out of domestic plastic waste. To work towards a circular economy, an increasing amount of municipalities in the Netherlands is separating domestic plastic waste, PMD, from residual waste. After collection, it is separated further into mono streams to bring these back in the circle. However, not all the plastics can be separated yet which results in one quarter of leftover mix fraction, consisting out of polyolefins of PE/PP and impurities. The composition and quality of the mix fluctuates which makes it a challenging material to work with. Half of the mix is still burned with energy recovery and half of the mix is recycled into new products. However, there still is variety of possibilities and challenges for implementing the mix into products.

The initial goal in this project was to develop a valuable product with the mix to show its potential value. It appeared that the mix was not processed with rotational moulding yet. By doing some tests with PO95 agglomerate, both with producing powder out of agglomerate and rotomoulding this powder, the potential of the material using rotational moulding has been proved. The characteristics of this material processed by rotomoulding are still unknown. The biggest challenge in further development is producing suitable powder out the agglomerate that is made by the recycler. The impurities are challenging, both in damaging the grinding system and constipating the sieves of the powdering machine. Besides the impurities, there is another challenge in finding the right additives for this material to improve the characteristics significantly.

Besides proving the potential of the leftover mix using rotomoulding, CirculEm has been developed. CirculEm is a small rain barrel, partially made out of the mix, that responds to two aspects regarding a circular economy. First, using waste as a resource, and secondly CirculEm responds to climate adaptation on a local level. The outside layer of the barrel is made out the mix that shows the expression of the recycled material. The inside layer of virgin PE provides strength and stiffness to the product. However, it is discussable to blend the mix with virgin material regarding to the end of life aspect of CirculEm. When characteristics are known, this multilayer construction could be optimised. The tap and the connection to the drain pipe are standardized components.

Research showed that products made out of the mix tell a good story. Combining ‘using waste as a resource’ with creating products that respond to other aspects that work towards a circular economy, like climate adaptation and energy transition, makes this story even stronger. Municipalities appear to be interested in products like these. The municipalities of Breda and Rotterdam, seem interested in CirculEm, because they are looking for solutions regarding water management on private area. CirculEm might be the missing link between municipalities and the commonality by starting the collaboration in tackling climate adaptation on private areas.

Samenvatting

Een samenvatting van het project

Nederland wil in 2050 circulair zijn. Een van de grootste uitdagingen hierbij is het terugbrengen van afval als een grondstof in de cirkel. Midwaste, een coöperatieve vereniging die afvalstromen reguleert is hierbij een zeer betrokken partij. Betreffende het kunststof dossier is Midwaste verantwoordelijk voor ongeveer 130 gemeenten in Nederland. Als opdrachtgever van dit project was de vraag vanuit hen om een waardevol 'sexy' product te creëren uit de overgebleven mix stroom van plastic verpakkingsafval uit huishoudens. Steeds meer gemeenten in Nederland scheiden plastic verpakkingsafval, PMD, van restafval. Na inzameling wordt de PMD fractie verder gescheiden in een fabriek in monostromen om deze terug te kunnen brengen in de industrie. Daarnaast blijft er ongeveer een kwart mix fractie over, bestaande uit polyolefinen van PE/PP en onzuiverheden. The samenstelling en de kwaliteit van de mix fluctueert wat het uitdagend materiaal maakt om mee te werken. Ongeveer de helft van de mix wordt verbrand met energie terug winst. De andere helft wordt verwerkt tot nieuwe producten. Er is echter nog een variëteit aan mogelijkheden en uitdagingen om de mix in producten te verwerken.

Het beoogde doel van dit project was het ontwikkelen van een waardevol product om op deze manier de potentiële waarde van het materiaal te laten zien. Uit dit onderzoek is gebleken dat de mix nog niet verwerkt wordt met rotatiegieten. Door het doen van testen met PO95 agglomeraat uit de mix, is de potentie van zowel het maken van poeder als het gieten daarvan bewezen. De eigenschappen van het materiaal verwerkt met rotatiegieten zijn echter nog onbekend. De grootste uitdaging in verder onderzoek, is het ontwikkelen van een geschikt poeder van het agglomeraat met de juiste vorm en eigenschappen. De onzuiverheden zijn een uitdaging, aangezien deze het maalwerk van de verpoedermachine kunnen beschadigen en de zeven hiervan kunnen verstoppen. Daarnaast is het een uitdaging om de juiste additieven te vinden zodat de kwaliteit het materiaal aanzienlijk verbeterd wordt.

Naast het bewijzen van de potentie van de mix in rotatiegieten, is CirculEm ontwikkeld. CirculEm is een kleine regenton gedeeltelijk gemaakt uit de mix die inspeelt op twee aspecten richting een circulaire economie. Enerzijds door het gebruik van plastic afval als grondstof en anderzijds doordat CirculEm inspeelt op klimaatadaptatie op lokaal niveau. De buitenlaag van de regenton is gemaakt van de mix kunststoffen waarbij de expressie van dit materiaal tot uiting komt. De binnenlaag van CirculEm is gemaakt van virgin PE om de sterkte en stijfheid van het product te garanderen. Het is echter discutabel om virgin plastic te mengen met de mix, kijkend naar de fase aan het einde van de levensduur. Als de eigenschappen van de mix bekend zijn, kan de multilaag constructie geoptimaliseerd worden. De kraan en de connectie naar de regenpijp zijn standaard onderdelen.

Dit onderzoek heeft tevens uitgewezen dat producten die gemaakt zijn uit de mix een goed verhaal vertellen. Het combineren van 'het gebruiken van afval als grondstof' en het ontwikkelen van een product dat inspeelt op andere aspecten richting een circulaire economie, zoals klimaatadaptatie en energietransitie, versterken tevens dit verhaal. Gemeenten lijken interesse te hebben in producten die zo een verhaal vertellen. Gemeente Breda en gemeente Rotterdam hebben beide interesse getoond in CirculEm. Zij zijn namelijk opzoek naar oplossingen die inspelen op water management op privaat terrein. CirculEm kan hierin de schakel zijn tussen gemeente en burger door het ijs te breken en het gesprek aan te gaan om samen te werken aan klimaatadaptatie op privaat terrein.

Acknowledgements

Who to thank

During this project, a lot of people have supported me. First, I would like to thank my supervisory team. Stefan van de Geer, the first professor of my studies and the chair of this project, thank you a lot for your patience and pulling me out of my comfort zone. You challenged me and made me rethink choices to see if these were sufficiently substantiated. Henk Crone, my mentor, thank you for the support during the summer, in which it was challenging to find the right parties for the test phase. You kept me focussed and hands on throughout the project. At last, Jurgen de Jong, my company mentor, who was willing to answer all my questions and connect me with the right people in the field of waste separation and recycling.

Besides my team, I would like to thank Pieter van 't Veer, CEO at Zweva, who made it possible to do tests with rotomoulding. Thank you a lot for sharing all your knowledge, taking the time to explain me everything and for inviting me to visit two of Zweva's factories in Belgium. On top of that, you were willing to continue this challenge within the innovation pilot together with Midwaste and me. I am very grateful for that.

Moreover, Jean-marc van Maren, from Cabka, thank you for guiding me in the beginning of the project by explaining a lot about how the recycling industry for mixed plastics works. During our phone calls you always took the time to explain details to me, which was very helpful. Besides that, I am thankful for the material donation of 1000kg to do the first powdering and rotomoulding tests.

From Midwaste, I would like to thank Machiel van Haaften. Thank you for your patience and your interest. We had inspiring talks during our travelling to Belgium. Besides that, I would like to thank Shekib Wakili, who arranged the transport of the material for me. Thank you for the nice talks during our travelling to Hubert Eing in Germany. Moreover, I would like to thank Valerie Petit for bringing the material to Zweva at Scheveningen.

Another thanks to Michael Sudhaus and Mechtild Ahuas for having me at their factory, guiding me around and sending samples and afterwards donating 1000 kg of material to do powdering tests on larger scale at Maag.

At last, I would like to thank my family. Not only for their support during my graduation project, but also for all the opportunities you gave me in this journey towards my graduation project. Secondly, my boyfriend and friends for the inspiring conversations, being patient with me and supporting me throughout my graduation project project.

Definitions and abbreviations

Definitions and abbreviations used throughout this report

Definitions

DKR Standards
Specifications established by Deutsche Gesellschaft für Kreislaufwirtschaft und Rohstoffe mbH (DKR), or comparable (www.dkr.de). For specifications regarding plastic flows this is specifically these specifics based on 'de Raamovereenkomst' seen as reuse.

Form
The mass of the shapes (Visser, de S., 2014).

Line
An actual or implied mark, path, mass or edge, where length is dominant (Visser, de S., 2014).

Melt flow index (MFI)
Melt flow index is a number that indicates the viscosity of a molten polymer at a particular temperature. In other words, it is a measure of its melt viscosity at that temperature (Crawford, R.J., 1992). It describes how fast the material flows in ten minutes through the capillary of the mould.

PMD / PBD
"Plastic, blik en drink pakken" which means plastic, tin-plate and drinking cartons. This is one of the waste streams that is collected besides glass, paper, electronic, organic and rest waste. PMD = PBD.

Shape
Any area bound by line, value or colour (Visser, de S., 2014).

Abbreviations

HDPE
High density polyethylene. The most common used plastic with rotational moulding.

LDPE
Low density polyethylene.

PE
Polyethylene. This is a common used abbreviation in which high or low density is not specified.

PET
Polyethylene terephthalate

PP
polypropelene

PMD / PBD
"Plastic, blik en drink pakken" which means plastic, tin-plate and drinking cartons

Process and report outline

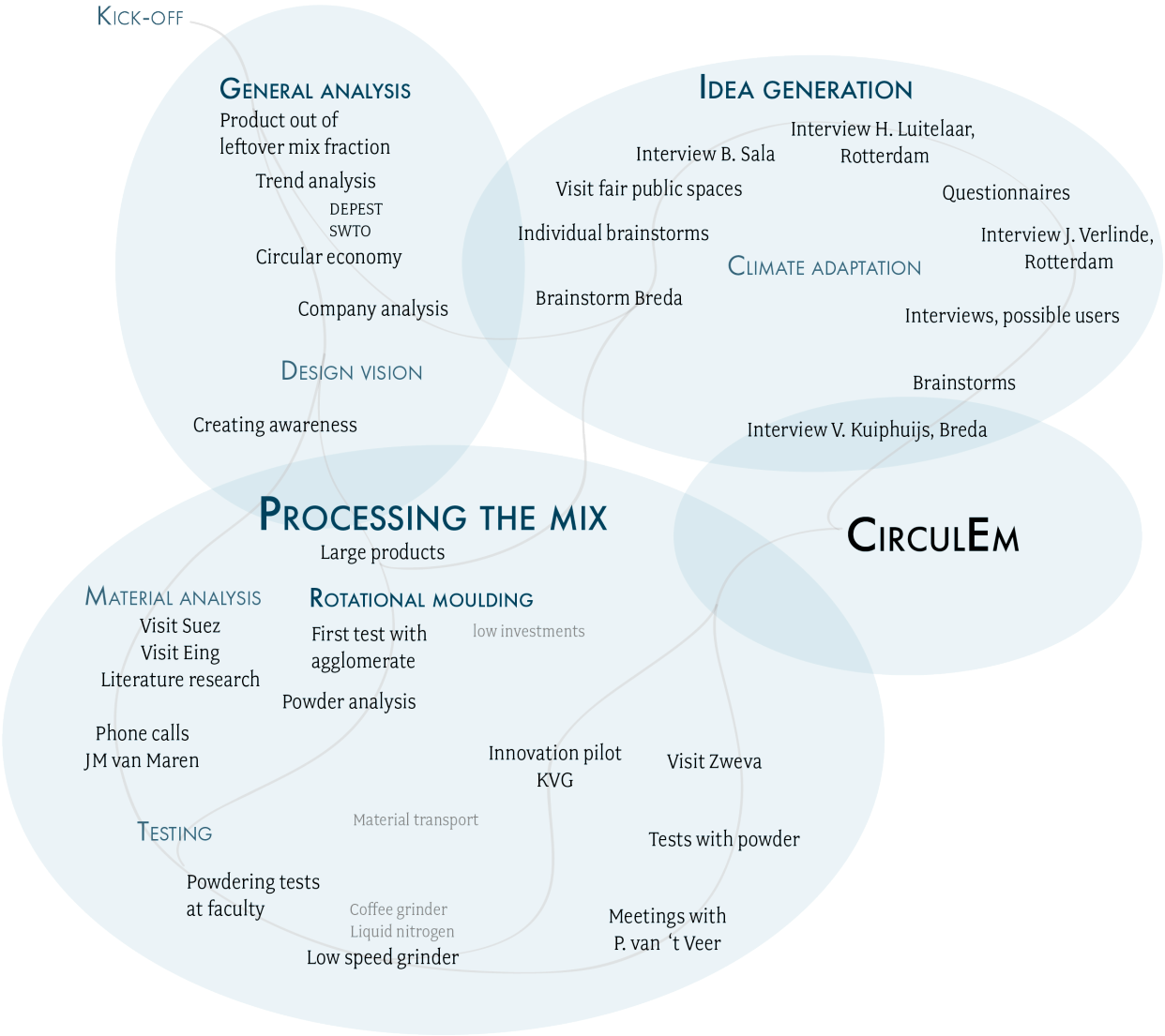
The structure of this report in combination with the process

In this section the process of this project is explained. This thesis report is a logic and relatively lineair. However, the process was far from lineair. Therefore this section will explain where to find what.

Where to find what

This report represents a summary of this project. In the flowchart, an impression of the process is presented. The general analysis is mostly described in chapter one. The idea generation phase is captured in chapter 3,4 and 5. The technique behind the processing of the mix is captured in chapter 2, 4 and 5.

Almost every paragraph of this report contains a box in which the most important insights are described. These insights provide both a summary and give good insight of the most important aspects taken out of that section.



1

Introduction

1.1 The world of plastics

An introduction of plastic in our society

This section provides a brief history of plastics and the role of plastic in our current world. An overview of the plastic demand in Europe is given and the role of plastic in waste streams is elaborated upon.

1.1.1 A brief history of plastic

Today, a world without plastics seems unimaginable. Yet, its large-scale production and use only dates back to around 1950. The first synthetic plastics, such as Bakelite, appeared in the early 20th century and until World War II, widespread use of plastics outside of the military did not occur (Geyer, Jambeck, and Lavender Law, 2017). The global production of resins and fibers increased from 2 mega tons (Mt) in 1950 to 380 Mt in 2015. The total amount of resins and fibers manufactured from 1950 through 2015 is 7800 Mt and half of this, 3800 Mt, was produced just in the last 13 years (Geyer, Jamback, and Lavender Law, 2006), shown in figure 1.1.

1.1.2 Plastic today

Currently, the largest market of plastics is packaging. In 2014 in Europe, 39.6% of the plastics have been used for packaging (see figure 1.2). In the Netherlands, this was 55.4% in 2013 (see figure 1.3) (Partners for innovation, 2015). Packaging is predominantly composed of polyethylene (PE), polypropelene (PP) and polyethylene terephthalate (PET) (PlasticEurope, 2015). The growth of this packaging market was accelerated by a global shift from reusable to single-use containers. The second largest market is the building and construction sector which covers 20.3% of the plastic use in Europa and 8.1% in the Netherlands.

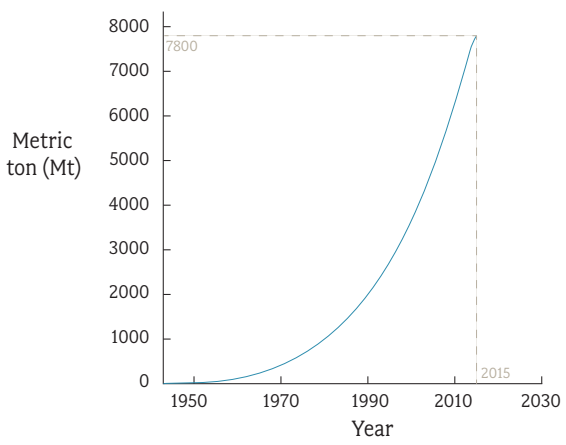


Figure 1.1 A schematic approach of the total production of resins and fibers till 2015. (Based on data of Geyer, Jamback, and Lavender Law, 2006).

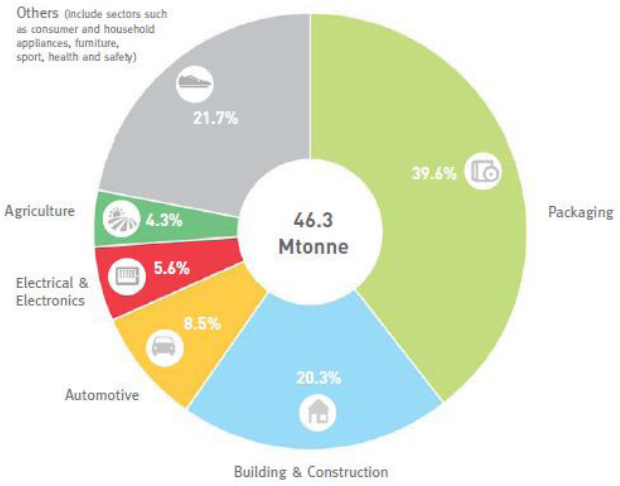


Figure 1.2 Plastic use in Europe in 2014 (PlasticEurope, 2014)

After the production and use phase, the plastics are disposed. From all these plastic products produced till now, approximately 600 Mt (9%) have been recycled so far and from the recycled plastics and moreover, only 10% was recycled more than once (Geyer, Jamback, and Lavender Law, 2017). Recycling plastic is less easy than most people are aware of. When plastic is recycled, the different types of plastics are separated into mono streams. These mono streams are used in new products. However, all

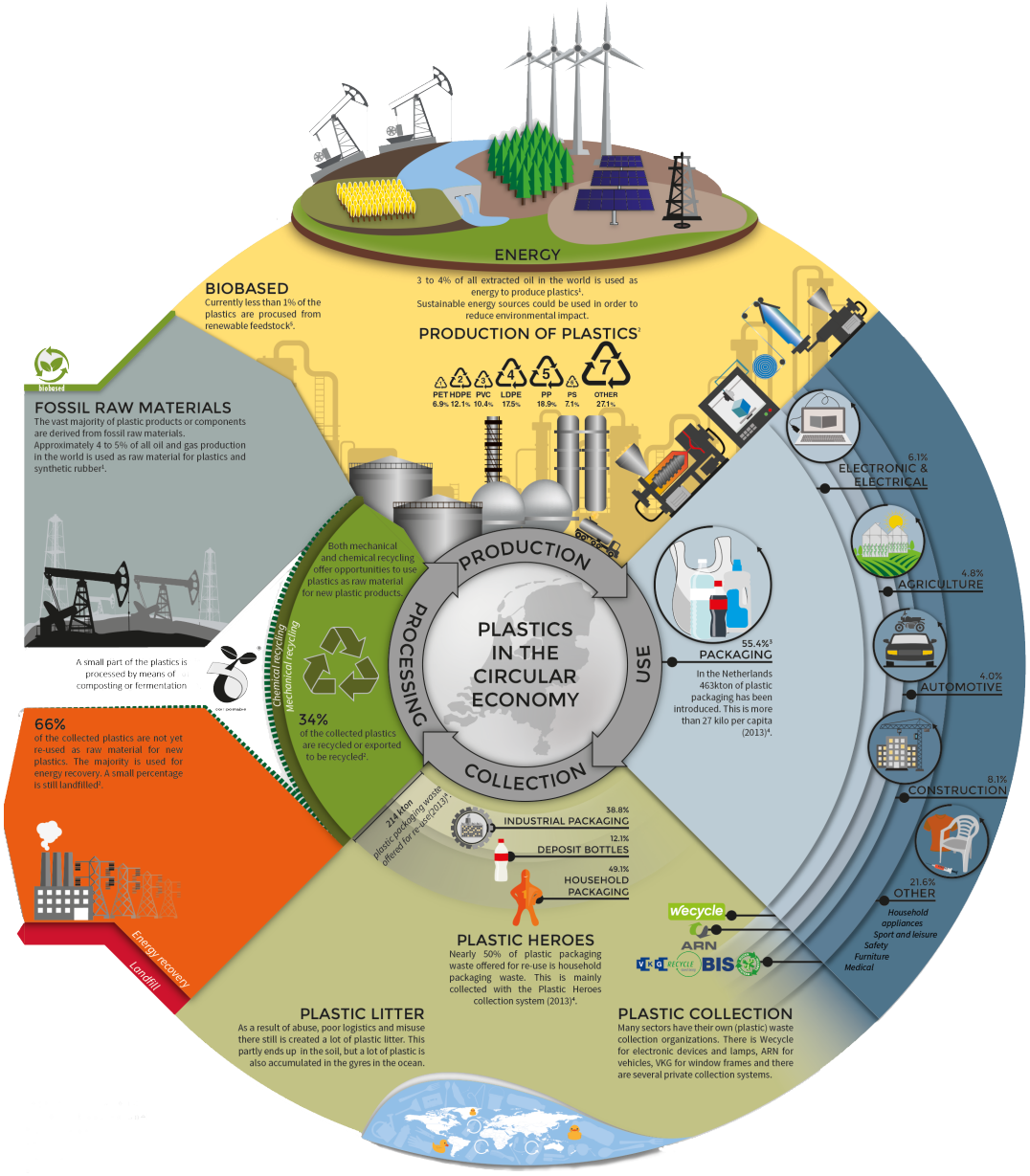


Figure 1.3 Plastic use in the Netherlands in 2013 (Partners for innovation, 2015)

these different types of plastics, all with unique material properties, are hard to split into mono streams. For instance; products with multiple particles are often made out of different types of plastic. The technology and especially its implementation (economically), is not developed far enough to split all kinds of plastics. This means that there currently still is a leftover of mixed plastics, which is barely used. This mix fraction is the focus of this project. This material will be described further in chapter 2.

Over the years, the demand for plastic is still increasing. Also, the demand for specific kinds of plastics is slightly shifting. As shown in the graph in figure 1.4, there is a slightly increasing demand for PET, PP and PE in the packaging industry in 2016 compared to 2013. The percentage for packaging compared to the total demand has slightly increased, from 39.6% to 39.9%. In 2016, 'Agriculture' and 'Household, Leisure & Sports' are added as categories, which might give a misleading view to a decreased demand in the 'Other' section.

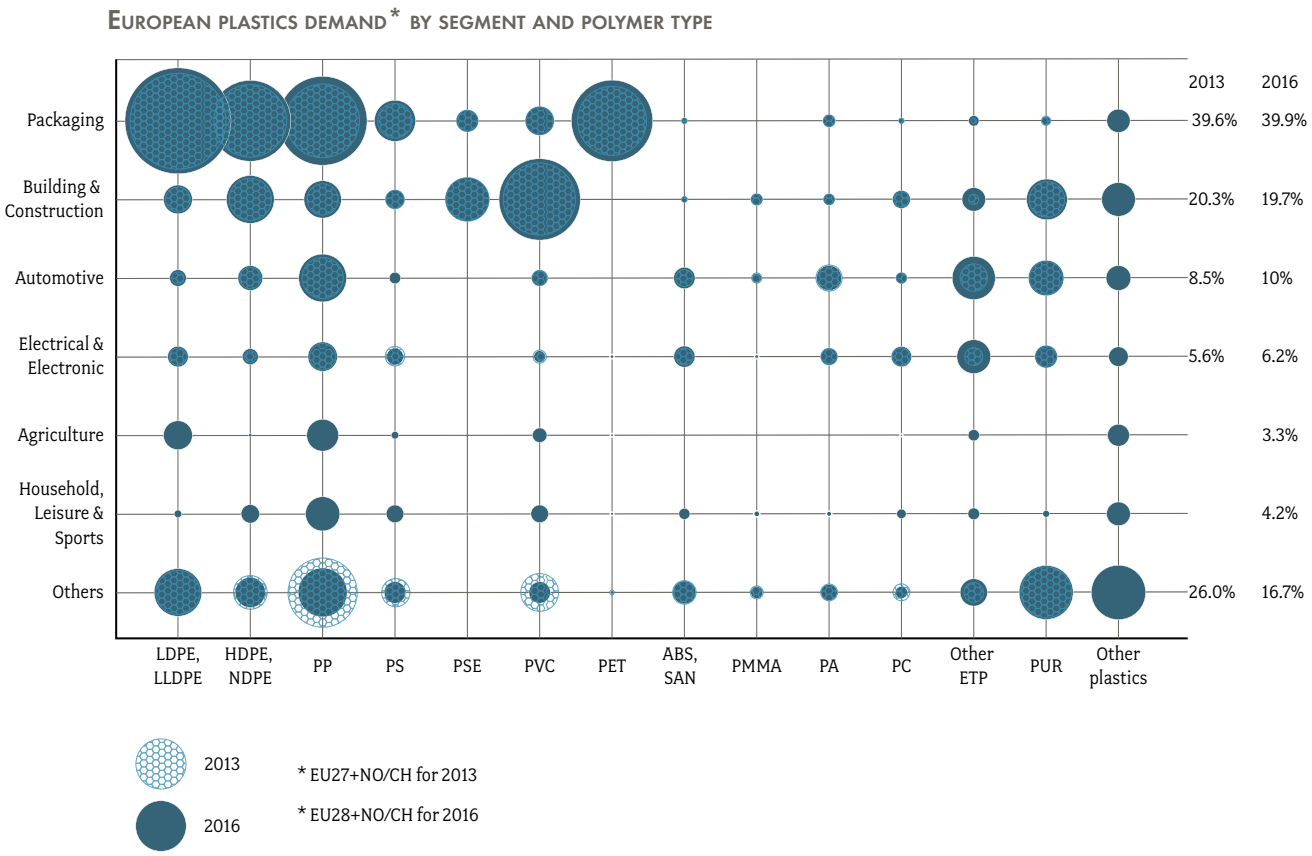


Figure 1.4 The plastic demand in Europe in different sectors in 2013 and 2016 (after PlasticsEurope (PEMRG / Consultic / ECEBD)

1.1.3 Plastic packaging in domestic waste

As mentioned before, domestic waste is separated in the Netherlands into: glass, paper/cardboard, organic waste, textile, small chemical waste (KCA), electronical equipment, PBD waste and residual waste (Rijkswaterstaat, 2016). However, not everyone is separating (correctly) yet. The residual waste is analysed (by sorting manually), which is shown in figure 1.5. There is still 15% unsorted plastic and 1% drinks cartons in the residual waste, which means there is a lot of room for improvement, since these percentages are based on the total weight (and not volume) and plastics are relatively lightweight.

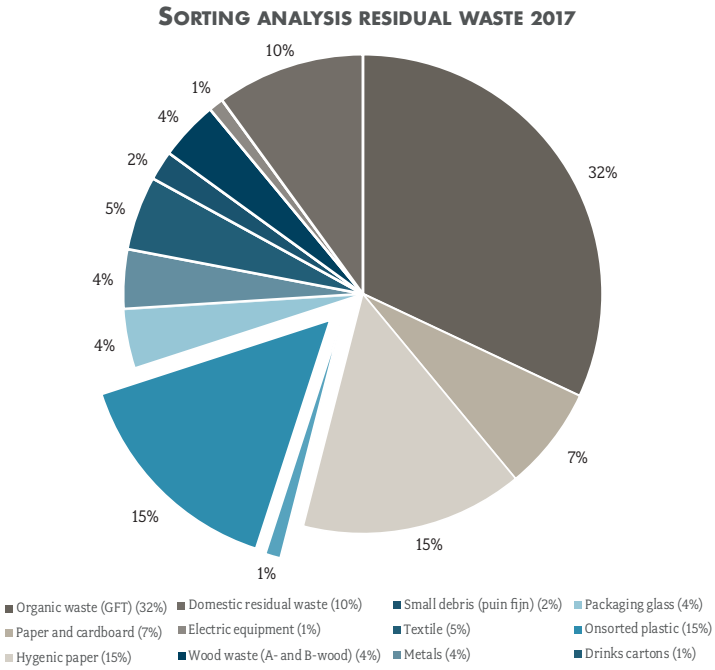


Figure 1.5 Sorting analysis of residual waste in the Netherlands in 2017, expressed in weight percentages (Midwaste, 2018).

1.1.4 Product study

An increasing amount of products are made out of recycled plastics, like public furniture, eco grids and in public play sets. A brief overview of products that are made out of (recycled) plastics are shown in figure 1.6.

This figure contains four categories. The first category is plastic products made from virgin plastics, by far the largest category. Think of (food-) packaging, toothbrushes, medical products, vacuum cleaners, car parts, construction materials, etc.

The second category represents products made from the recycled plastic mono streams. These

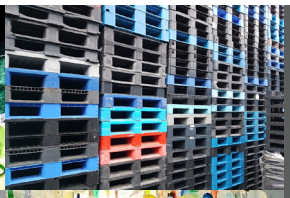
Plastic products

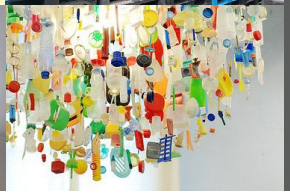
Products made out of virgin plastics

More than you can imagine

Products made out of mono streams from recycled plastic

More and more initiatives





Reusing or made by reusing plastics

Mostly out of plastic bottles and plastic bags
Pallets are reused and reselled repeatedly

Products madeout a leftover mix of plastics

Mostly non-attractive construction materials

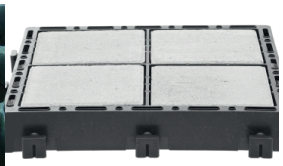


Figure 1.6 A brief overview of plastic products in different recycling catagories

monostreams are processed again into products. This quality is as good as products made out of virgin plastics. An example are the "Pod Chairs" of Benjamin Hubert made from PET bottles. Elho made a watering can out of the mono streams domestic waste (SUEZ, 2018). Another example is the stroller of Greentom. The fabric is made from PET and the frame from recycled PP.
However, this recycled monostream is often mixed with virgin plastics and moreover, a lot of products consist out of more parts from which only one part is made out of recycled plastic.

In the third category, plastic products are reused and given a new life by the user of the initial product. For instance, a food house for birds. Also refill a plastic bottle is a form of reuse. Plastics pallets are reused a lot and sold and resold. Pawel Grunert made a chair, literally out of plastic bottles for the "Eco Trans Top" exhibition at the Colombari Gallery in Milan, Italy (Yodena, 2012).

The fourth and last category is about products that are made out of the left over mix of plastics. For instance, street furniture, play sets, flooring, eco grids and roadside poles. These products are also often mixed with virgin and often aesthetically unappealing. An aesthetically more appealing initiative is the ocean sneaker from Adidas which is made out of different kinds of recycled materials out of plastics from the ocean (McAlone, 2016). Another interesting initiative is "The Blocker", by Gregor Gomory, CEO from ByFusion. This brick is made out of plastic waste out of the ocean and saves 95% greenhouse gas emissions, compared to concrete bricks (ByFusion, 2018). These bricks are plastered after placement. The plastic recycling industry is booming, but there is still a lot of room for improvement, foreseeing a circular economy.

Insights

It is almost impossible to think about a society without plastics. However, things have to change in how plastics are produced, used, reused and recycled.

There is already a lot happening in this world of plastic recycling. New developments about regulations, new products and new policies within companies are released in press almost every day. So, the relevance of this project is very clear.

More and more products are made out of recycled plastics, but the leftover mix fraction is a tough one. Most products made out the mix fraction are injection moulded or extruded into bulky products.

Circular Economy 1.2

More than recycling

In this section, the definition of circular economy is elaborated upon. Moreover, an introduction is given how to contribute to a circular economy model into designing by explaining a framework.

1.2.1 What is a circular economy?

The Netherlands aims to be completely circular in 2050 and the government strives for a decrease of 50% of raw (virgin) material usage in 2030 (Rijksoverheid, 2016).

But, what is a circular economy? According Van den Berg and Bakker (2015) a circular economy describes a model of a closing material loops in an economically attractive way to decouple wealth from resource usage. This circular economy model focuses on the challenges of the current world population where the consumption is growing. This is leading to unsustainable usage of finite resources with increased price volatility and higher prices. This model is based on five principles that is inspired by natural systems:

- Design out of waste
- Build resilience through diversity
- Shift to renewable energy sources
- Think in systems
- Think in cascades, a lot of small actions make a big difference.

(Ellen MacArthur Foundation, 2012)

A major aspect to achieve a circular economy is recycling. Recycling means "any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purpose. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into material that are to be used as fuels or for backfilling operations" (NKR Recycling, 2018).

However, recycling can be done in many ways and can be captured into four categories, presented in figure 1.7; longer use of products, reuse of products with maintenance, reuse parts by remaking products and reuse of materials by disassembly and recycling. The collection part where waste is burned with energy recovery and put to landfill are not part of recycling. These components have to be eliminated to be completely circular, if it is not composable by nature.

For the recycling loops; the bigger the loop, the bigger the required action. In the first place, we can use products longer before disposing it. The second loop is about maintenance, where you bring it back to the sales or service provider to replace a broken component. Remanufacturing is similar as maintenance, but then the product goes back one party further; the manufacturer, where the product can also be completely rebuild. In the last loop the product is brought back to raw materials.

The 'longer use phase' of the cycle, is important in this project regarding the design, since the mix fraction is hard to recycle. The recycling phase is the cycle of action in this project.

To work towards a circular economy, there are three major themes; waste as a resource, climate adaptation and energy transition.

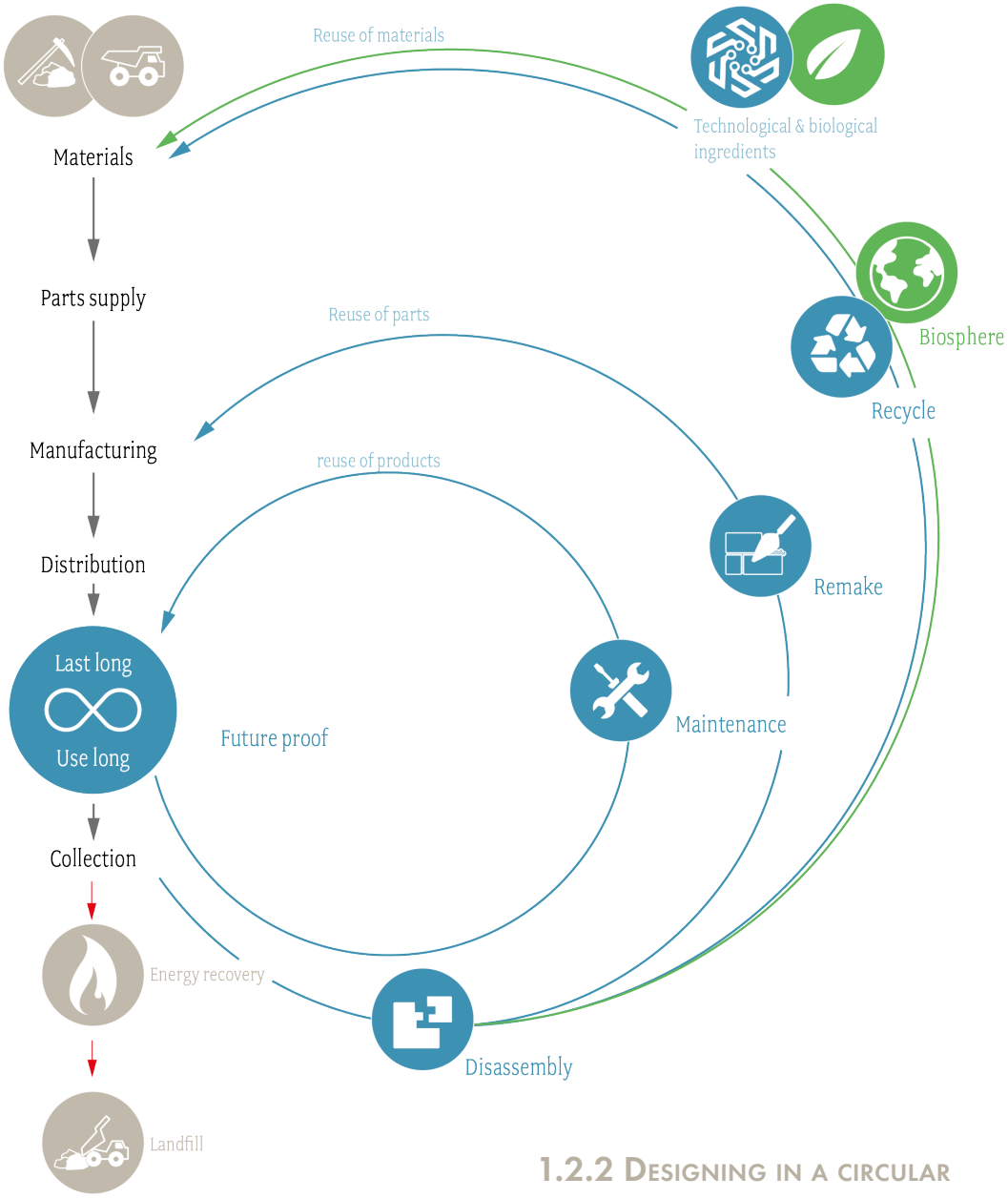


Figure 1.7 Circular product design framework (After van den Berg, and Bakker, 2015).

1.2.2 Designing in a circular economy

In a circular economy, products need to be designed circular, but what is exactly circular design?
"Circular design, in other words, the improvements in material and product design (standardisation and modularisation of components, purer material flows, and design for easier disassembly)" (Ellen MacArthur foundation, 2012).

"Circular product design: Elevates design to a systems level (1), strives to maintain product integrity (2), is about cycling at a different pace (3), explores new relationships and experiences with products (4), and is driven by different business models (5)" (Bakker, Hollander, van Hinte, and Zijlstra, 2014).

Insights

Looking into developing a circular product, processing and the time of usage are important aspects to take into account. Moreover, the 'end of life' aspect also should be considered.

MIDWASTE 1.3

AN INTRODUCTION OF THE COMPANY INVOLVED IN THIS PROJECT

In this section, Midwaste is introduced in what they do and which phases of the chain they cover. Afterwards, an overview of the members, partners and stakeholders of Midwaste are given. At last, the stakeholders involed in this project are described.

1.3.1 INTRODUCTION

An important party in the Netherlands which contributes to a circular economy by regulating waste is Midwaste, located in Delft. Midwaste, founded in 2001, is a non-profit cooperative association, existing out of thirteen garbage and cleaning companies. They work in all kinds of waste sectors; glass, paper, textile, wood, electronics, small chemical waste, industrial waste and PMD (plastics, tin and paper drinks cartons). Midwaste covers around 130 municipalities, which means 2.3 million households, in the Netherlands in plastic waste, for which they do the transshipment, transfer, storage, splitting and marketing of these materials (Midwaste.nl, 2017). In this project, the focus is on the highlighted mix fraction of plastics from which the collecting, sorting and processing flowchart is shown in figure 1.8. The assignment is discussed in paragraph 1.5.

The plastic waste is collected by municipalities and arrives at Midwaste, where they do a first selection of the waste. In this stage, there is a loss of around 3% from waste that is disapproved (Midwaste, 2018). Since June 2017, these selection criteria became more strict, so Midwaste expects that this amount will increase. The residue of this selection (25%) is brought to a energy recovery burning installation.

The PBD is brought to sorting companies where it is split and sorted into different kind of plastics. From here the different materials are sold to processing companies, making new agglomerates out of the plastics. Besides the mono streams, Midwaste also ends up with a mix fraction of 24% (in 2017). From this mix fraction with DKR 350 standard specifications*, new agglomerate is

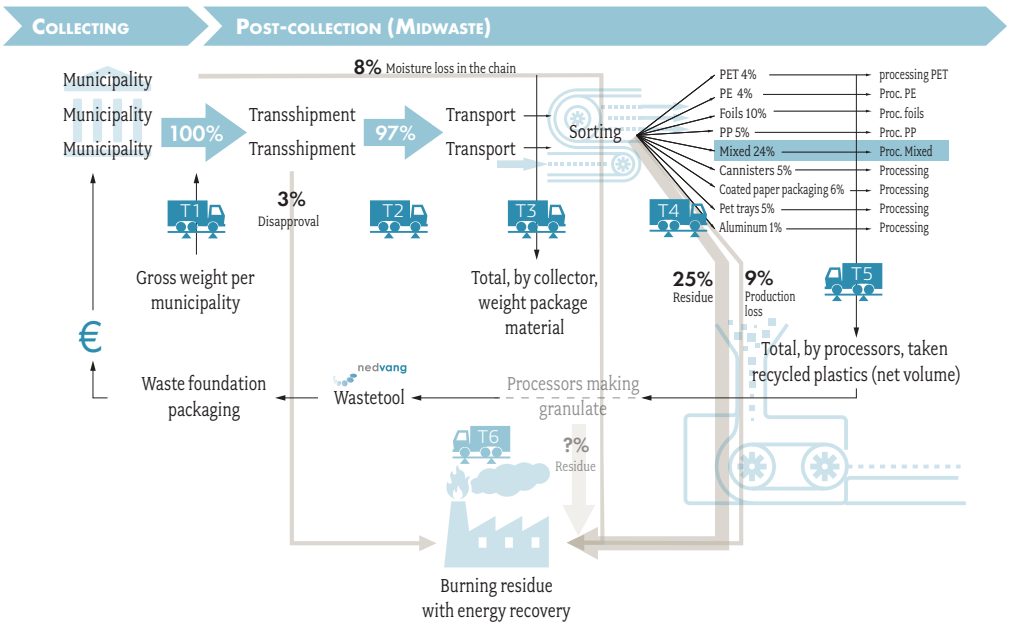


Figure 1.8 Flowchart of domestic waste, controlled by Midwaste (After Midwaste, 2017) The percentages are from 2017
** see list of definitions*

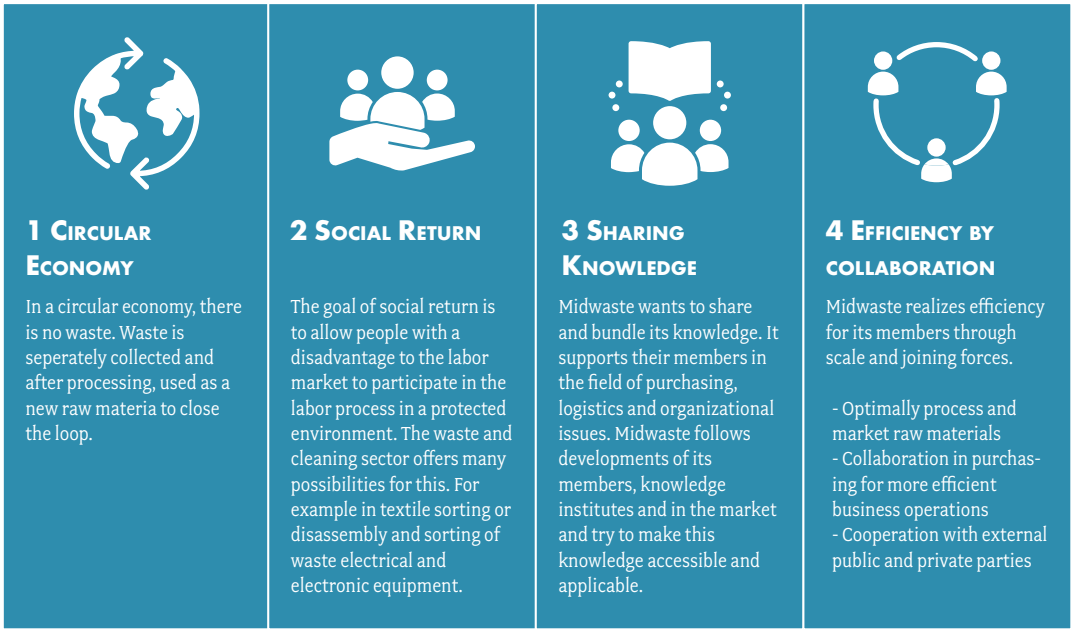


Figure 1.9 The four pillars of Midwaste; circular economy, social return, sharing knowledge, efficiency by collaboration (After Midwaste, 2017)

developed to make products. This DKR standard is a standard that gives quality requirements on the material.
Currently, there is a residue in every step. In a circular economy, this residu has to be tackled as well.

Midwaste has four pillars driving them in decision making and in their strategy. These pillars are; circular economy, social return, sharing knowledge and efficiency by collaboration to upscale so more waste is regulated correctly (Midwaste.nl, 2017). In figure 1.9, these pillars are shown and explained.

1.3.2 Stakeholders of Midwaste

Midwaste, as any other company or association, has its own stakeholders. To define these stakeholders and get an overview of their role, the stakeholder circle methodology is used (Bourne, 2006). These stakeholders are shown in figure 1.10 and described below.

Checking and monitoring

First, Midwaste is checked by the supervisory board (Raad van Toezicht). Secondly, there is the framework agreement (raamovereenkomst) among the Ministry of Infrastructure and Environment, the waste foundation of packaging (Afvalfonds verpakkingen) and VNG (Vereniging van Nederlandse Gemeenten); association of Dutch municipalities. This agreement concerns glass, paper and cardboard, metal and plastic waste. VNG also checks Midwaste (Raamovereenkomst, 2012). Nedvang, besides the supervisory board, is checking Midwaste by monitoring and registering the amounts of waste.

Members

The members are the closest stakeholders of Midwaste and without the members, Midwaste would not exist. As mentioned before, Midwaste is a cooperative association with thirteen members. These members are located all over the country, shown in figure 1.13. These members are both waste collecting companies and some municipalities that have their own waste collection system.

Together with these members, waste is collected all over the Netherlands and Midwaste provides them with advice in purchasing by determining the strategy together with the members to optimise and professionalise this purchasing process (Midwaste.nl, 2017). The members individually do not have the power to 'kill' Midwaste, but together, they have.

Partners

The partners afterwards contribute in the collaboration in sorting and processing PMD waste and in optimizing this process. Midwaste works together with companies that sort the plastics or/and process the mix fractions to granulate. If the mix fractions are brought to their partners, Midwaste is no longer responsible. Besides the processing and sorting companies, Midwaste also

Figure 1.10 The stakeholders of Midwaste; the members, partners, municipalities and citizens. The radial surface means the involvement of the party. The closer the it gets to the center, the more inluence they have and the power to kill Midwaste.
*Ministry of Infrastructure and Environment (Ministerie van Infrastructuur en Milieu)

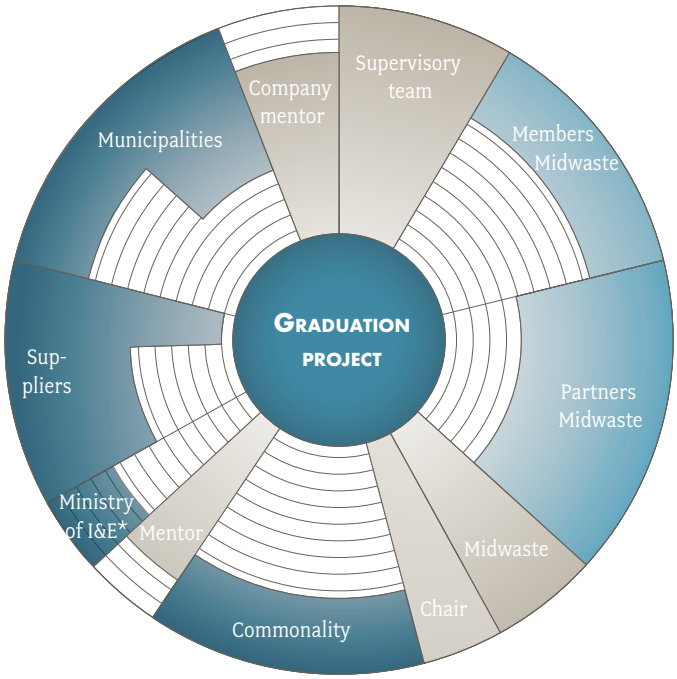


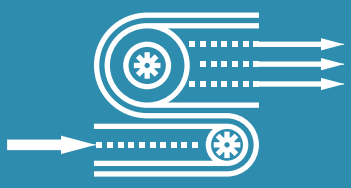
Figure 1.11 The stakeholders of this project. The radial surface means the involvement of the party. The closer the it gets to the center, the more inluence they have and the power to kill the project.
*Ministry of Infrastructure and Environment (Ministerie van Infrastructuur en Milieu)

had a partnership with HVC for the PBD waste. HVC is a non comercial waste collection company which also produces sustainable energy (hvc.nl,2018). HVC is responsible for 30% of the plastic input and together with Midwaste they cover 130 municipalities.

The sorting and processing companies of Midwaste which are partners in the plastic industry are listed in figure 1.12. Most of their processing partners are located in Germany. Recently, Omrin, HVC and Midwaste opened a new sorting line (KSI; kunststof sorteer instalatie) in the north of the Netherlands. This KSI line is still optimising their process, but will be completely running soon in which they process up to 65 kton (kiloton) PBD (afvalgids, 2016; Midwaste, 2018). In 2017, the leftover mix that was processed was 25.3 kton.

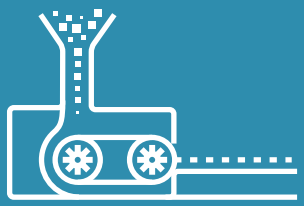
Municipalities and commonality

Besides the partners, there are municipalities and the commonality which are the core of the existence. From the connected municipalities, the commonality produce waste which needs to be dealt with. The municipalities collect this waste and from there, Midwaste is responsible for this waste.



Sorting companies

Augustin GmbH
SUEZ Rotterdam
SUEZ West GmbH



Processing companies

Borchers kreilaufwirtschaft
Cabka GmbH & Co. KG Eifel
Hubert Eing Kunststoffen-verwertung GmbH
PURUS PLASTICS GmbH
Relux Recycling GmbH & Co. KG
Hahn Kunststoffe GmbH

Figure 1.12 Sorting and processing companies, connected with Midwaste.

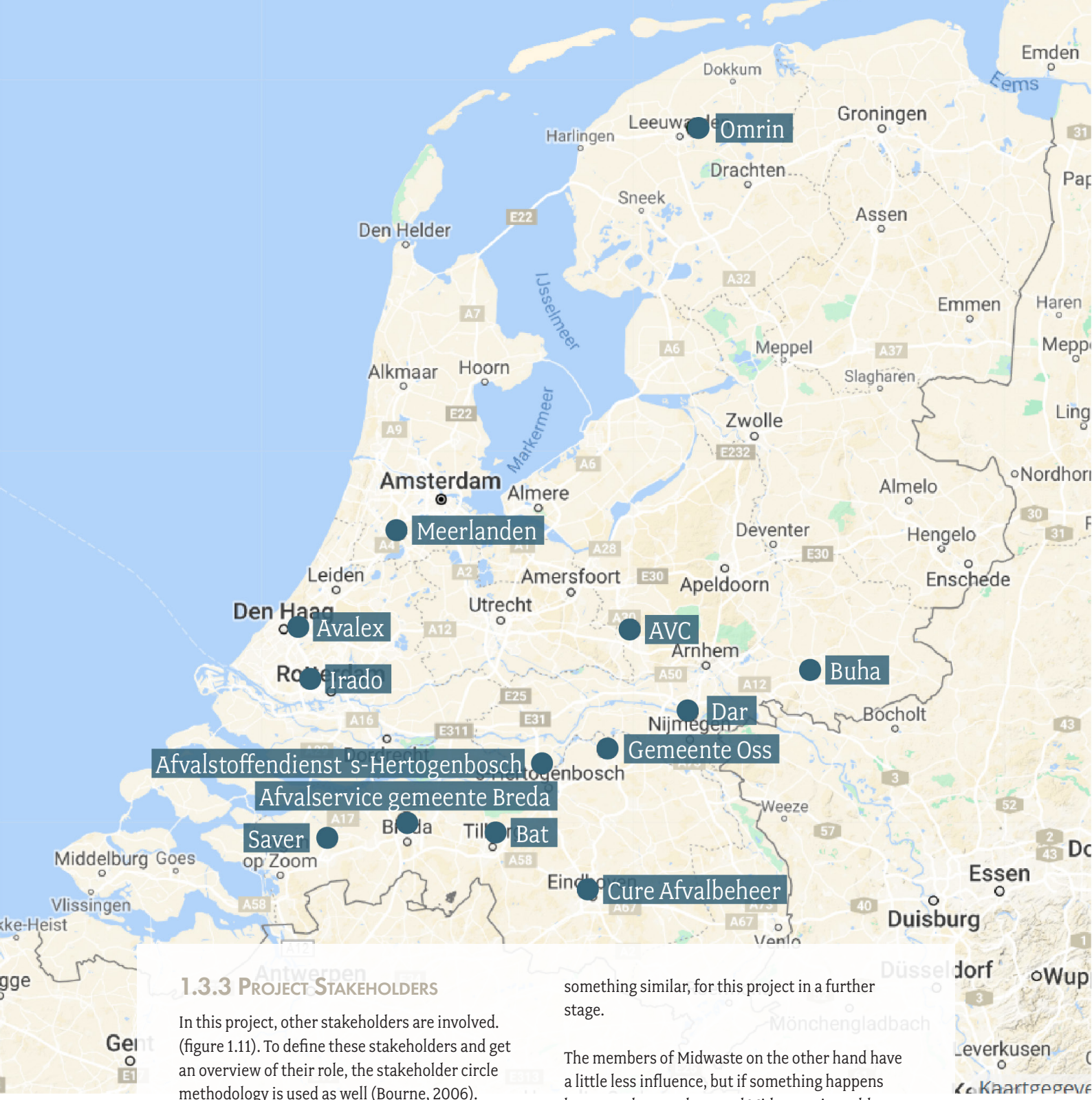


Figure 1.13 The members of Midwaste, located all over the Netherlands

1.3.3 Project Stakeholders

In this project, other stakeholders are involved. (figure 1.11). To define these stakeholders and get an overview of their role, the stakeholder circle methodology is used as well (Bourne, 2006).

In the middle of the circle, the project is located. The stakeholders that have the power to kill this project are the company Midwaste, the supervisory team and the chair; who is also part of the supervisory team. The company mentor and the mentor, as individuals, do not have this power, but together with the supervisory team they have. The chair, the mentor and the company mentor, also together in the supervisory team are closely involved into this project.

The partners of Midwaste are also involved since they might help developing prototypes, or something similar, for this project in a further stage.

The members of Midwaste on the other hand have a little less influence, but if something happens between the members and Midwaste, it could influence the project.

Then, there are the municipalities which could have an influence since they are possible buyers of the product. Thereby, the commontality is also involved into this project. since they are possible users.

At last, there are the suppliers who also influence this project in prototyping phases, with delevering material.

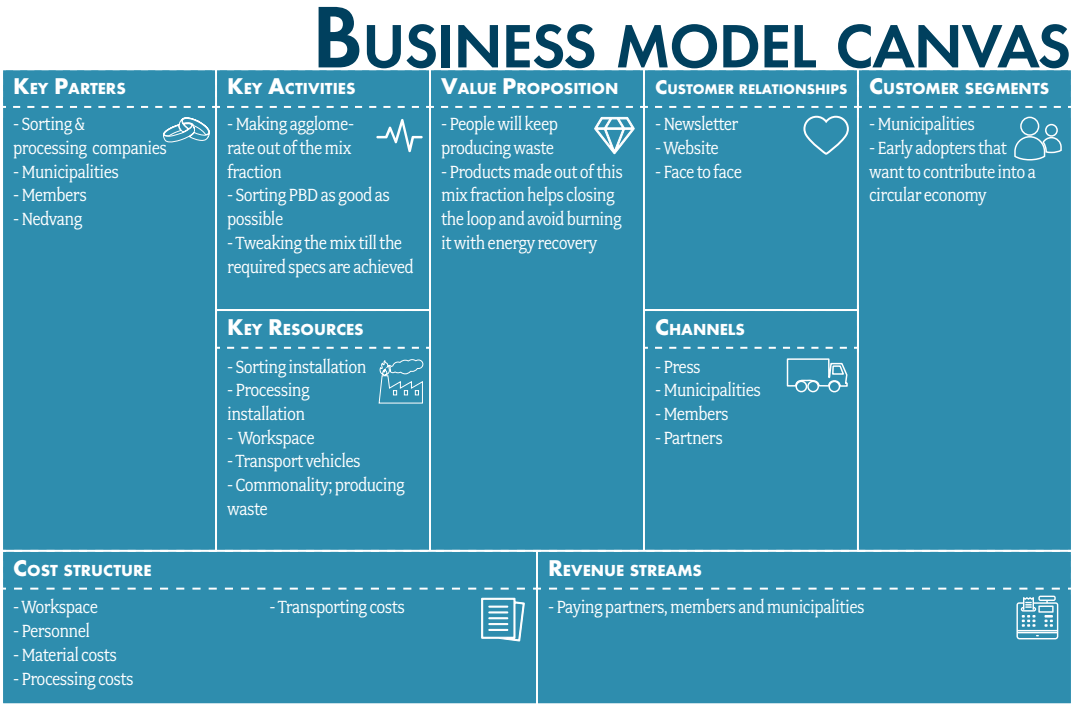


Figure 1.14 Business model canvas of Midwaste regarding the plastic waste stream

1.3.4 Business model canvas

To get a better idea of the core business of Midwaste in the plastic waste industry, a business model canvas is made (figure 1.14). This canvas provides an overview of different aspects of Midwaste, regarding the plastic waste stream. This canvas also shows that making products with the left over mix fraction, which is the assignment in this project, is out of their scope.

1.3.5 Products of Midwaste

Currently, Midwaste already did some projects with product developments made out of recycled plastics. For instance, together with Cedo, they developed garbage bags which they sell to municipalities. This is made out of the mono stream of foils. Secondly, together with QCP and ELHO, they made a watering can. Also, this is made out of a mono stream.

So far, Midwaste only did a development project with the mix fraction together with Cabka to make grids to put in stones or grass to strengthen the soil. Therefore, the possibilities of the mix fractions are interesting to look at.

Insights

Midwaste mainly focuses on getting the waste streams at the right spot, where it can be processed further. This project assignment helps optimising this process by giving them insight in how the left over mix can be processed.

Midwaste has very interesting connections with, among other, municpalities to create a market for this project.

Since they cover 2.3 households in the Netherlands, this project could have a significant reach.

1.4 Trendanalysis

DEPEST and SWTO analysis

In this section, a trend analysis is done after which these are clustered into macro trends. Moreover, these trends are used to get a better insight of the strength, weaknesses, threats and opportunities of the mix fraction against virgin material.

1.4.1 The scope of the trendanalysis

The scope of this Strength, Weaknesses, Threats and Opportunities analysis is about the mix fraction, compared to virgin plastics. What is the difference between virgin plastics and mix fractions in the recycling industry, working towards a circular economy. Besides that, there is the DEPEST trend analysis which focuses on general trends.

1.4.2 DEPEST trends

To get an overview of trends in different fields, a DEPEST analysis is done (Toolshero.com, 2018); looking into demographical, ecological, political, economical, social and technological trends. An overview of these trends is given in figure 1.15. Clustering these trends, these are roughly dividable into three macro trends;

- Climate change
- Healthy lifestyle and human empowerment
- Growing worldpopulation and urbanisation

These trends and correlating developments are described later in this paragraph.

Besides these macro trends, there are some unclustered trends worth mentioning. Firstly, the EU probably will come up with stricter regulation regarding single use plastics (Vmt.nl, 2018). The European Parlement already voted to ban plastic cutlery, straws and cotton swabs from 2021 (nos.nl, 2018). Unfortunately, there is still a lack of knowledge regarding the long term consequences of plastic.

On a social level there is still an increase of plastic use, but there is an increasing awareness among people of the influence of plastics (CBS, 2016, PWV.nl, 2018).
There is a growing amount of initiatives to clean up the ocean, for instance; plastic whale, 4Ocean and Ocean Cleanup.

The attitude towards recycled products is changing. There is an increasing amount of people that prefer products with recycled material. It is no longer a shame to show that products are made of recycled materials and irregularities and imperfections are a good thing.

Climate change

The climate change is definitely is a hot topic in the news nowadays. In the Netherlands, it is prospected that rain will increase and also its intensity, and on the other hand there will be more extremely dry periods (KNMI, 2018).
The sea level is rising and sweet water could become scarce (IPCC,2007). The CO_2 emission needs to decrease globally and durable, sustainable and clean energy sources are needed. In this trend, circular economy is a returning term. Urban mining and seeing waste as a resource are part of the new mindset.

Human empowerment and healthy lifestyle

Besides the climate change, human empowerment is still the future; individualism is still growing (trendwatching.com, 2018). People have the urge for personalising which results in an increasing

Figure 1.15 Depest trend analysis; demografical, ecological, political, economical, social and technological

amount of customisable products and services, both in expression and in function(s). One size fits all does not longer exist.
On the other hand, possession is shifting towards an experience and people are sharing more (sharing is caring). The leasing business is becoming more popular instead of buying (marketplaceplatform.com, 2018).

Being in control is another aspect in human empowerment that also complements the urge for customisable products. Modularity is one of the terms to think of. For the control part, think of words like fake news, data, privacy and feeling safe.

Then, there is the healthy part of this trend where people control their body. People are exercising more than ever and more people become vegetarian (also for environmental impact reasons) (volksgezondheidenzorg.info, 2018; medihelp-assistance.com, 2018). This exercising can done collectively and in public spaces. Doing this collectively could motivate people.

Strengths	Weaknesses	Threats	Opportunities
- Cheap - Fitting in a circular economy - Fancy to say it is recycled plastic (for customers) - Last long - Possibilities to adapt specifications - Lot of material available	- More difficult to process - ' Ugly' colour - Not homogene - Hard to 'sell' to companies - Grove surface finishing - It smells, also after processing - Vulnerable for sunlight	- Mix might be sorted further so material becomes unavailable - Processing could be more expensive than virgin plastics	- Substituting expensive virgin plastics - Substituting construction like materials as wood and concrete - Making a product that ' needs' the 'ugly' colour - Products without a fine surface finishing - Durable products

Figure 1.16 Strengths, weaknesses, threats and opportunities of the mix fraction compared to virgin plastics.

Growing world population and urbanization

The last macro trend considered important is the still growing world population. Moreover, people have higher life expectations. Older people, more than younger people, have problems with stability and walking and prefer having the option to sit down often in public areas.

For the growing world population, resources are needed, so the demand for resources and products are rising. This currently also results in more waste.

Besides the growing population, people are also still moving towards cities, mostly to find work (Populationmatters.org, 2018). Highrise is a solution to give all these people a place to live. On the other hand, in this high rise buildings, waste management is hard (verenigingafvalbedrijven.nl, 2017). Houses will get smaller which could make shared public areas more important (hypotheker.nl, 2018). People work hard and people are dealing with a lot of stress nowadays. In their free time, space for recreation is popular.

Insights

The trends are important to combine to get to a meaningful design. Energy transition or climate adaptations are themes of a circular economy and could add value to the product.

The substitution of the mix fraction for wood or concrete could be interesting and the expression of recycled material is something which can be used as an advantage.

The threat of the mix is that virgin plastics that are often cheaper, due to the processing costs. Looking into posibilities how to compete with virgin plastic is important.

1.4.3 Strengths, weaknesses, threats and opportunities

Besides these trends, an overview of the strengths, weaknesses, threats and opportunities is made for the mix fraction, compared to virgin plastics (figure 1.16). The most interesting part are the opportunities, which are; substituting virgin plastics, wood or concrete and using it as a construction material. Besides that, it could be an opportunity to use the expression of the material instead of seeing it as ugly, which is a weakness.

A combination of trends is an important step to come to a meaningful product. This combination of trends could be summarised in macro trends and these can be combined. Combining the design of the product with other themes towards a circular economy, energy transition and climate adaptation, could be valuable.

Assignment 1.5

An explanation of the project assignment

In this paragraph the project assignment is explained. A problem definition will explain the relevance of the project. Afterwards, the assignment that follows from this problem definition will be described.

1.5.1 Introduction

The Netherlands is aiming to become circular in 2050 (Dijksma, Sharon A.M.Kamp, H.G.J., 2016). Therefore, among other things, waste is separated more and more. Plastic, tin-plate and paper drink bottles called PBD (Plastic, blik en drinkpakken) or PMD (Plastic, metaal en drinkpakken) is one of this waste streams. This stream is collected and sorted further. Besides mono streams of plastics, there is still a leftover mix fraction which cannot be split further yet. In this project, a research is done through the possibilities of this material and by the use of this knowledge, a product is designed with this material.
Therefore, a problem definition has been defined after which the assignment is briefly formulated. The full assignment, in which among others the approach is discussed, can be found in appendix A.

1.5.2 Problem definition

The problem consists out of a business part and a technology part which are described below.

- Out of plastic waste, different plastics are split into (nearly) raw material again and sold to suppliers. However, Midwaste ends up with a mix of materials that cannot be split further (yet). Midwaste has to pay almost €200,- per ton at the recycler, in which a lack of demand plays a major role. Currently, recyclers retrieve the usable parts and leave a rest part that is burned (preferably with energy recovery). Midwaste would like to show suppliers the value of this leftover mix, by searching for new applications. They are looking for a product which shows the potential of this material.
- The properties of this mix of materials fluctuate, resulting in an unstable material from which it is harder to control the quality. The mix still has specification requirements, but there is still a lot unknown in processing this material. Additionally, it is not as easy to process as a pure material. There is a field of tension field between designing a product which does not require high material properties and designing a product that is smart and visually attractive.

1.5.3 Assignment

This project is a research of the possibilities of making products out of this mix of plastics, with at least the DKR 350 standard*. Therefore the material itself and the possible production methods will be researched.
Moreover, a smart and aesthetically appealing product will be designed for municipalities. This product has to show the partners of Midwaste, the potential value of this material; a showcase product for Midwaste.

* See list of definitions

2

TECHNOLOGY

2.1 Separation techniques

Separation techniques in both in PMD waste and during making agglomerate

In this section the techniques to sort PMD waste and techniques to process the bales into agglomerate are briefly explained. The extensive description from both separation and processing can be found in appendix B1.

2.1.1 Introduction

Separation of plastic or packaging waste, can be done in different stages, as can be seen in figure 2.1. Separation at home is called source separation and separation in a factory after collecting is called post separation. Company waste is directly going to a recycling industry. Domestic waste is separated first before going to a recycling company.

2.1.2 Separation techniques

In figure 2.2, the techniques that are used to separate the plastics, both at the sorting companies and the processing companies, are shown. There is some overlap in techniques used in both sorting and processing companies, but gives an overview of the available existing techniques. In figure 2.3, the flowchart in how these techniques follow up is shown, including a schematic working principle of the technique itself. The extensive description of these separation techniques are described in appendix B1.

Mechanical and chemical separation

There are two main different separation techniques: mechanical and chemical separation. Currently, the majority of the techniques are based on mechanical separation.

Mechanical

There are several methods to separate packaging material mechanically. In a later stage, mechanical separation is also used to separate different kinds of plastics. These mechanical methods can be divided into six sub groups: cleaning, fragmentation, size, weight, magnetism and optical separation, shown in figure 2.2.

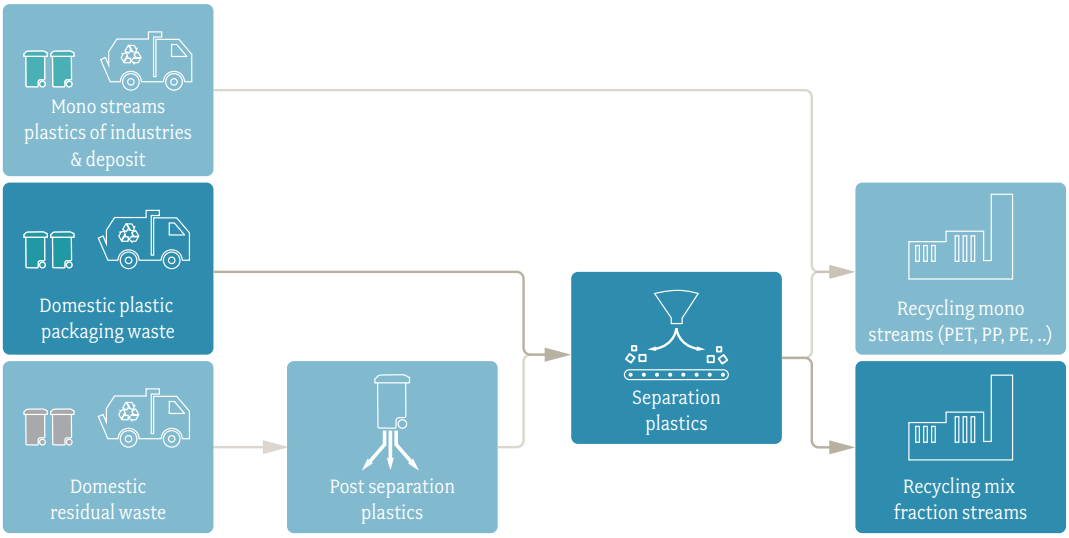


Figure 2.1 Waste streams flowchart (after KIDV, 2018). The focus in this project is on the domestic plastic packaging waste, as highlighted in this figure.

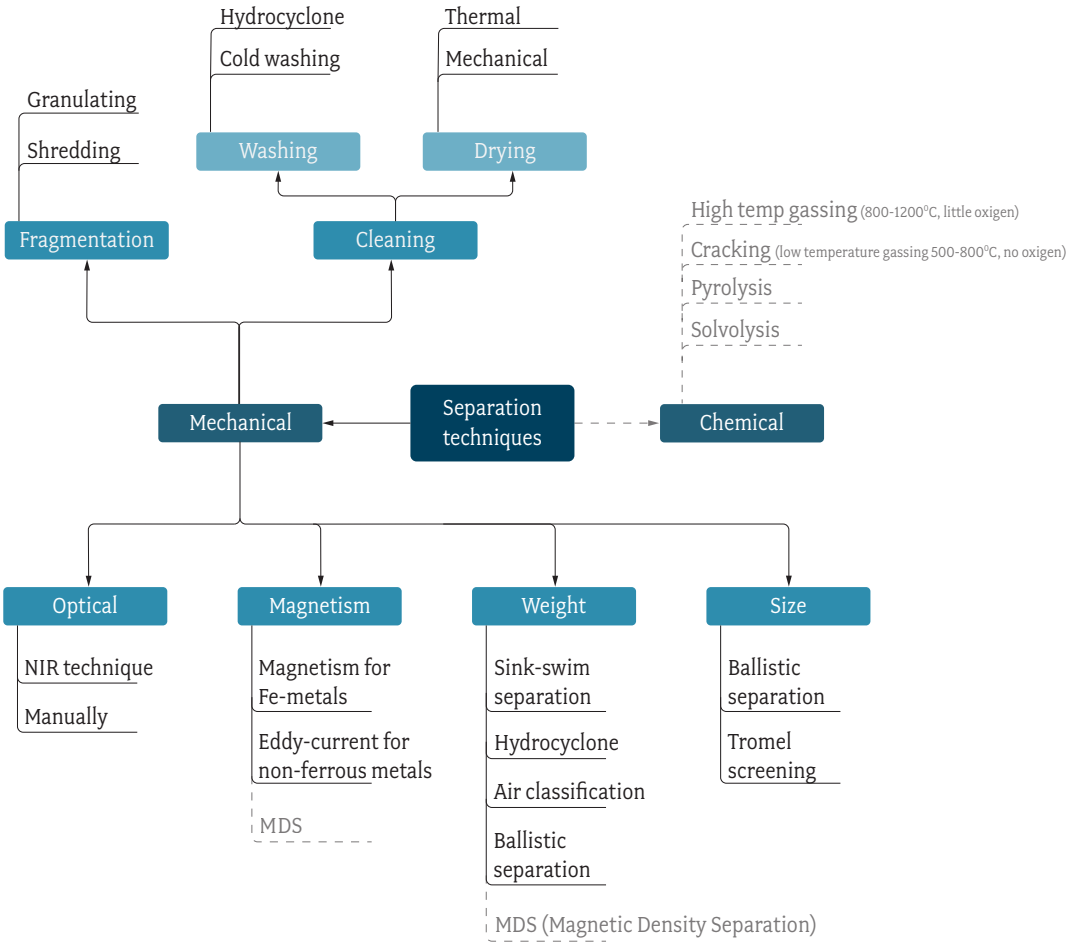


Figure 2.2 Sorting and separation techniques

Chemical

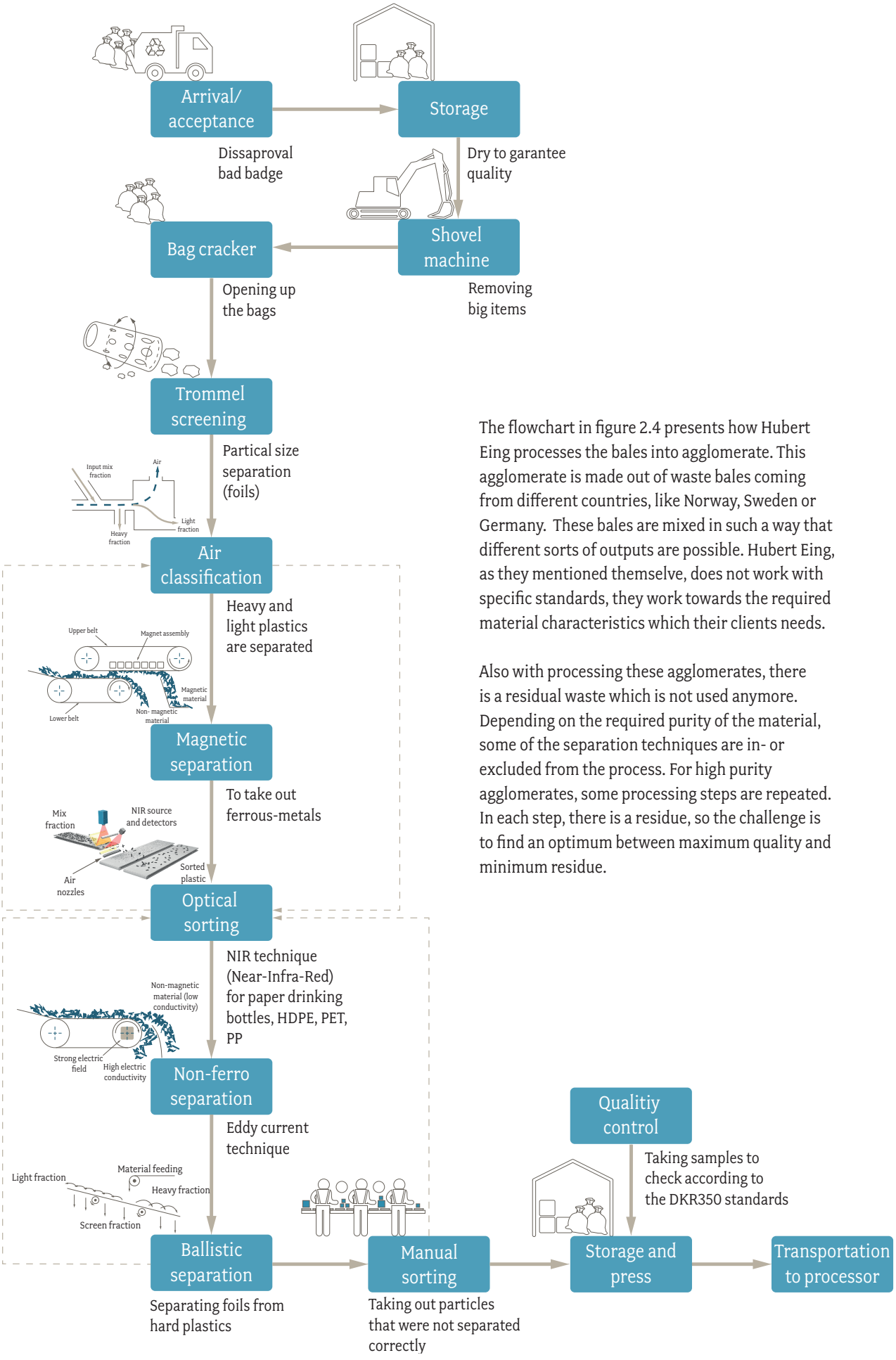
Besides mechanical separation, there is chemical separation. There are four ways of to separate chemically: solvolysis, pyrolysis, cracking (low temperature gassing) and high temperature gassing. The KIDV presented a research in 2017 where these techniques are explained (appendix B1). An important drawback of chemical recycling is that a lot of energy is needed for the processing. Moreover, only high temperature gassing is a suitable technique for the left over mix fraction.

Conclusion

Mechanically, already a lot can be separated and these techniques are becoming more sophisticated. However, complete separation seems impossible, especially for the multilayer plastics.
In a circular economy, chemical separation shows potential, but needs further development, especially to process the leftover mix fraction. Chemical separating will however probably never substitute mechanical separation (KIDV, 2017).

2.1.3 Processing the Mix fraction into agglomerate

In figure 2.3, a flowchart is shown of the separation techniques that separation companies like SUEZ and Attero currently use to separate the PBD waste. The output of sorting this PBD waste, results in mix bales. This mix fraction, which is about one quarter of the total PMD waste (see figure 1.8)(Midwaste, 2017), is processed further at processing companies like Hubert Eing, to make new agglomerate out of this bales. On the 6th of June, Hubert Eing Kunststoffvertwertung was visited. The description of this visit can be found in appendix B2.



The flowchart in figure 2.4 presents how Hubert Eing processes the bales into agglomerate. This agglomerate is made out of waste bales coming from different countries, like Norway, Sweden or Germany. These bales are mixed in such a way that different sorts of outputs are possible. Hubert Eing, as they mentioned themselve, does not work with specific standards, they work towards the required material characteristics which their clients needs.

Also with processing these agglomerates, there is a residual waste which is not used anymore. Depending on the required purity of the material, some of the separation techniques are in- or excluded from the process. For high purity agglomerates, some processing steps are repeated. In each step, there is a residue, so the challenge is to find an optimum between maximum quality and minimum residue.

Figure 2.3 Separation techniques of sorting companies like SUEZ and Attero.

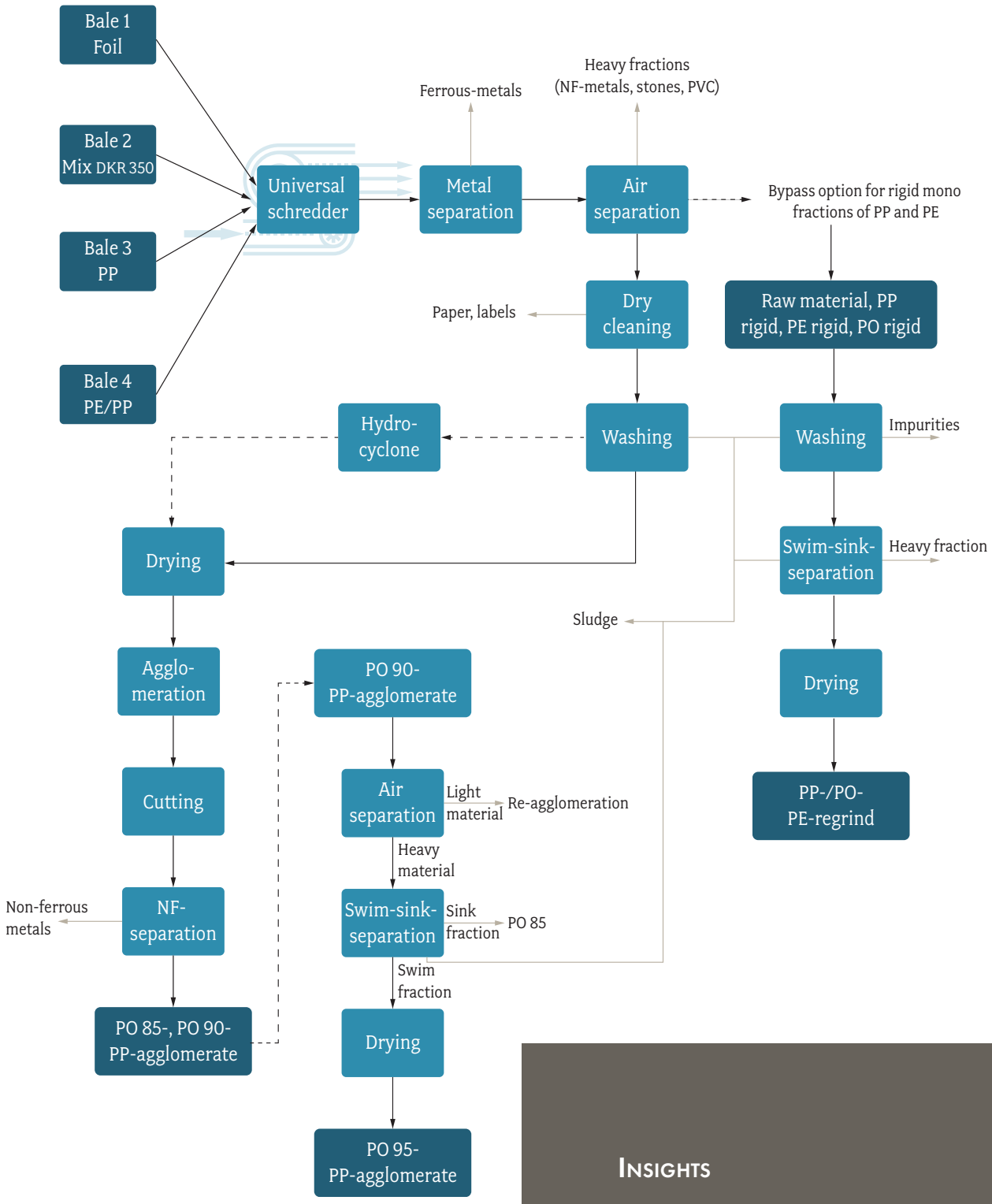
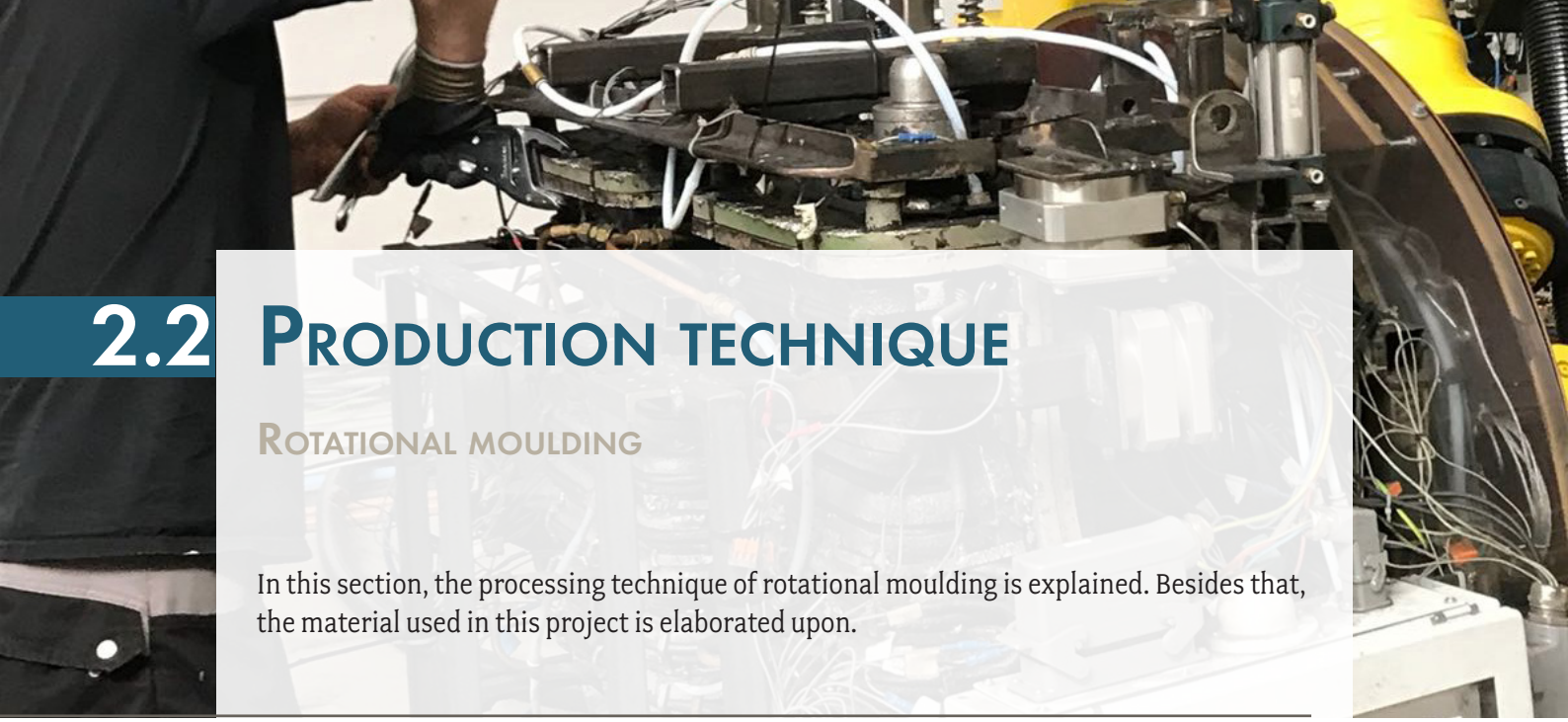


Figure 2.4 Processing flowchart of Hubert Eing (After Hubert Eing, 2018)

Insights

Currently, mechanical separation is the main separation technique. Chemical separation shows potential for the future, but needs more development.

The number of methods to process mix bales into different agglomorate are endless. Choosing a specific agglomerate provides more focus. Results of testing a specific agglomerate can be implemented in further development.



2.2 Production technique

Rotational moulding

In this section, the processing technique of rotational moulding is explained. Besides that, the material used in this project is elaborated upon.

2.2.1 Introduction

Currently, the agglomerate of the left over mix fraction is processed with (slow) injection moulding and extrusion. For this project, a new technique for the mix is researched, rotational moulding. A schematic overview of this technique is presented in figure 2.5. The low investments for this technique makes this it interesting. Besides that, big hollow and double walled products are made with this technique, which could help by creating awareness. A third reason to choose for this technique is the form freedom.
The description of the two other techniques, extruding and injection moulding, can be found in appendix B3.

2.2.2 Rotational moulding introduction

Rotational moulding, also rotomoulding or rotocasting, is a no pressure technique mainly produces big hollow and double walled products. In figure 2.3, a schematic overview is shown of the principle of this technique. Powder is fed into a mould after which this mould is heated and rotated around two perpendicular axis. The powder melts and sticks on the walls of the mould. Then, the product cools down and is demoulded. There are in general three types of machines:

- Shuttle type machines
- Fixed arm carousel machines
- Independent arm carousel machines

The shuttle type machine is the most simple concept where the mould runs on a track between three stations (the loading or charging, the heating and the cooling station).

For a fast production, it is more common to have a multiple arm carousel. A more simple version of this machine is the machine with fixed arms (Crawford, R.J., 1992).

Moulds of this technique are inexpensive (thousands to tenthousands euros) and relatively simple. This is mainly because rotomoulding is a pressureless process. There are no internal stresses and welding lines or sprue marks caused by the processing. Another advantage of rotational moulding is that changes in wall thickness do not require any mould modifications. In other techniques, this requires extensive mould modifications. A drawback of rotomoulding compared to injection moulding and extrusion is that material costs are relatively high because the input has to be powder. Powder incorparetes more effort to produce than pellets, granules or agglomerate. In section 2.2.4, this is explained further.

2.2.3 Rotomoulded products

In figure 2.6, an overview is given of products made with rotomoulding. In general, products that are rotational moulded are relatively big. Since these products do not have internal stresses, construction products are made with this technique. Another application is furniture. Remarkable is that with this technique, the different parts can be all integrated into one part. Since the products are hollow, another application which is often seen is lighting.

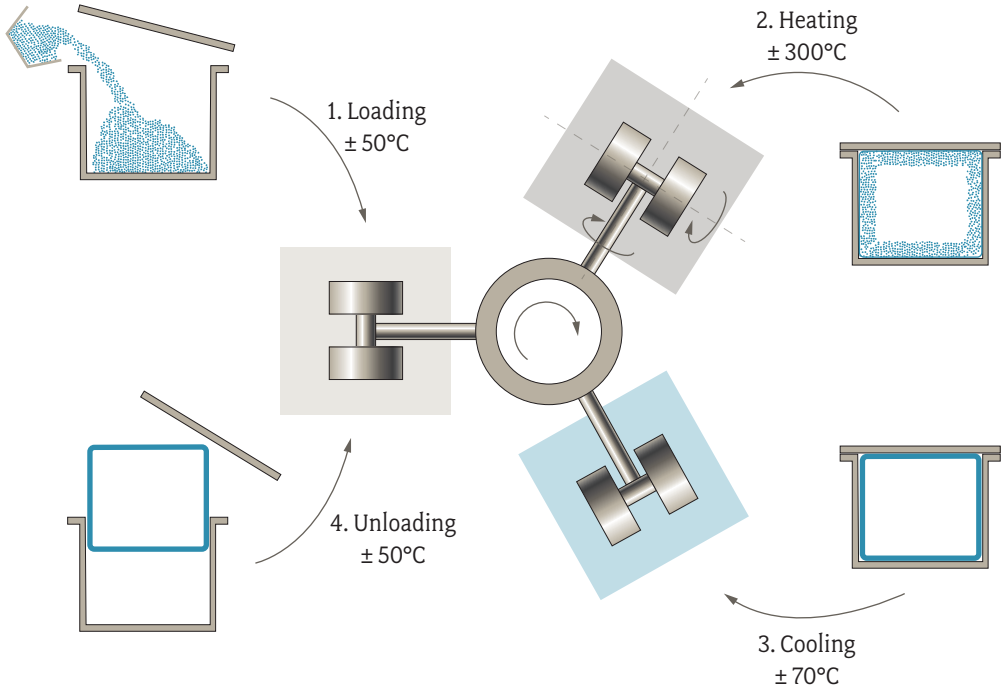


Figure 2.5 A schematic overview of the working principle of rotational moulding (after pentasmoulding.com,n.d)

2.2.4 MATERIAL

Compared to injection moulding, the possible deviation in materials with rotational moulding is limited. Suitable materials for this technique, compared to injection moulding are limited. More than 95% of the products are made out of PE (Nugent, P., 2018). In 1955, Pallman developed a grinding method at moderate temperatures for PE. This eliminated expensive cryogenic techniques which boosted the industry and especially tanks in the range of 1 500 - 4 000 L (Nugent, P., 2018). Besides PE, PVC, nylon, polycarbonate and other thermoplastics can be rotomoulded. Where granulate is the input for most techniques, powder is used in rotomoulding. Powder transfers the heat more easily than pellets, which is benificial since plastics are poor heat conducters. The powder melts and fuses together to a form a solid mass.

However, powder is not just powder. In this powder there is an optimal deviation in particle size and also particle shape is important.
The average size of individual particles is about 300 microns, with a maximum size of 400 to 500 microns. The size, the distribution, the shape and the ability of the powdered particles to flow freely when poured, will all have an effect on the efficiency of the process and the quality of the moulded part (Crawford, R.J., 1992).
The process to create small particles of PE pellets, granules or agglomerate is quite complicated. Figure 2.7 shows an overview of this process. The further details of this process and important characteristics for this powder, are described in appendix B4.

Regarding the leftover mix fraction, metals are very unwanted, since these particles could damage the advanced grinding systems. Additionally, the siews could get constipated by paper and textile.

2.2.5 DESIGN PARAMETERS

A good quality piece design is the result of a good combination of the capabilities, limitations and unique requirements of the material, the tooling and processing technique together with attention to design details. Crawford (1992) described these capabilities and limitations for rotational moulding. The challenge is to use specific processing tools both in the mould design as in the designed part.

MOULD DESIGN

The most important aspects of the mould design are:

- Parting lines
- Removable cores
- Kiss-off ribs
- Heat transfer

























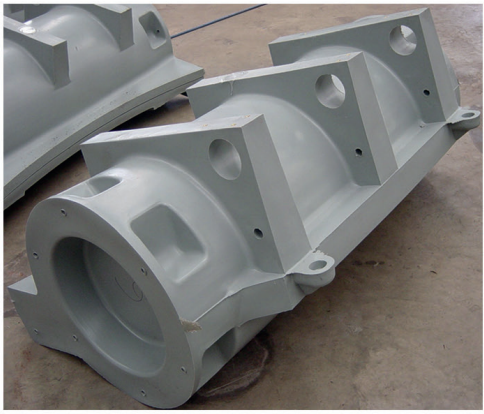


Figure 2.6 Products made with rotational moulding

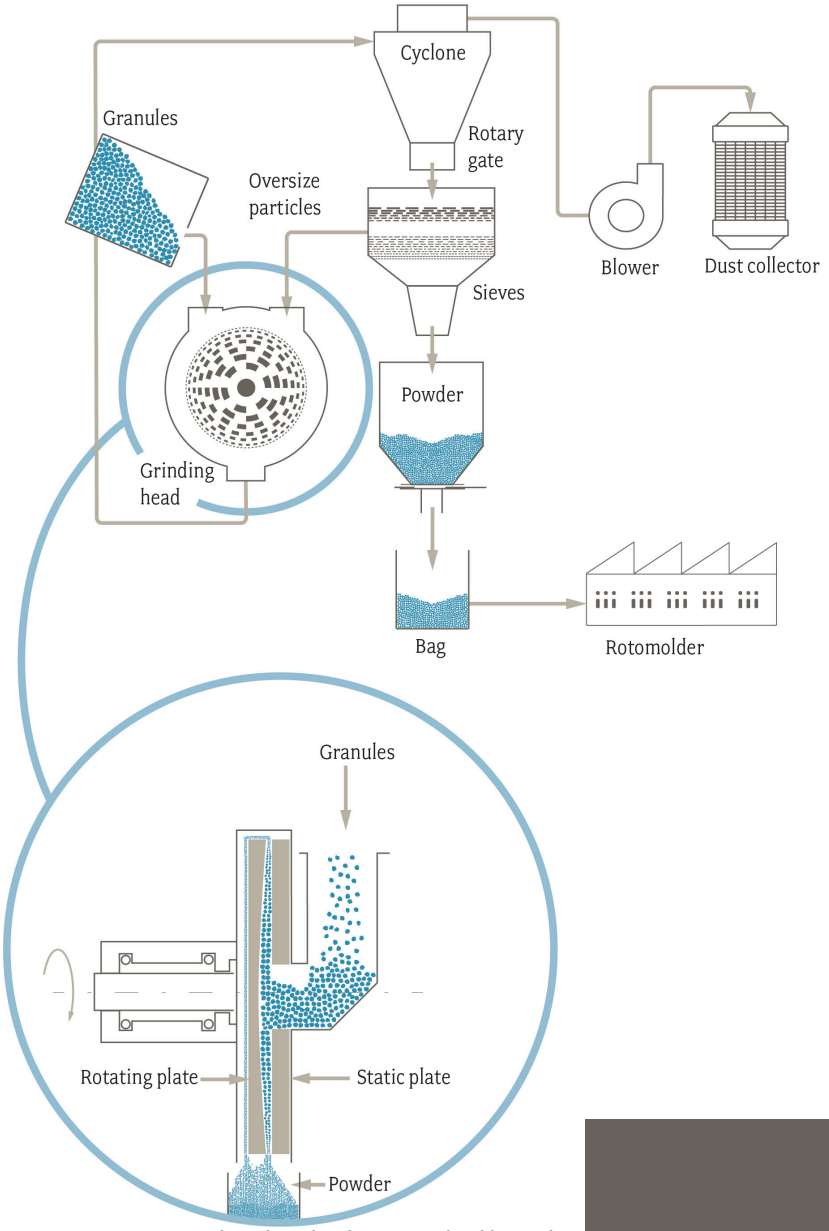


Figure 2.7 Stages in grinding of powders for rotational molding and the disintegration process in detail (after Crawford, R.J., 1992)

Designed part

The most important aspects to think of during designing the product are:

- Wall thickness
- Closely spaced parallel walls
- Warpage
- Stiffening ribs
- Kiss-off ribs
- Draft angles
- Surface finishing
- Undercuts
- Holes
- Corner radii
- Tolerances

Therefore, an elaborated study is done. The extensive description of these parameters is given in appendix B5.

Insights

Making powder out of the left over mix fraction is quite a job. It has to be cooled enough to prevent hairy powder. PE can be grinded without cooling, but PP and other polymers require cryogenic techniques to prevent melting. Besides that, impurities like paper and textile can become a problem during sieving. Moreover, metal could damage the grinding tools.

To make this material work in the first place, the highest potential can be found in multilayers or foaming, working with virgin. Additives should be added to stabilise the material. The composition of these additives require more research and time. Due to time limitations, this is left out of this research.

2.3 Recycled packaging material

Material specifications of the leftover mix fraction and the material used in this project

As explained in the section 2.1, there are a lot of different ways of separating plastics which result in many different outputs. In this section, the specifications of the material used in this project are given.

2.3.1 Introduction

In this project, the focus is on the left over mix fraction of domestic plastic waste. Midwaste has to pay for this material to process it, instead of receiving money like they do for mono streams. This project should show the value of this material. As mentioned before, this mix fraction has specific requirements which are expressed in a DKR standard. For the mix fraction, this is the DKR 350. However, this is only an input material for recyclers and does not say much about the agglomerates that come from this mix. The output materials are mainly PO agglomerates:
PO85
PO90
PO95
PO99

According to the DKR, Deutsche Gesellschaft für Kreislaufwirtschaft und Rohstoffe mbH (2009), this mix of PP/PE, polyofines, has to be at least the number standing after the PO% of the total mass. So, PO95, 95% of the total mass.

For the testphase, PO95 is used. The testphase is described in section 4.6.

2.3.2 What exactly is in this mix?

This material, DKR 350, is a mix of mainly PP and PE (A.M.M. Ansems; T.N. Ligthart, 2017).
Then, there is 10% mass of impurities which can consist out of different materials. In these impurities, there are restrictions as well:

- Metallic and mineral impurities with an item weight of > 100 g are not permitted.
- Paper, cardboard < 5 mass %
- Other metal articles < 2 mass %
- PET bottles, transparent < 4 mass %
- PVC articles other than packaging < 0.5 mass %
- Other residual materials < 3 mass %
- Examples of impurities:
    - Glass
    - Composite paper/cardboard materials (e.g. beverage cartons)
    - Other materials (e.g. rubber, stones, wood, textiles, nappies)
    - Compostable waste (e.g. food, garden waste)

When this DKR 350 material is processed into agglomerates it is again purified, depending on which output is required. For the PO95, the polyolefines are 95% of the total mass. Besides the impurities, in the remaining 5% there is also 0.30 to 1.00% left over moisture (Hubert Eing Kunstoffverwertung, 2017).

2.3.3 Characteristics

Plastic in general, is a very bad conductor, so it barely conducts temperature for instance compared to steel. Besides that, plastics have a long durability and is barely influenced by weather conditions excep sunlight. This influences the colour and the quality of the material significantly. This vunerability, and other specifications, can be influenced by antioxidants, (uv-)stabilizers and other additives as mentioned in appendix B4.

Figure 2.8
Shredded and washed material shown during the visit at Hubert Eing

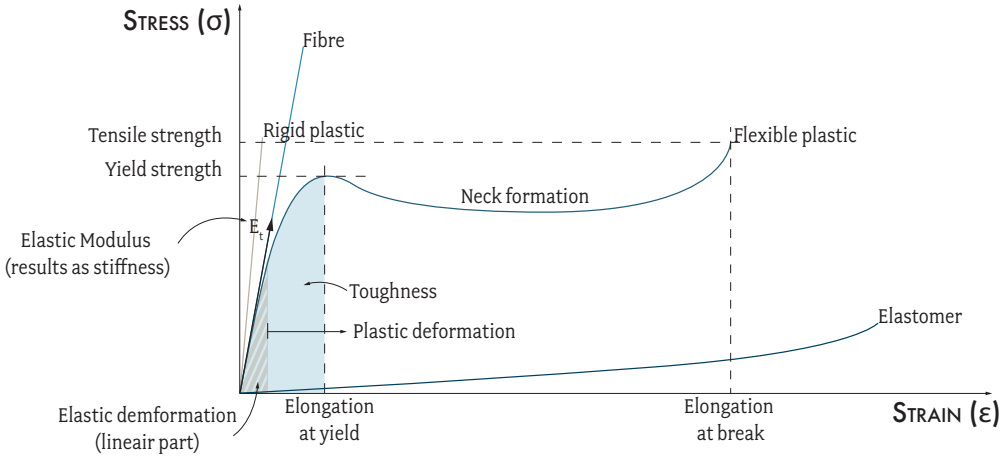


Figure 2.9 Stress-strain graph of different plastics (After plasticprop.com,2018)

2.3.4 Parameters in material

There are many characteristics in material, for instance: chemical, mechanical and thermal properties. For instance a diffrent melting temperature. In addition to the design parameters described in appendix B5, some basic information about tensile strength in material is given to provide insight how failure in materials work.

Tensile strength

Tensile strength is the ability of a material to withstand a pulling (tensile) force, in other words: the maximum amount of tensile stress that it can take before the material fails, which means breaking or permanent deformation (corresionpedia.com, 2018).
Tensile strength also specifies the point when a material goes from elastic to plastic deformation which is shown in figure 2.9. Elastic deformation is when the curve is linear, when it becomes non-linear, there is plastic deformation.

The strength parameters is mostly expressed in megapascals (MPa) (corresionpedia.com, 2018) and there are three types of tensile strength:

- Yield strength: the stress a material can withstand without permanent (plastic) deformation.
- Ultimate strength: the maximum stress a material can withstand without breaking.
- Breaking strength: the stress point where the material breaks, the coordinate on the stress-strain curve where the line ends.

When engineering a product, the forces on the product should not get higher than the yield strength to prevent plastic deformation during normal use.

Tensile strength is a limit state of tensile stress that leads to tensile failure (see figure 2.10).

There are two types of failure:

- Ductile failure: yield as the first stage of failure, some hardening in the second stage and breakage after a possible "neck" formation
- Brittle failure - Sudden breaking in two or more pieces at a low stress state

Rotational moulded products do not have internal stresses, which significantly decrease the chance of a brittle failure. Therefore rotomoulded products are very impact resistant.

Types of tensile failure

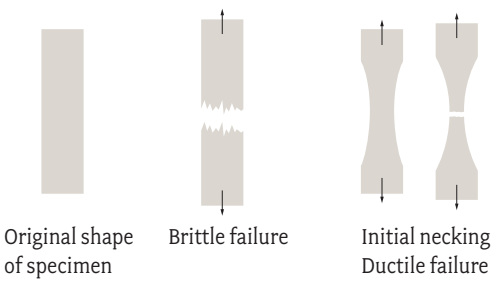


Figure 2.10 Types of tensile failure caused by tensile stress

Insights

The different melting temperatures could result in unmelted particles in the moulded part. When these parts do not melt, it could help showing that the product is made out of recycled material to create awareness, so aesthetically speaking this is not a bad thing. However, the product could become weaker and more brittle due to a decrease in homogeneity.

3

CONTEXT ANALYSIS

3.1 Design context

From research towards a design context

Besides the trend analysis, a brainstorm was done with a municipality, the fair for public space was visited and questionnaires have been carried out. Moreover, interviews and conversations with experts have been conducted. This gave insights in what the product should become. In this section, the development towards a design context is described

3.1.1 Target group

The stated 'target group' of this project are municipalities, as described in the assignment (section 1.5). Giving a product made out of domestic plastic waste back to municipalities closes their circle of waste using as a resource. Therefore, at the absolute beginning, an email was sent to all the municipalities that are connected with Midwaste. This email served as an introduction to the project and asked municipalities about their ideas regarding the plastic mix waste stream. The email itself and the responses can be found in appendix C1. The main insight following from this email and additional conversations with employees of Midwaste is that most municipalities like to get feeded with ideas instead of initiating ideas themselves, also because they often do not know what is possible, besides street furniture and road signs.

However, the 'target group', municipalities, was not specifically a target group. The product should be attractive for municipalities to buy. So, it could be a product that fits in public space, but it could also be for the commonality, sold or subsidised by municipalities, with municipalities acting as selling channels. To get a better idea of what municipalities like to see and like to buy for their commonality, a brainstorm was carried out with the municipality of Breda. The complete description of this visit can be found in appendix C2. The most important insight of this brainstorm was that it would be interesting to combine the product with other goals, like climate adaptation or energy transition, to achieve a circular economy. This would make a good story that strengthens the product idea.

As briefly mentioned in section 2.2, large products are a good way to create awareness, since large products, catches the eye more easily than small products. When a product tells a good story, it could also be a conversation starter and create awareness.
Looking into products that are made with rotomoulding, more than 70% is any form of tanks (Nugent, P., 2018). Water is something associated with tanks and water management, as described in the trend analysis, is something which is an important aspect regarding to climate adaptation. Making a large product which responds to climate adaptation creates an interesting focus of this project.

3.1.2 Climate adaptation on private area

The focus area of climate adaptation within municipalities is shifting from the public area towards private areas according to Johan Verlinde, an advisor in climate adaptation in Rotterdam. 60% of the surface in Rotterdam is private property so designing something for the private area, could have a significant impact. Besides that, a product for private areas, subsidised by the municipality starts a collaboration between municipality and commonality and involves private areas. Involving individuals also responds to the human empowerment that is discussed in the trend analysis. During the conversation with Verlinde, he pointed out embracing the idea of combining the theme 'waste' as a resource with climate adaptation.

Figure 3.1 An impression of the fair for public spaces. On the left, Helga van Leu giving a lecture

An inspiring event regarding climate change, climate adaptation and working towards a circular economy in an innovative way, was the fair for public spaces (figure 3.1). During this visit, there were many interesting conversations with people from different companies and fields. The description of this visit can be found in appendix C3.

3.1.3 Design vision and idea generation

During this project, a vision was created to have a focus during this project:

I want to design a valuable product that contributes in a circular economy by using the mix fraction in significant amounts to create awareness amoung the commonality and especially people between 20 and 45 years old.

In this vision, the contribution in a circular economy is only with using the leftover mix fraction. However, during this research, it turned out to be valuable to combine this with climate adaptation. Combing the product with climate change also responds to the part of creating awareness among the commonality. The target group, people between 20 and 45 years, could also be described as starters and young families. With this vision in mind, during the project, several ideas have been generated. Talking with a diversity of people about ideas guided this project into the right direction.

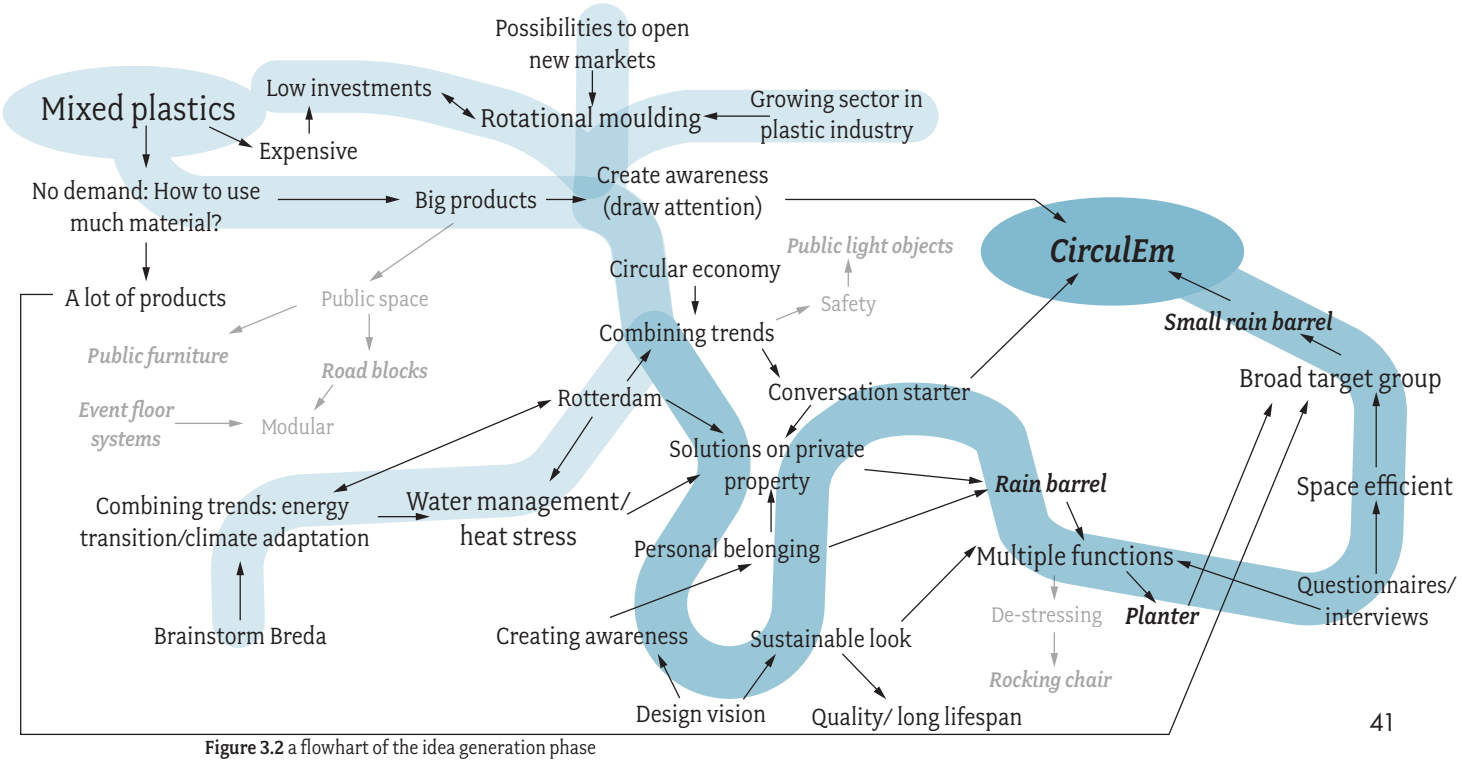


Figure 3.2 a flowhart of the idea generation phase

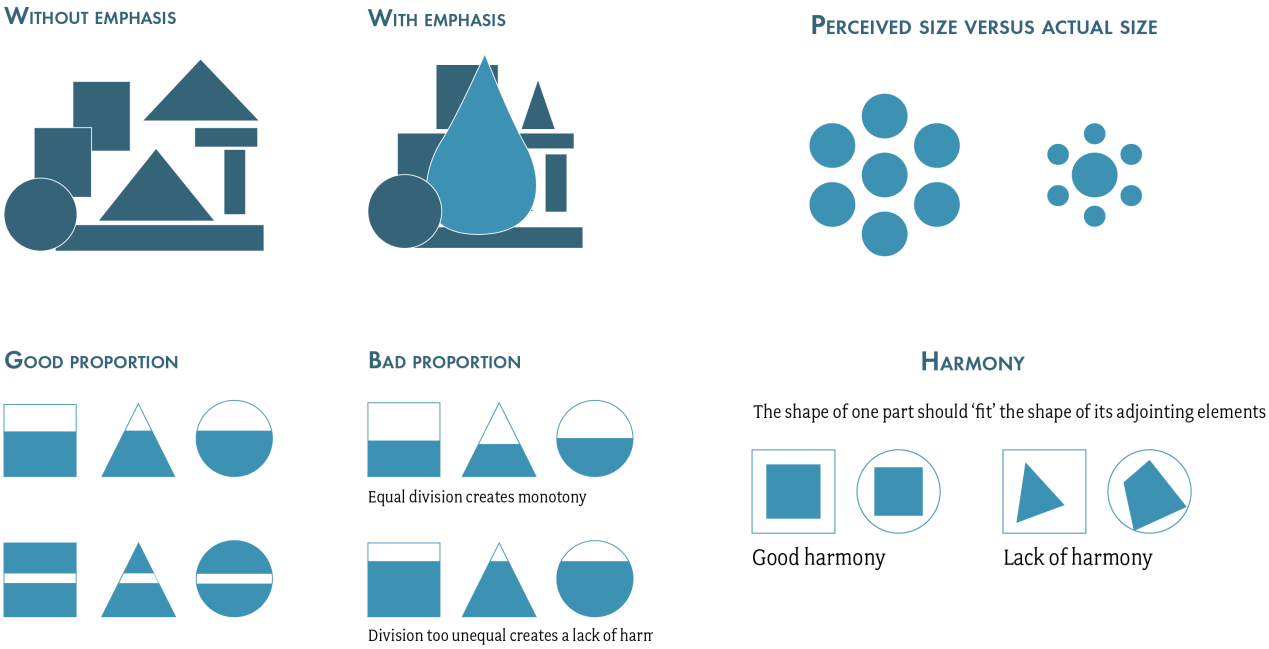


Figure 3.3 The theory of using emphasisand proportions in design. On the right, the theory of perveiving size and harmony in combining different shapes.

This idea generation phase, is captured in the flowchart shown in figure 3.2. The ideas are highlighted with the bold italic words. The ideas and 'in between conclusions' are given in appendix C4.

3.1.4 Design expression

One of the aspects to draw attention is by giving the product a sustainable expression, but how does a sustainable product or sustainability look like? Besides a brainstorm with the municipality of Breda, a workshop had been executed with the employees of Midwaste. The goal of this workshop was to get insight in what people associate with sustainability. A more elaborated description of this brainstorm can be found in appendix C5.

One of the main important outcomes of this workshop was that people seems to associate sustainability with quality, a long lifespan. Also pure and natural surface finishing and multifunctionality was interpreted as being more sustainable.

Besides that, I want the product to be aesthetically appealing. Appendix C6 elaborately describes the theory behind what looks aesthetically appealing to people, based on studies of Paul Hekkert (2006) and and Sam de Visser (2014). Figure 3.3. shows some aspects regarding the theory.

The material has a specific appearance which is preferably used as a design aspect to show the value of the material to users. The expression of the material shows that it is made of different materials. This expression is explained further in section 4.3. If there is more demand for this material, the value increases and it is also less likely be seen as waste.

Insights

Combining the design vision with the information and insights out of the conversations, the brainstorm and the trend analysis, a product that responds to climate adaptation on private area is a good solution. This solution is even more complete when this product is made out of plastic waste. Since this material smells, it should be a product for outside use. Collecting rain is an interesting directions within this search area.

Rain barrel 3.2

From the analysis to a product

A rain barrel is made in this project. In this section it is described why a rain barrel is a good solution in the project context. Besides that, an overview is given and a brief analysis is done from rain barrels that on the market right now.

3.2.1 From context to product

Looking into the complete analysis it is concluded that a rain barrel is a good product solution, as shown in figure 3.1 and appendix C4.

One direction during this process that is worth mentioning is combining the rain barrel with a rocking chair or a rocking deck chair to add a distressing feature. An online questionnaire was conducted and people prefer a rocking chair, especially if they do not have much space outside. The results of this questionnaire can be found in appendix C7. However, this idea was a bridge too far. People do like to have products with multiple functions, but the target group would become smaller if the product becomes very specific. Besides that, something like a rocking chair would take more space than a rain barrel which makes it less practical for people with a small outside space, the target group of this project. Moreover, municipalities and Midwaste preferred the idea of a rain barrel over the rocking chair.

However, it is discussable if a rain barrel could also contribute in water management in urban areas. Harry Luitelaar and Albert Kemeling, experts in sewage systems, say that a rain barrel is a fantasy tool. Bas Sala, a designer which is working on smart rain barrels since 2013 says that extensive testing however proofs that it could make an impact when placed and used correctly.

Looking into the available rain barrels right now, most of them are round(ish) which make them inefficient in the space they occupy (see figure 3.4). Rain barrels are made in various colours, materials and sizes. Also, rain barrels vary a lot in price, from €30,- to over €500,-. According to Bas Sala, the most important factor to buy a rain barrel is price. The idea of a rain barrel made out of waste, adds value which might evoke people choosing this rain barrel over a standard cheaper version. A rain barrel made out of waste, subsidised by municipalities could start the conversation between municipality and its commonality to tackle water management together.

3.2.2 Rain barrels

A rain barrel is interesting because, it is a relatively big product. This could also increase the awareness reagarding water management, because it draws attention. Besides that, a rain barrel is a good product to produce with rotational moulding, since it is a big hollow product. Moreover this idea responds to climate adaptation by reducing heat stress, because people could supply water to their plants during dry periods (with grey water).

'People generally buy the cheapest rain barrel. However, this could change in this society where people become more aware of the climate change'

-Bas, Sala, 2018.

Rain barrels, sometimes integrated

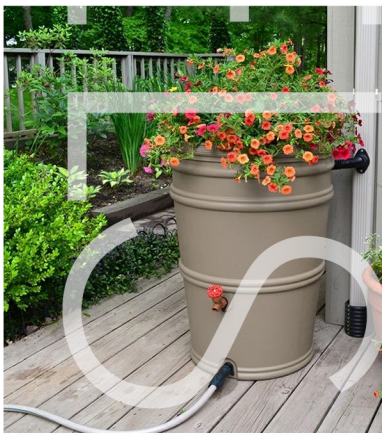




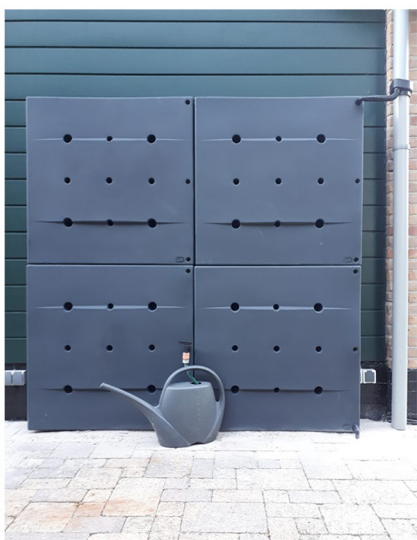



Multiple functions



Modularity



3.2.3 A look into outside spaces

To get idea an of what people prefer and do not like in rain barrels, a second questionnaire was conducted. This questionnaire had 30 respondents and in addition 5 interviews with respondents has been conducted by phone. The purpose of the additional interviews was to get a better insight of what people think about a rain barrel combined with another function and modularity of the rain barrel.

Questionnaire and interview insights

People with a small garden often use something like a watering can to supply water to their plants, which makes it unnecessary to store the garden hose. People are willing to give up space for something like a rain barrel but generally, not more than 1m2. Giving it multiple functions, makes a the product more attractive. The barrel should be practical in shape, and making it modular could be interesting, especially to make it more flexible in how you place it in your outside space.The results and the complete description of this research can be found in appendix C8.

'It is amazing, this idea of a rainbarrel made out of this mixed material, since it embraces more aspects towards a circular economy!'

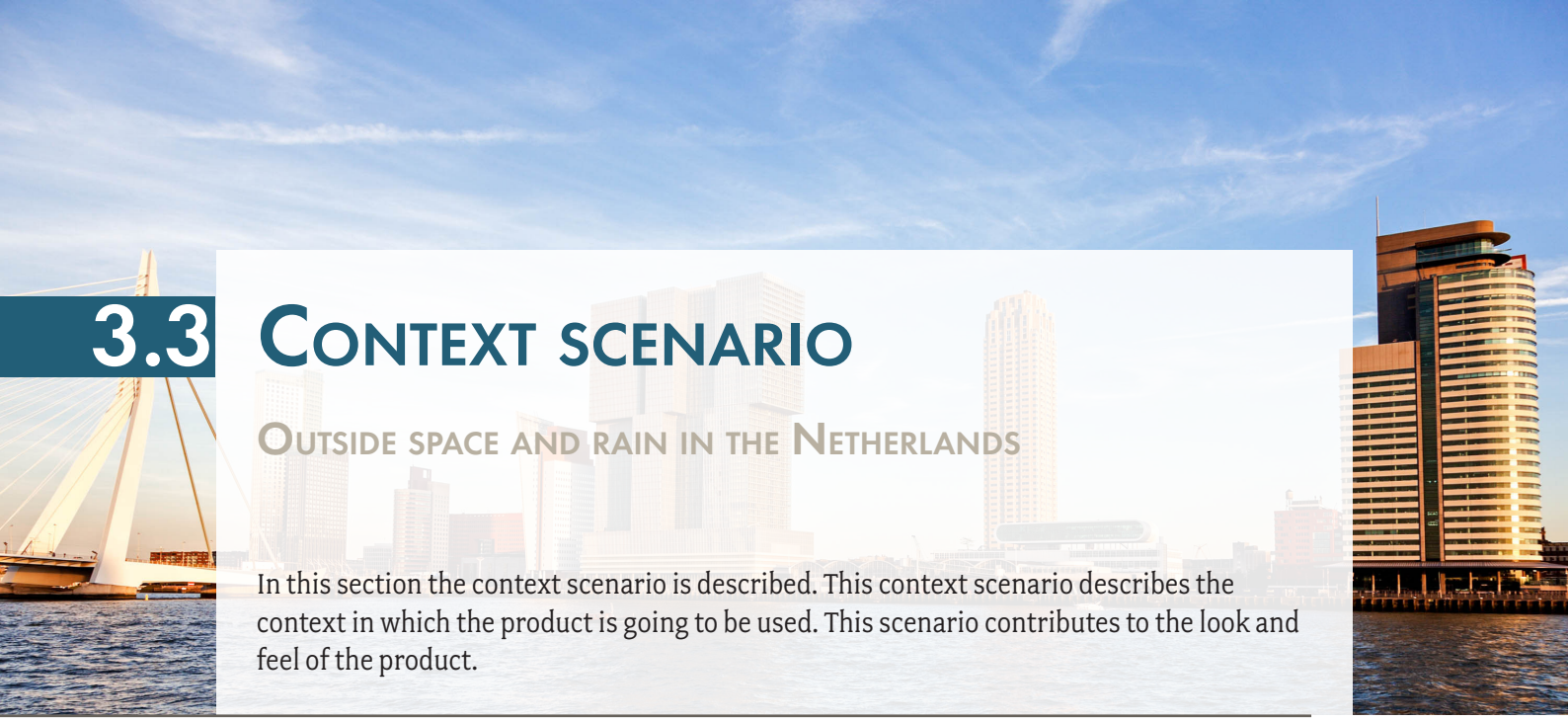
- Johan Verlinde, 2018

Insights

Price is something to keep in mind, since price probably is the main reason people choose a rain barrel, especially people in the middle class society.

People who do not have much private outside space do not want to give up more than $1m^2$ for a rain barrel. It is more important how the barrel looks, since you cannot hide it. Making it part of the outside space, by proving an extra function adds value.

<- Figure 3.4 A collage of existing rain barrels



3.3 Context scenario

Outside space and rain in the Netherlands

In this section the context scenario is described. This context scenario describes the context in which the product is going to be used. This scenario contributes to the look and feel of the product.

3.3.1 Introduction

A scenario context is created to get an idea in which context the product will be used. Therefore, the city of Rotterdam, located in the Netherlands is chosen since Rotterdam is actively working on how to deal with climate adaptation and water management (Verlinde,J, 2018; Kemeling, A., 2018).
Rotterdam currently counts 318 219 households (oozo.nl, 2018) with an average space per person of 53.85m² (CBS, 2108). The total area of Rotterdam counts 32 416 hectares, from which two third, 21 564 hectares is land (oozo.nl, 2018) and about 10 000 hectares is inhabited city centre, as shown in figure 3.2. The average garden in Rotterdam is 83m² (Bouwens, C., 2018), the most common is between 60 and 70m². However, roof terraces and balconies are not included in this average garden surface. Exact numbers are unknown, but based on the questionnaires, a lot of people only have an outside space like a balcony or a roof terrace, shown in figure 3.6. The focus group will be people with a similar outside space.

3.3.2 Rain in the Netherlands, Rotterdam

The average rain in the Netherlands is 800 mm yearly, which means 800 L/m², based on statistics from 1981 to 2010 (KNMI.nl,n.d). However, the rain in the Netherlands has increased with 18% since 1906 and especially autumn and winter have increased rainfall of 26%. This 800 mm of rain drops in 570 hours, which is not even 7% of the time. Moreover, there are 125 days without rain. The Netherlands does not have a rainy season, the rain is divided pretty equally during the year. However, due to the climate change, summers will get drier but when it rains, the rain is more intense as can be seen in the graph in the infographic (figure 3.5). Heavy rainfall is defined as a rainfall of 50 mm or more during one day (24hrs). Such rainfalls averagely occur once in seven to ten years. The last couple of years, this amount of heavy rainfall significantly increased (KNMI.nl, n.d). Besides a heavy rain, there is a cloudburst which is defined with a rainfall of 25 mm or more within one hour or/and 10 mm or more within 5 minutes. This occurs in a random place in the Netherlands once per 10 years (KNMI.nl, n.d).

3.3.3 Collecting water

A terraced house generally has 50 m² (bestaandewoningbouw.nl, 2009). This means, that the roof also has a surface of 50 m². Considering that 2 households are living under one roof, having one rainpipe each, every household has 25 m² roof. This means, that 800 L x 25 m² = 20.000 L of relatively clean water each year per household which is going into the sewage system. This water could also be used in dry periods to supply water to plants, wash clothes or cleaning windows. Plants and other green responds to heat stress (Sala, B., 2018; Leur, A. van, 2018), especially in urban areas. According to Helga van Leur who gave a lecture during the fair for public spaces (2018), increasing heat stress due to the climate change is a real problem in urban areas, because it is almost always hotter in cities than in surrounding areas (ruimtelijkeadaptatie.nl, n.d). This difference can rise up to 7 degrees after sunrise.

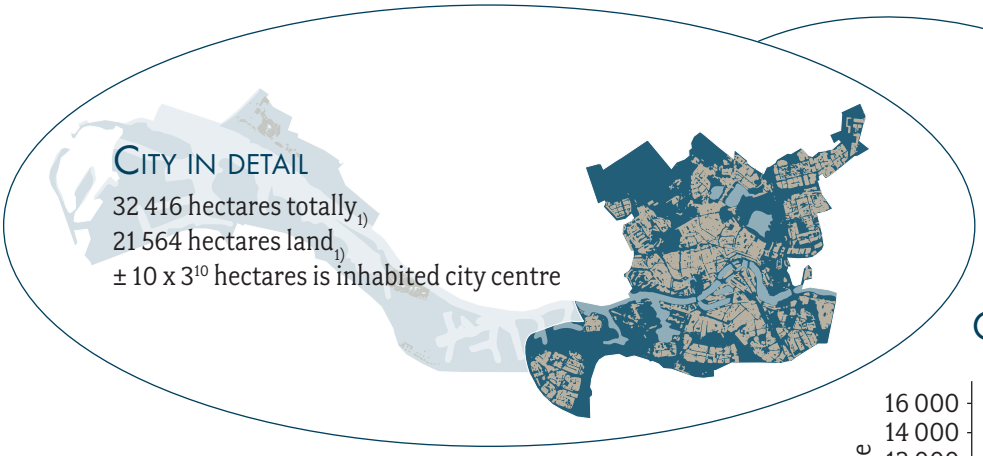
Figure 3.5 -> Infographic about rain and garden surfaces of people living in Rotterdam

Rotterdam

The Netherlands

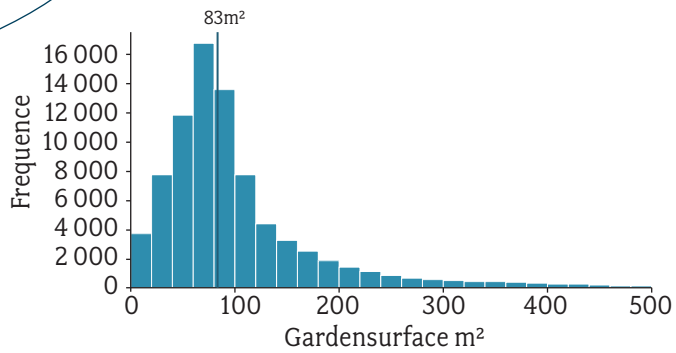
City in detail

32 416 hectares totally[1)]
21 564 hectares land[1)]
± 10 x 3^{10} hectares is inhabited city centre



Centre of Rotterdam
Buildings connected to the sewage system[2)]
Water

Garden surfaces of Rotterdam



Statistics

318 219 Households[1)]

2.0 People per household on average[1)]

83m² garden surface, 125m² nationally[5)6)]

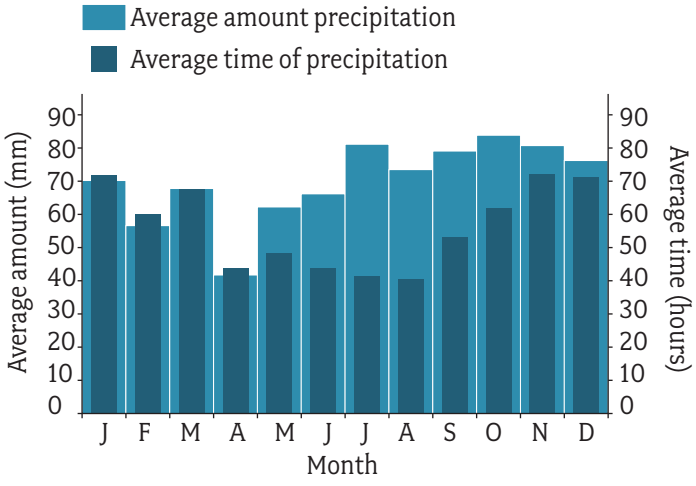
12.0 km² flat roof & 4.7 km² sloping roof .
Total 16.7 km² that is connected to the sewage system[2)]. That is 16.7% of inhabited land.

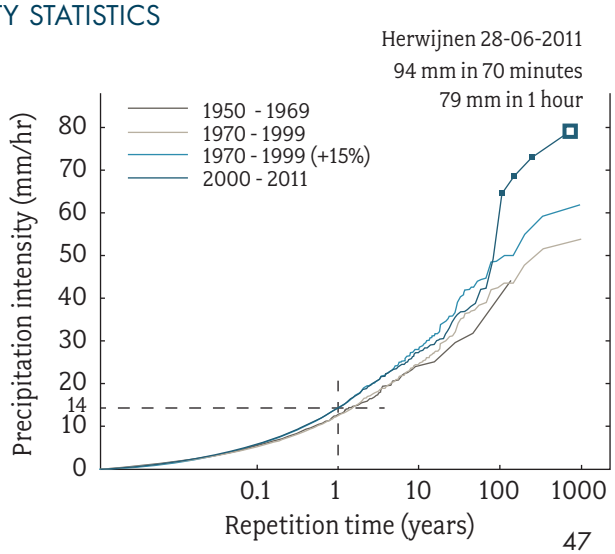
1mm rain = 1 liter of rain per m²

800 mm per year, in the Netherlands, during summer, the rain is more intense (see left figure)[3)].

In 2011, a 79mm rain in one hour occured in Herwijnen. The four highest peaks registerd in the last ten years (see the right figure)[4)].

Rain intensity statistics





1) CBS.nl, 2018
2) Kemeling, A., municipality of Rotterdam, 2018
3) KNMI.nl, n.d.
4) Bouwwerkbegroeners.nl, n.d
5) Bouwens, C., municipality of Rotterdam, 2018
6) voertonnen.nl, 2015

So collecting rain water to supply green with rain water during dry periods might help. In order to collect this rain coming from roofs, a rain pipe is required. 16.7km² of the roofs in Rotterdam is connected to the sewage system, which means that these houses have rainpipes (Kemeling, A., 2018). During an interview with Albert Kemeling, advisor urban water at the engineering firm of the municipality of Rotterdam, houses built in the sixties often have their rain pipe hidden inside the house and not on the outside wall. It is hard to say how much households have this type of drain pipe on the outside, but not the complete 16.7km² roof is suitable to collect water.

3.3.4 Water usage in a garden

An average garden in Rotterdam is 83m², based on an analysis of municipality of Rotterdam. However, in this calculation, balconies and (roof)terraces are not included. There is no data available about these kinds of outside space. An average amount of water needed on a year basis, for a garden of 125m² (average garden size of the Netherlands) is 2500 liters (info.voertonnen.nl, 2015). For a small garden, roof terrace or balcony as shown in figure 3.2, less water is needed.

Figure 3.6 Context scenario of the outside space of people within the focus group

Insights

Due to the climate change, heat stress in urban areas is increasing and the rain barrel could contribute in reducing heat stress in urban areas.

Municipalities are looking for solutions on private areas regarding water management.

It is discussable whether a rain barrel could contribute in water storage in urban areas.

4

IDEATION

4.1 List of requirements

List of requirements and wishes

In this section, the problem definition is described an the most important requirements and wishes of the rain barrel are given. The complete list of requirements and wishes can be found in appendix D1.

4.1.1 Introduction

A list of requirements and wishes actually defines the result of the designing process. However, it should contain as less as possible shape constraints. It should specify the required and wished properties of the new product. The product has to meet all the requirements, but not necessarily the wishes.

4.1.2 Problem definition

The problem definition is the starting point of this list of requirements and wishes. For this problem definition it is important to know what the problem is, who this problem has, what the goals are and what the side effects and the contraints are (Roozenburg, N.F.M., and Eekels, J.,1998).

In this project, there is one main problem as a starting point: a lack of solutions for the leftover mix fraction of plastic domestic waste after separation. Midwaste has to pay almost €200,- per ton for this mix fraction when it is brought to a recycling industry instead of receiving money, like the mono streams.

Midwaste is the problem owner of paying money to recycle the leftover mix fraction (DKR350). A goal would be to make this mix fraction cheaper to sell to the recycler by creating a demand for this material. Making a product with value out of this mix fraction shows its potential value.

One of the possible side effects would be that, at some point, separation techniques are that good and chemical recycling might be the standard, that this material would disappear. If there is demand created, this demand could no longer be fulfilled. However, the quality of mono streams will probably always be better than the mix. So, the disappearance of this material is not a negative development. Actually this is something to strive for. The development of chemical recycling and optimizing separation techniques would take at least ten to fifteen years and till then, the challenge of the mix fraction has to be faced. Another side effect could be that the mix fraction is mixed with a virgin or mono stream plastic, since the properties of the mix fraction might not fulfill the technical requirements.

One of the product constraints is that the product have to be made out of this mix fraction and should be attractive to municipalities. Besides that, it has to be made with rotational moulding and the product should be for outside usage (because it smells).

Another problem, which came out of the analysis phase, is water collection during a heavy rainfall especially in urban areas. Municipalities have this problem and it is a burden to the commonality when the streets, and maybe even more, are flooded. So the target is to make a product that might unburden the sewage system. However, creating awareness about the climate change will have the focus, because that may change people's behaviour, also regarding waste.

The problem definition of these two main subjects results in a list of requirements and wishes. To create these lists, the checklist of Pugh (1990) is used.

4.1.3 Brief list of requirements

The requirements which have a significant influence on the design are listed below:

- The rain barrel should house a minimum of 40L.
- If the rain barrel is filled, the overload of water has to flow into the sewage system.
- The product should take less than space than $1m^2$.

4.1.4 Brief list of wishes

Besides the requirements, also the more relevant wishes are listed below:

- The product should be variable in size, modular.
- The product should contain as less as possible different particles.
- The product should use standardized connections.

4.2 Principle solutions

Principle solutions of design problems within the rainbarrel

In the design of the rain barrel, there are some connections and other principles that has to be designed. In this section, these design challenges are given and an overview of the chosen principles are presented.

4.2.1 Introduction

The rain barrel has a couple of design challenges that need to be designed:

- The shape of the barrel
- The overflow principle
- The connection with the rain pipe
- The tap
- The height of the barrel to make sure a watering can of 40 cm fits underneath the barrel.

For these cases, different solutions has been sketched and modelled. Out of these solutions, the best are combined into a final concept design which is described in chapter 5. The chosen principles are described below. These sketches can be found in the appendix D2.

4.2.2 The barrel shape

For the shape, a form study was done. This study can be found in appendix D5. Besides sketching, some 3D modelling in Fusion 360 was done and some testprints on a 1:10 scale were made. Important for the shape of the barrel that is that it takes as less ground space as possible. Additionally, it should be possible to place efficiently in a corner. The barrel should house about 50 L of water, which is enough for households with a balcony or a (roof) terrace.

Looking into the design parameters (appendix B5), flat surfaces should be avoided wherever possible. The rounded surfaces give the barrel an elegant look and 'hide' possible warpage at the same time. A concept shape of the barrel is shown in figure 4.1. The final shape of the barrel will be discribed in chapter 5.

Figure 4.1 The concept shape of the rainbarrel

4.2.3 Overflow and rain pipe connection

A good solution for the overflow of the rainbarrel is shown in figure 4.2. With this principle the overflow is integrated with the connection to the rain pipe so less adaptation on the drainage pipe is required. Besides that, the connection with the barrel is simpler which is both beneficial for the amount of required connections and for the design. The design will draw the most attention, instead of the connection. The length of the flexible pipe is adaptable which makes the placement of the rain barrel flexible. That makes it applicable in more different balconies, terraces and (small) gardens.

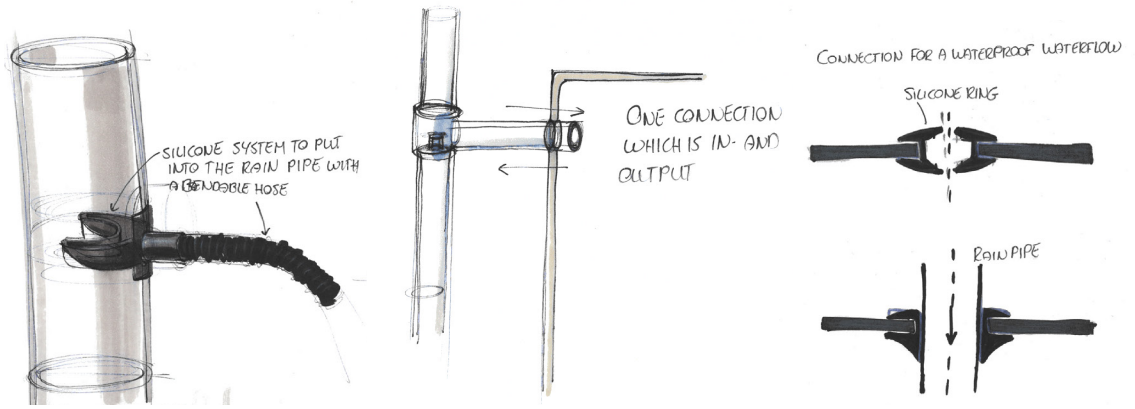


Figure 4.2 Principles for the overflow and the connection between the rain pipe and the barrel

4.2.4 The tap of the barrel

For the tap of the barrel, a screw thread tap has been chosen (see figure 4.3). For this principle an insert in the mould is required. A screw thread is inserted into the mould so the barrel contains a thread as well. Into this thread, a tap can be placed. The opening of the thread is will close during the moulding, so after moulding, this has to be removed (figure 4.3). This gap can also be closed of with a lid if there is no tap placed. The tap itself could be both designed and being a standardised part.

Figure 4.3 shows this principle of a stand. During further development, this stand eventually is integrated into the barrel. This is decribed in chapter 5.

4.2.5 Placement of the barrel

To make sure that a watering can fits under the barrel, the barrel needs to be placed higher. Several options can work, but the simplest one is coming out best. Placing the barrel on a stand under which the watering can can be stored. This solutions requires the least effort and adaptation in the surrounding.

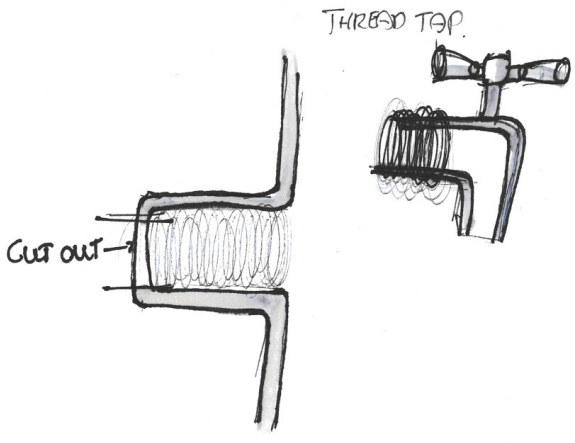


Figure 4.3 The screw thread connection for the tap

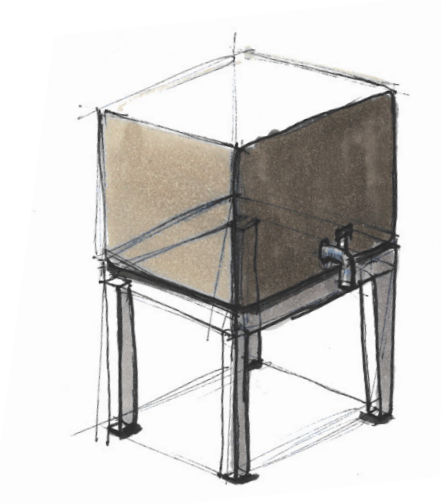


Figure 4.4 The princple for the placement to heighten the barrel

4.3 Testing phase

Making powder and doing rotomoulding tests

In this section, the testphase is described. These tests are both about making powder from the agglomerate and executing rotomoulding tests. The first tests to make powder and shred the matarial were caried out at the faculty, afterwards tests were executed at Zweva.

4.3.1 Introduction

As far as known, the leftover mix fraction has not been processed with rotational moulding before (nothing has been published). Therefore, tests had to be executed to show the potential of the mix using this technique.

As described in scetion 2.3 the input material of rotomoulding is powder, so the agglomerate has to be grounded into powder. Therefore, a search started finding a grinding and rotational moulding company. It turned out that rotational moulding companies mostly do not grind their own material. Getting the right powder specifications is craftsmanship, so this is done by companies specialised in making powders for the rotational moulding industry. Big machines are used for the powdering process, which made a lab scale set-up hard to find.

Additionally, grinding companies are hesitant about metal which could be in the material. Since the grinding process needs to be very accurate, the machinery is expensive. Metal could damage the machinery faster than other materials. Moreover, textile and paper are bad for this process. They will constipate the sieves which will slow down the process.

4.3.2 Zweva and first professional tests

Then, Zweva appeared. Zweva is a company that develops rotomoulded semi-underground waste tanks and rotomoulded access chambers, battery boxes, tanks and closures (Zweva.com,n.d). They cover the hole chain, from the first idea till the final product which makes them a very interesting party to work together with. Pieter van 't Veer, the CEO of Zweva was open to do some tests. A first test was executed with sample material from Hubert Eing, whole agglomerate, mixed with virgin material (see pfigure 4.5). The agglomerate sticked to the virgin material. That showed enough potential to do some further testing with powder out of agglomerate. Therefore, powder needed to be made and consequently, 1000 kg material was needed. Cabka was willing to donate this 1000 kg of PO95 agglomerate so tests could be carried out. This was

Figure 4.5 The first test with non powdered agglomerate together with virgin material into existing moulds of Zweva

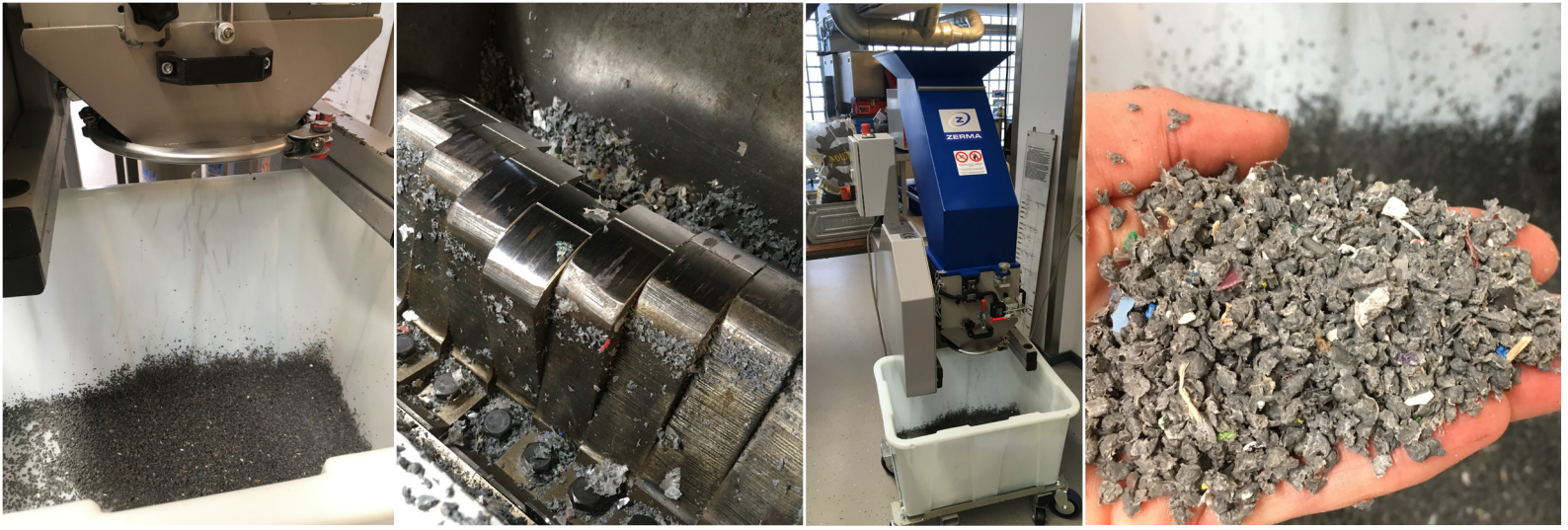


Figure 4.6 Doing tests with the slow granulating machine at the faculty. The picture on the right shows the result of the shredded material

transported from a division in Belgium, to Zweva Engineering, also in Belgium. Zweva contacted their own material grinder company who had a smaller testing machine to make powder out of the agglomerate.

One of the problems that occured was that grinding machines had an input of material with dimensions of 5x5x5 mm. The agglomerate is varying in size till 15 mm, which makes it unsuitable. Therefore, a test was executed on the faculty with grinding this material in a slow grinding machine, as shown in the pictures in figure 4.6. This slow grinding machine worked out pretty well. This test material was brought back to Belgium where a small test was carried out with grinding the shredded material. This worked out pretty well, powder was made (see figure 4.8)! However, the dryflow turned out to be 0, as can be seen in the picture in figure 4.7 .

Even though the dryflow was 0, moulding tests were carried out. The first test had a multilayer structure. Virgin PE was feeded into the mould first after which the powder of the agglomerate was added. This test showed potential, but when looking through a microscope, the recycled material looked brittle and not solid (shown in the third picture in figure 4.8). An iterative second test was done with only recycled material, where the temperature was risen. This turned out in a much better homogeneous material, looking through a microscope again (figure 4.10).

Additionally, two tests were executed with trying to foam the recycled material (picture on the most right, figure 4.8). However, this did not work out yet. It looks very similar as the first test with the multi-layer structure. Some additional tests are required to see if foaming has potential.

Another 1000kg PO95, is donated by Hubert Eing, which is transported to Maag, a German grinding company that carried out tests with making three sizes of powder out of the agglomerate: 425, 500 and 630 microns (shown in figure 4.12). First tests with these three powders are executed and the 425 microns seems to have the best surface finsihing. Rising the temperature to optimise surface finishing does not help. The material even burns, which also happens with virgin material according to Van 't Veer. Futher inspection and testing is required to draw conclusions for these powders.

4.3.3 Tests on the faculty

Besides the tests in Belgium, previous tests to make powder out of the agglomerate were carried out on the faculty of Industrial Design Engineering.

Figure 4.7 From left to right, making powder, measuring the dryflow, test setup and first test with virgin material

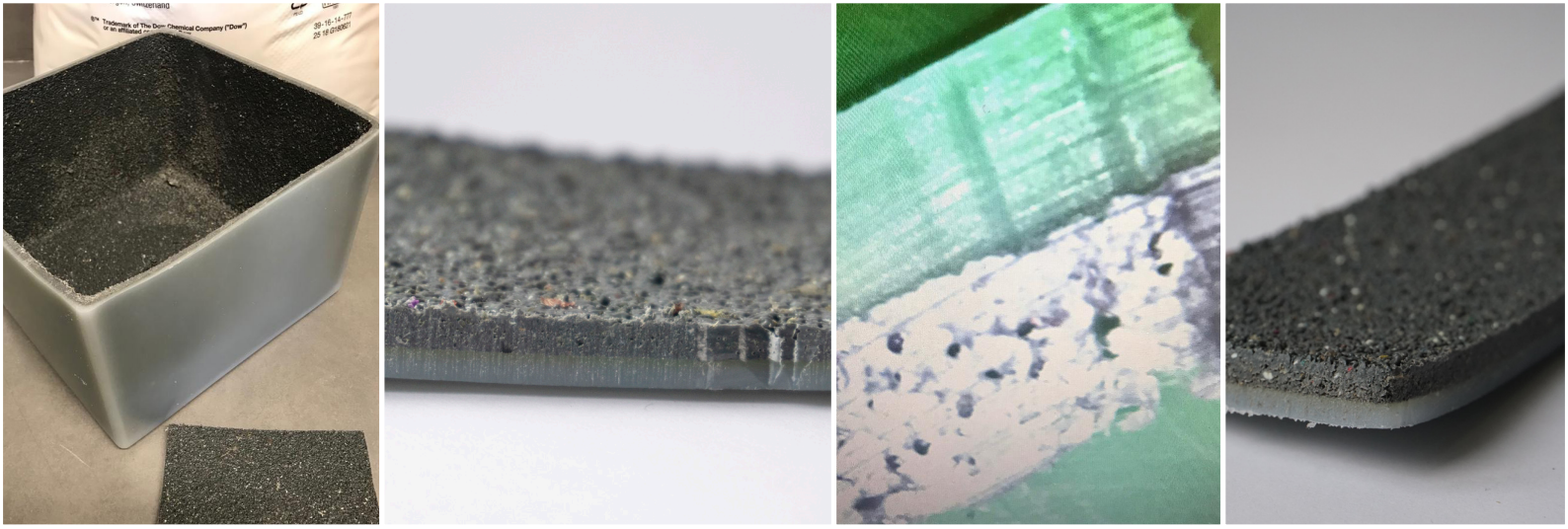


Figure 4.8 First test with multi layer structure. Virgin on the outside, recycled content on the inside. The right picture is a test with foaming.

A first test was done with a manual coffee grinder. This grinder was very small and not strong enough to grind the material. Besides a manual coffee grinder, an industrial automatic coffee grinder machine was tested. The material melted right away because of the friction that brings heat (figure 4.11). A second test with this automatic grinder was done with liquid nitrogen to see if the material would be grindable when frozen up to - 196°C. The material was put into a basket after which liquid nitrogen was thrown over it (figure 4.11). Then the frozen material was feeded into the coffee grinder. This can be seen in the photos. This worked out better, but the machine got also stuck. Also a test with a manual meat grinder was done, since this is a slow grinder which might prevent the material from melting. This meat grinder (figure 4.11) was very old and not sharp anymore. It worked out a little, but is was a lot of effort and it did not make powder, only slightly shredded the material.

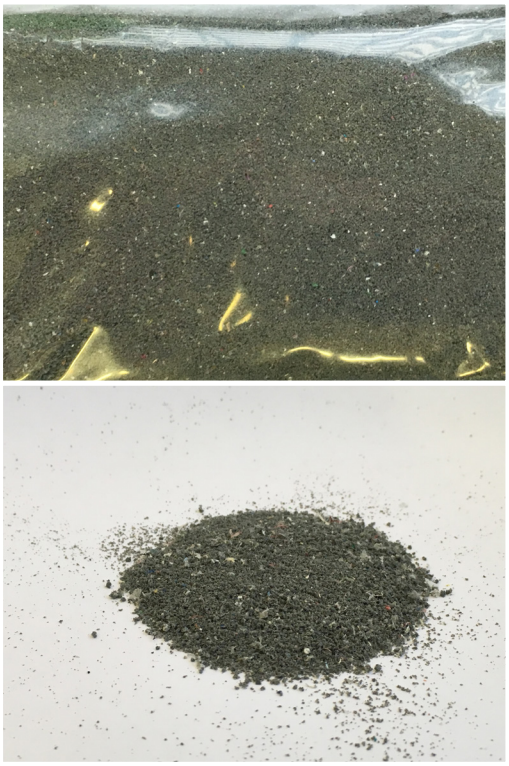


Figure 4.9 Powder out of the machine showed in figure 5.5. In the powder, irregularities and larger pieces of foil can be seen

4.3.4 Conclusion

The tests that were executed in Belgium really showed potential of this material processed with rotational moulding. It can be called a breakthrough, since this is not done before.

Figure 4.10 Test with 100% agglomerate. Under the microscope, it can be seen that the material turned out more homogeneous.

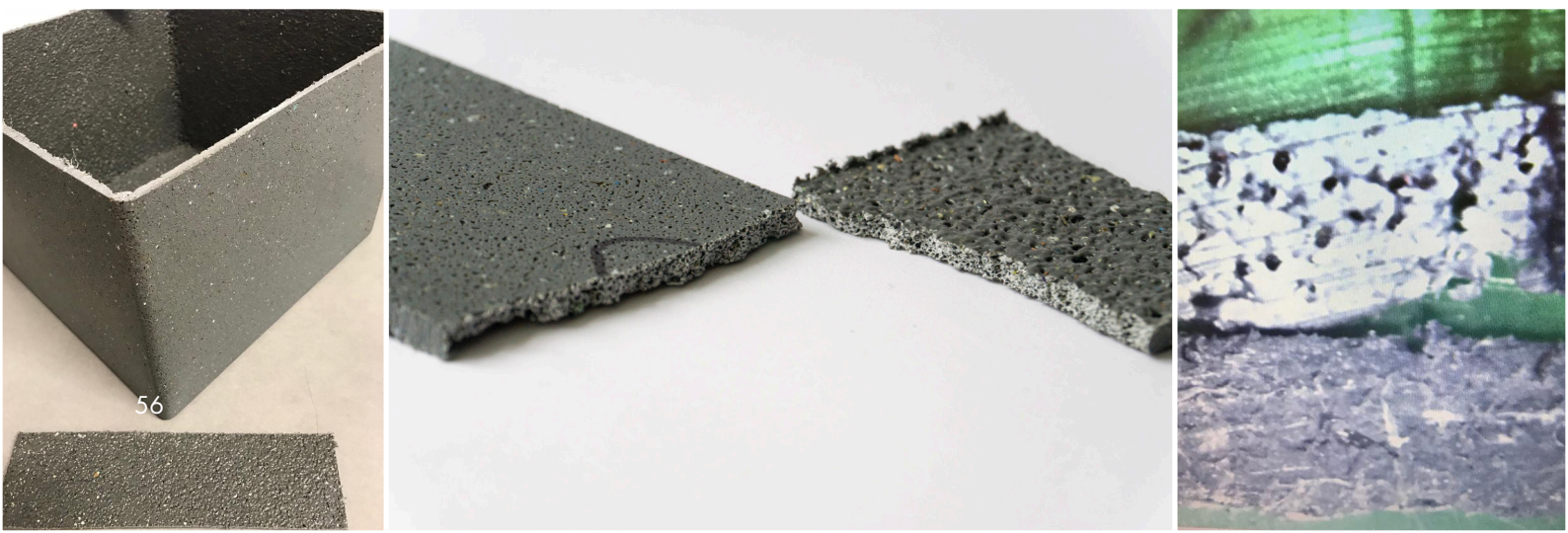


Figure 4.11 From left to right: the testing material PO95 agglomerate, melted plastic in the coffee grinder, and the meat grinder with a some shredded agglomerate.

Look and feel

Looking closer to the test with 100% recycled material, the look and feel is nice. The test piece contains a lot of little bubble holes, also on the surface. These little holes together with the colour, makes it look like concrete. When looking closer, some little white and coloured grains can be found which give it a nice expression. These grains contribute in the material looking recycled in a positive way.

This subsidy was 50% maximum of the complete budget, so the companies have to invest as well. Midwaste together with Zweva applied and almost €48 000 was raised, which is a very good start to develop the material to make it applicable in the current rotational moulding industry, Besides that, it could open a new market to develop products like the rain barrel.

4.3.5 What's next?

Making powder out of the agglomerate is the biggest challange, but tests showed potential. Besides developing suitable powder, tests need to be carried out regarding to the additives to provide the material with better quality. Additionally, the characteristics of the material needs to be defined.

To help the development in optimising the material qualities further, an application was sent to request subsidy. This subsidy was part from an innovation pilot from KIDV (Kennisinstituut Duurzaam Verpakken) and 'Rijkswaterstaat' under the programme 'Kunststof Verpakkingsafval als Grondstof' (plastic packaging waste as resource).

Figure 4.12 Tests with the poweder produced at Maag, left 425 microns, middle 500 microns and right 630 microns.

Insights

The testphase was tough since it did not work out on small lab scale at the faculty. The dependency of other parties carrying out tests delayed the project. However, it was all worth it, since potential is shown. Making powder in a complicated process, which was a little underestimated. The charateristics regarding strength and stifness of the material needs to be tested in further research.


Circuleen

5

Detail Design

5.1 CirculEm

A space efficient rain barrel for urban areas

In this section, CirculEm is introduced. A rain barrel for people with a small outside space that want to participate in a circular economy, want to save some rain water for their plants to reduce heat stress in dry periods and want to have a modern rain barrel.

5.1.1 Introduction

CirculEm, shown in figure 5.1 and 5.12, is a relatively small rain barrel, especially developed for households with a small outside space because of its space efficient design. The collected rainwater can be used to supply water to plants or to clean windows.

5.1.2 The story behind

The modern design blows a freshwind through the dusty image of rain barrels, which makes it attractive for young families and starters. Moreover, it is an interesting product for everyone who wants to participate in working towards a circular economy.
CirculEm sets up the collaboration between municipality and communality to tackle heat stress and water management, something which municipalities long for. Municipalities are looking for climate adaptation solutions on private areas since the major surface of cities is private area. CirculEm would be a good starting point to create awareness among their inhabitants about water management on private area. To really tackle water management, it should be on a larger scale, in which a next step would be big underground water tanks. It became clear during conversations with municipalities, that they are working on their policies regarding households collecting their own rain water (Municipality of Rotterdam and Breda, 2018) in which CirculEm is a good conversation starter. Besides that, it is a good conversation starter about separation of waste using as a resource to create valuable products out of it.

"Offering a package as a whole is absolutely adding value to the product. I wanted to buy a rain barrel, but I was completely lost when I was looking for the right overflow"

- Vincent Kuiphuis, Advisor Public Space, municipality of Breda.

CirculEm

The definition of CirulEm is: the first-person plural imperative form of something circular. CirculEm is a an early adopter in combining two aspects of working towards a circular economy. At its own, it will not make a difference, but together it could, which refers to plural. Besides that, the last two letters of CirculEm refer to my personal name.

5.1.3 The complete package

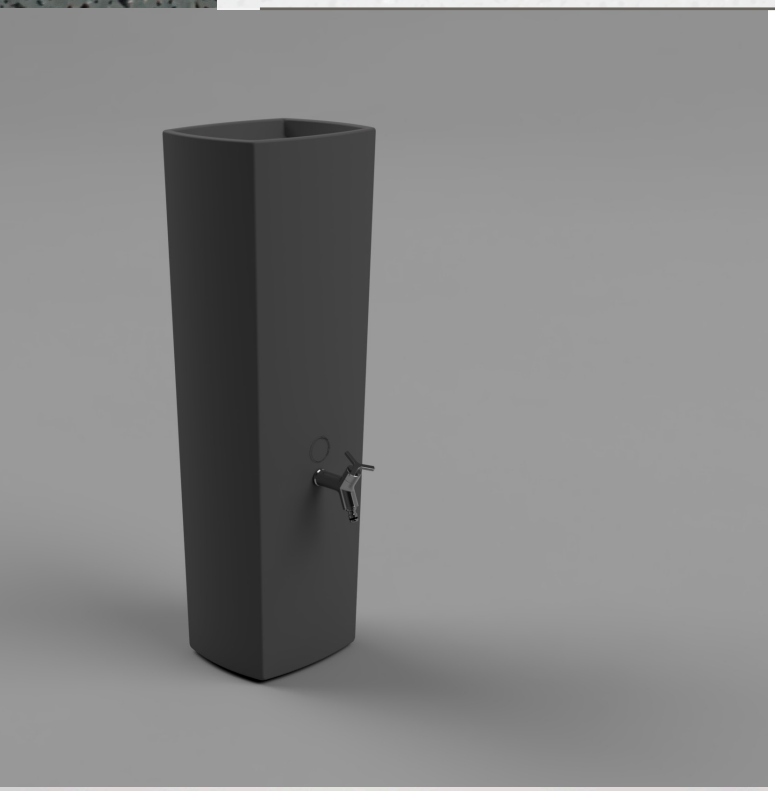
The tap and the rain pipe overflow are delivered together with the barrel, which makes it a complete package and easy and fast to install. Per municipality it could also be combined with a social workplace that provides people to install this rain barrel at people's homes. This would even add more value to the product and creates an extra social return to inhabitants of municipalities.

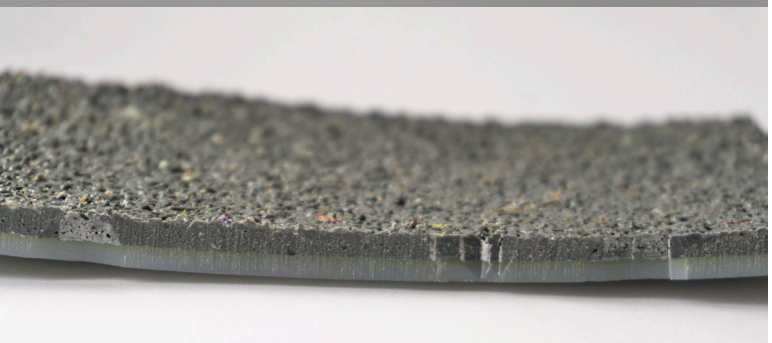
Reflecting on the theory of a circular economy described in paragraph 1.2, CirculEm is thus responding on different aspects of working towards this circular economy. Firstly, using waste as a resource, secondly creating a product that responds to heat stress and in direct on water management and thirdly with saving water.

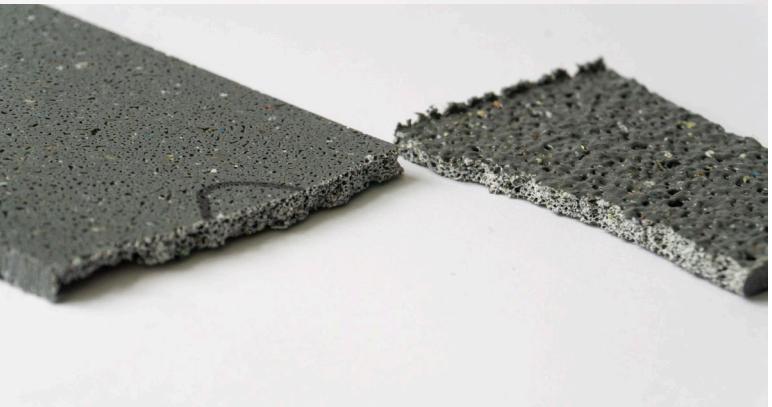
Parts in detail 5.2

The barrel, tap and overflow

In this section, the different parts of CirculEm, the barrel and its mould, the tap, and the overflow connection, are described and visually shown.







5.2.1 Introduction

The barrel consists out of three main parts: the barrel, the tap and the overflow. These three parts can be disassembled, which makes it easier to recycle. These three main parts and the connection among these parts are described below.

5.2.2 The barrel

Composition

The barrel consists out of two layers, the outer layer made from the leftover mix fraction and the inner layer made out of virgin HDPE. The outer layer gives the appearance of the product. The specific expression of this material shows that the barrel is made out of recycled material. If you look closely to the surface, different colours can be distinguished and irregularities in the material is visible (figure 5.1). Since the material characteristics are still unknown, the inner layer of virgin material will provide stiffness and strength to the barrel. When the material characteristics of the mix are known, the virgin layer might become thinner or even unnecessary. Besides the two layer composition, a brass insert is moulded into the barrel for the placement of the tap.

The stand of the barrel in integrated in the design (see figure 5.1). Therefore, no connection between the stand and the barrel is needed. Besides that, the barrel will be stabilised by the weight of the water that will remain in the barrel. This water will only leave the barrel if the barrel is tilted. This also makes the product more lightweight

Figure 5.1 The design of CirculEm, the multi layer construction and the surface finishing.

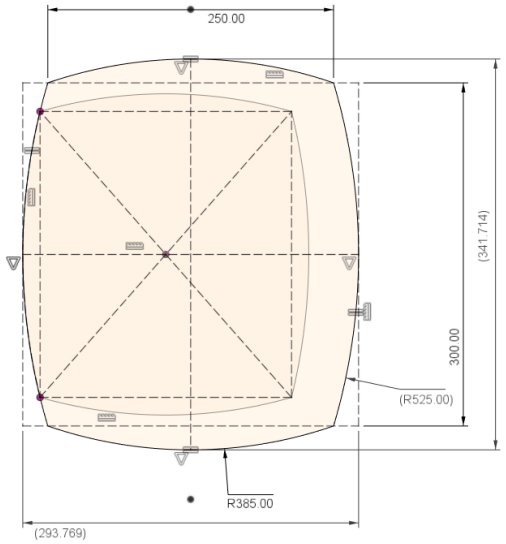


Figure 5.2 The topview sketches of CirculEm

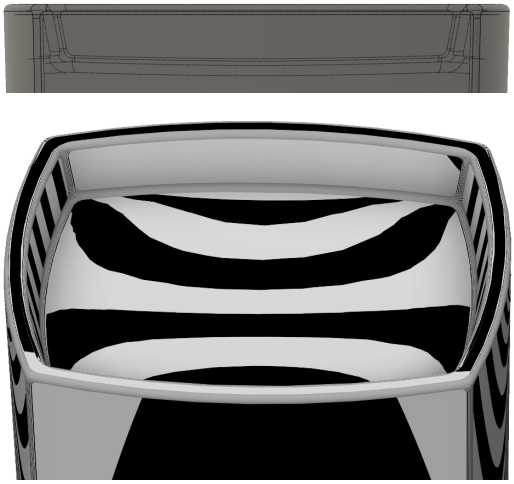


Figure 5.3 The bended surface in the caption on the top

during transportation, since the barrel is empty during transportation. This is better for the working conditions and it saves CO_2 emission during transportation. After placement, the barrel should be filled up till tap height to stabilise it. The formstudy to integrate the stand with the barrel can be found in appendix E1.

Aesthetics and construction

The shape of CirculEm is almost symmetrical. Looking from aside, the angle of the backside of the barrel is straight and at the front, this wall it tapering out in upside direction. This irregularity is to put the barrel close to the wall. It gives a satisfying feeling saving space by putting it close to the wall, something which people pointed out being an advantage during the conducted interviews.
In the front view, the barrel is symmetrical in the vertical axis. The placement of the tap is on about 1/3 of the height which makes it unsymmetrical (see figure 5.1 and 5.8). This height gives a good feeling of proportion without looking boring.

The curved shape of CirculEm is both elegant and practical. Looking at the design parameters (appendix B5), flat walls need to be prevented where possible. Curved walls both provide stiffness and prevent warpage. If a little warpage occurs within a specific situation, it is less visible than with flat walls. Moreover, these curves increases the angle (figure 5.2) which makes its easier to be moulded. The edges are rounded with a 6.5 mm radius which is the ideal angle for PE (see design parameters in appendix B5).

On the top of the barrel, a caption is made to put in some small plants or flowers, or make it a swimming pool for birds. The surface is slightly bent inwards which is shown in the zebra analysis and side view in figure 5.3, to prevent warpage. At the same time, this caption demotivates people to sit on the barrel, an unwanted behaviour. The downside of the barrel contains a rib structure to add stiffness and again to prevent warpage, shown in figure 5.4.

The tapered shape in vertical direction, makes the shape interesting and at the same time, nice draft angles arise which makes it easier to demould the barrel.
Lastly, the barrel has a small caption on the bottom which makes it look lightweight and elegant, shown in figure 5.4.

The barrel is 29.3 cm deep, 34.2 cm wide, and 104 cm high, also partly shown in figure 5.2. The complete barrel could contain 75 L of water, of which 50 L can be used. 25 L of water will remain in the barrel in the area under the tap to provide stability. By tilting the barrel, it could be emptied during winter time, to prevent breakage due to expanding ice, or to refresh the water.

To check if the barrel is stable enough, the required force is calculated on different heights of the barrel

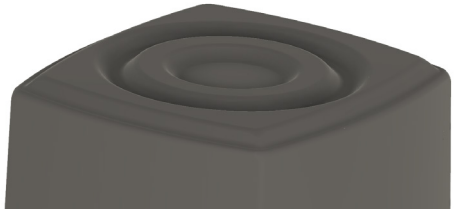


Figure 5.4 The bottom of the barrel with the rib structure and the caption

Required force to tilt the barrel for different water levels

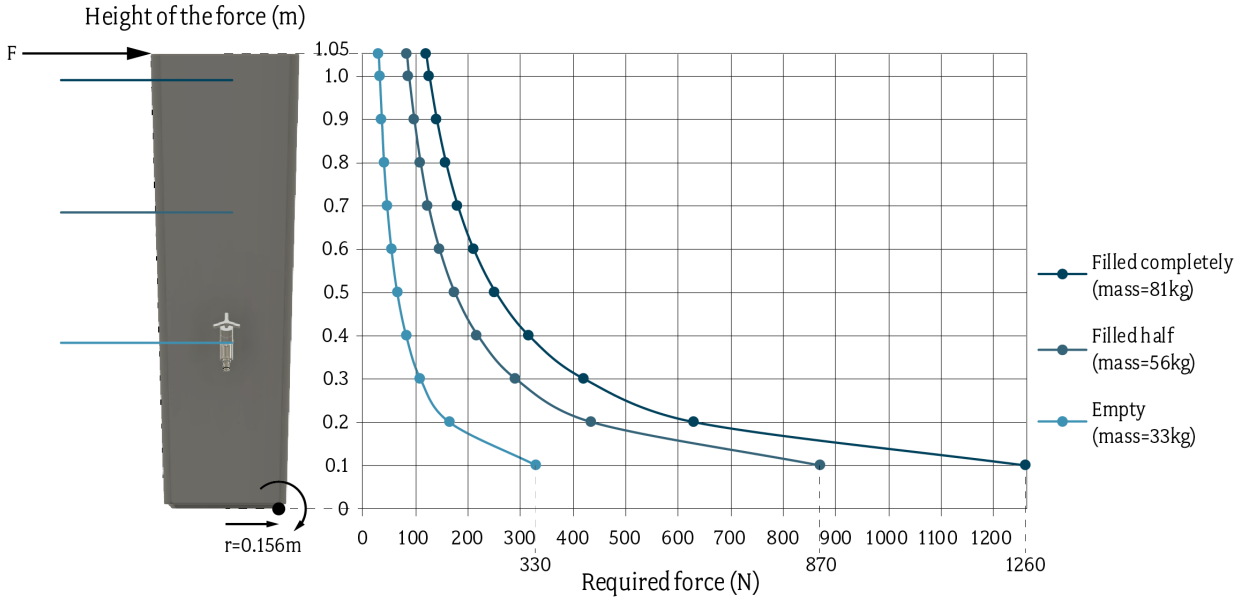


Figure 5.5 The required force tot tilt CirculEm on different heights and on different water levels.

and with different water levels. Figure 5.5 shows the results of this calculation, the table of this calculation can be found in appendix E2. When the barrel is completely filled, 126 N is needed to tilt the barrel, equally to 12.6 kg. When the barrel is 'empty', 33 N is required.

At three different water levels, a wind velocity of 145 km/h when completely filled, 120 km/h when filled half, and 74 km/h when 'empty', is required to tilt the barrel.
These wind velocities will not occur very often and the barrel will be be sheltered in most situations, which makes the chance to a wind load of that power even smaller. The calculation of this wind load can be found in appendix E2.

Wall thickness

Looking at existing similar rain barrels, the wall thickness seems to vary. Four barrels has evaluated and the thickness varies from 2 to 8 mm. The overview of this study can be found in appendix E3. The thickness does not necessarily relate to the size.

Besides looking into existing models, a simulation is done in Fusion 360. Three different wall thicknesses (1, 5 and 7 mm) are simulated in two different situations. The first situation is a hydrostatic pressure simulation in which the barrel is exposed to the highest possible water level. This is halfway the overflow pipe at the height of 950 mm. The second simulation is a drop test from 1 m

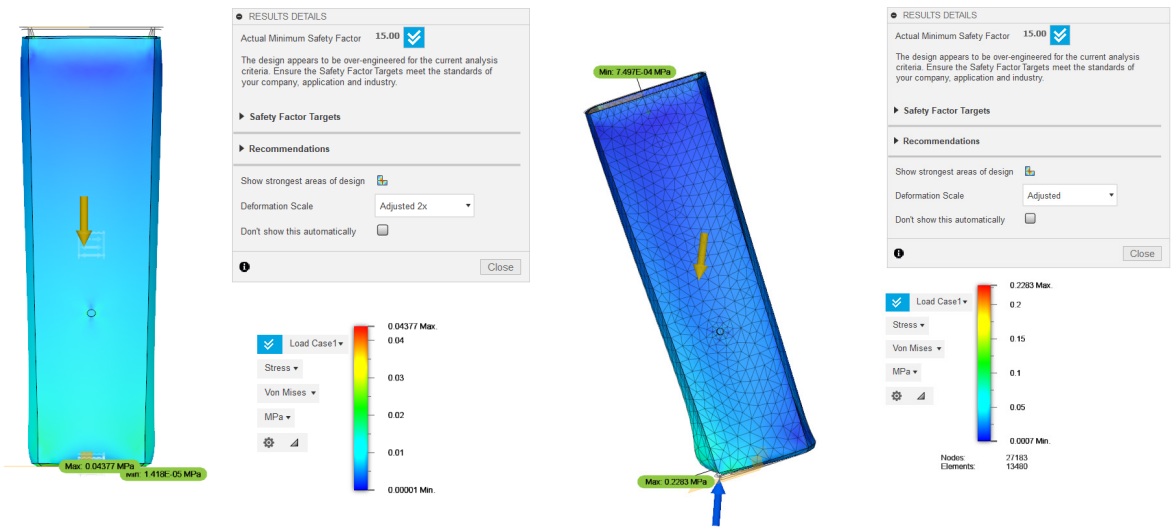


Figure 5.6 Two simulation tests in Fusion 360. Left, a hydrostatic pressure test , right,a droptest. Wall thickness is 5mm in both cases.

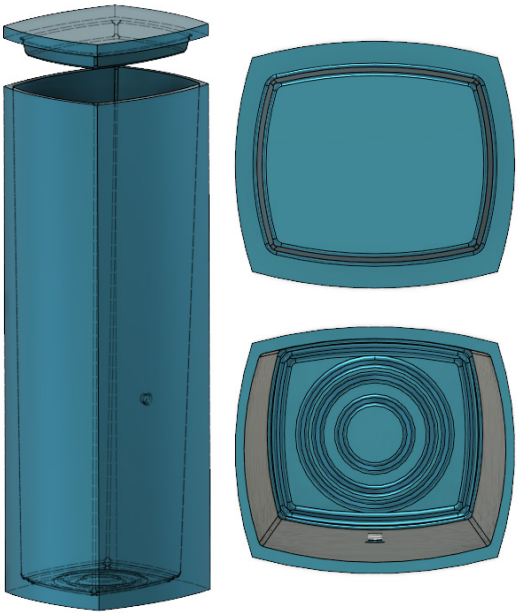


Figure 5.7 The mould of CirculEm, left, tot two parts of the mould, right, the topview of the two parts.

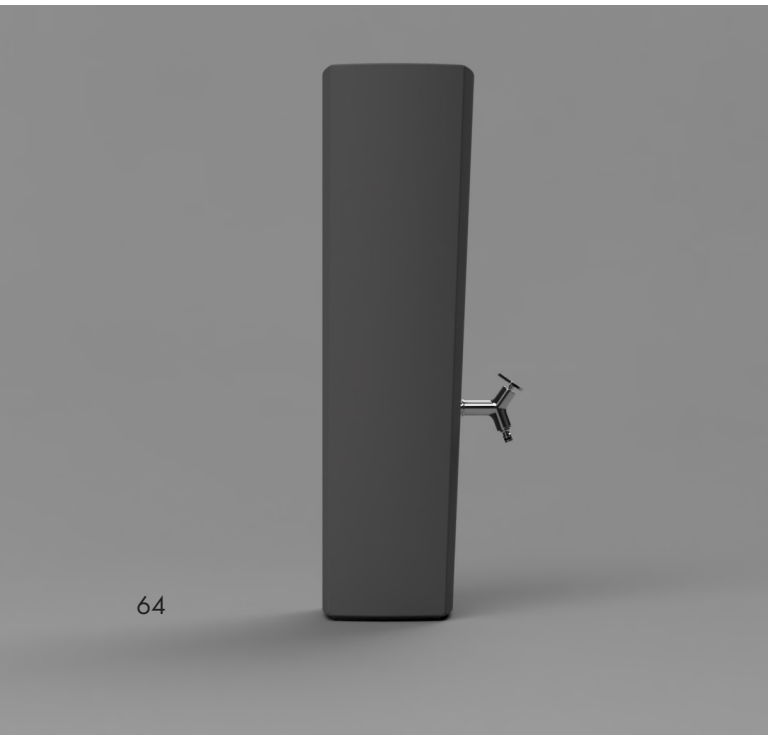
height, when the barrel is completely empty. Both cases are shown in figure 5.6. This situation could occur during transportation and installation. The set-up of these simulations and the results can be found in appendix E4.

Based on existing barrels and guidelines of Zweva, the wall thickness is put on 6 mm, consisting out of 3 mm virgin HDPE, and 3 mm of recycled material.

Mould

The mould of the barrel is pretty straight forward. Figure 5.7 shows the two parts of the mould. The parting line will be on the top of the barrel and will be a visible line in the product. The only difficult part is the insert of the tap which needs to be installed before starting the moulding process and removed before demoulding the product.

Figure 5.8 The sideview of CirculEm



Moulding this barrel will take about 30 minutes. After the moulding, the overflow connection has to be drilled and the product needs to be packaged before transported.

5.2.1 Tap

The tap of CirculEm is a standardised part (see figure 5.9). A more modern tap has been chosen to make it fit to the looks of the barrel. The main reason to go for a standardised part is to save costs.

This tap is from Garantia and costs €23,90 at mytoolsstore.com. When purchasing this component in larger amounts, this would costs around €9,50 ex VAT.

With the thread, it is easy to install the tap into the barrel. With seal tape, leakage can be provided. To install the tap, it needs to be turned only five times.

5.2.2 Overflow

As well as the tap of CirculEm, the overflow to the rain pipe is standard part. For this connection, the least adaptation was required. Besides that, the connection between the barrel and drain pipe is flexible which provides flexibility in the placement of the barrel.

Figure 5.9 The tap of CirculEm

Figure 5.10 The overflow of CirculEm

Figure 5.11 Overflow systems which are possible to close or off or with an included filter.

The connection system costs €18,95 at tuinadvies.nl. When purchasing this component in larger amounts, this would costs around €7,50 ex VAT.

To install this connection, a hole has to be made with the provided drill attachment. Then, the silicone part needs to be put through this hole and the other side of the pipe must be pushed inside the barrel, shown in figure 5.10. The pipe needs to be as horizontal as possible to make sure the overflow system works optimal.

This connection does not provide the option the close off the water supply into the barrel or filter it to save costs. Figure 5.11 shows the two options of the water filter of the closing off system.

5.2.3 Packaging

The packaging of CirculEm should be very simple, consisting out of cardboard. The dimensions of the packaging should be 40*30 cm to make it possible to transport 8 rain barrels on one euro pallet. A very first impression can be found in appendix E6.

Figure 5.12 An impression of CirculEm on a balcony

5.3 Costs

What is the price of CirculEm?

In this section, the costs of the production of CirculEm are given. These prices are based on the knowledge of experts and is a rough estimation. These prices can be interpreted as high.

5.3.1 Introduction

Currently, Midwaste is responsible for 2.3 million households in the Netherlands concerning the plastic dossier. This means that 2.3 households are the possible sales market. To make a rough estimation, a small 1% of this target group is taken as a possible buyer.

The price of CirculEm excluding VAT, is about €67,- . This price is based on prices of the mould, the material, the production, transportation and standardised parts. The full description of how these costs are calculated can be found in appendix E5.
The most valuable part of the product is the production cost. Besides that, the tap and the overflow are relatively expensive. Probably, these parts could be cheaper.

The retail price could be around €165,-. If CirculEm is subsidised by municipalities for 25%, the price could be around €125,-

Design conclusion and discussion 5.4

Discussing the results of the design

This section describes the result of the design in different parts: the conclusion and the discussion with recommendations. It focuses merely on the design and technical aspects of the concept. Discussion related to the project can be found on in chapter 6.

5.4.1 Conclusions

CirculEm is a rain barrel that tells a story about working towards a circular economy. Using grey water, made out of waste; a perfect conversation and innovation starter. A conversation starter about climate change and how to create value out of waste. An innovation starter by showing the possible value of this material used to make useful products and a way to show that it does matter if you separate your waste. CirculEm has a space efficient design for people who wants to participate working towards a circular economy, but do not want to give up much of their valuable outside space. With the expression of the shell that shows that it is different than other rain barrels, CirculEm is unique in the market. A minimalistic design which the user could personalise with the caption on the top. Putting plants inside, or leaving water for birds to bath.

CirculEm is made out of mix plastics for about 30%. Since the characteristics are still unknown, the stiffness and the strength of the barrel are coming mostly from the invisible virgin layer. When there is more information about the material characteristics regarding strength and stiffness of the mix agglomerate, the amount of virgin could decrease.

The barrel is easy to mould since there are no undercuts and wide draft angles. The brass' insert will require an extra step in placing before moulding and removing before demoulding. After moulding, a whole for the overflow connection needs to be drilled which is also an extra step.

Requirements and wishes

CirculEm houses 50 L of water that can be used and only takes about 0.1m2 groundspace (0.35*0.30m). It is lightweight which is preferable during transportation. Installing is easy. Only making a small hole in the drainage pipe after pushing the connection into the pipe and the barrel. The barrel could be stabilised by filling the barrel with some water. This overflow system makes sure that when the barrel is filled, water will flow into the drainage pipe automatically, when installed correctly. CirculEm uses standardised connections which makes adaptation and replacement possible. Therefore, CirculEm meets all the requirements and the most important wishes.

5.4.2 Discussion and recommendations

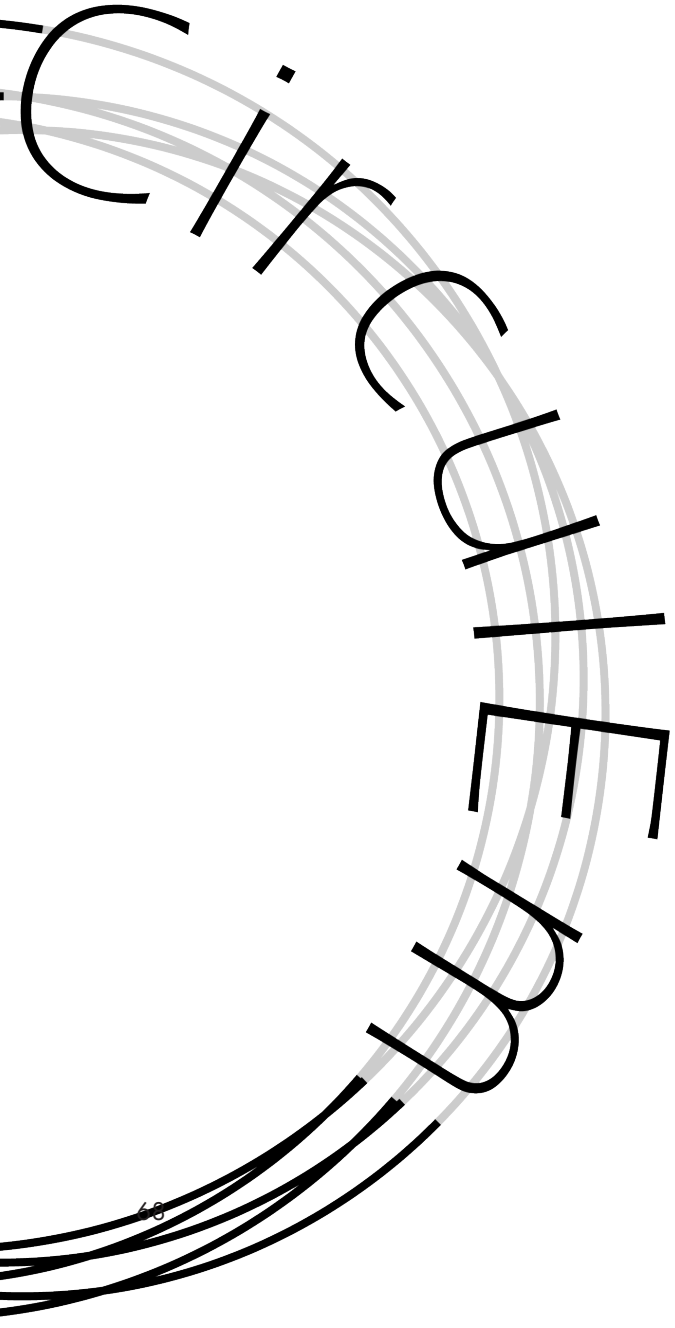
Wall thickness

The wall thickness of the barrel might not be optimal. The simulation shows that 1 mm already meets the safety factor stated by fusion 360, but this does not seem realistic. An optimisation step could be done to find the optimal wall thickness of the barrel. A good way of finding this, could be done during the first tests with the mould. These tests could be done easily without mould adjustments, a significant advantage of rotomoulding. The model in the simulation also has been simplified to make the calculations faster and easier. The rounded edges have been neglected in the model. For the result, this would influence a stress concentration in and around the edges. This stress would become

less when edges are rounded. The stress peaks are currently in the bottom edges of the barrel, but might decrease a little when the edges are rounded.

Two layer construction

As mentioned before, the wall consists out of two layers. A drawback of this multi-layer construction is that it is harder to recycle again after discarding. However, when the product is discarded at the end of its life, the chemical separation might has developed further. Otherwise, the barrel could still be recycled, but will end up in a similar stream as it is currently from, the leftover mix fraction.
Besides the recycling part of the multilayer construction, the behaviour between these two layer has not been researched yet. Looking at the first test pieces, there is a yellowish haze in the white virgin part. Floris Roukens, another expert in the field of rotational moulding, evaluated this as 'sweating' of the recycled layer. It could be a thermal reaction, but it is still unknown. Moreover, there could be a difference in shrinkage between virgin PE and the leftover mix fraction. If there is a difference, possibble solutions could be researched in the adaption of additives.



Insert

When CirculEm is discarded, the brass insert, needs to be taken out of the plastic part. This insert is not optimal, looking at the end of life part of the barrel. However, this connection assures watertightness of the barrel on a vulnerable spot and could provide a better lifespan of the product.

Modularity

During this process, modularity has also been researched. However, the focus was on developing a module which was a product on its own, since the most households only need one module.
The study that has been conducted to make CirculEm modular, can be found in appendix E. The modularity was considered less important, since the biggest part of the target group only needs one module, so it was important to make one module, a product as a whole. Besides that, households who prefer having more water, so more modules or a larger barrel, most probably have a larger garden or balcony. In these cases, space efficiency less important. Moreover, CirculEm focuses on people who want to participate in a circular economy and makes people aware of recycling both domestic plastic waste and water. It offers a solution for people with smaller outside spaces in which the current market does not offer that much.

6

Conclusions

6.1 Conclusions

The conclusions of this project

6.1.1 Recap

In this project, the possibilities of the leftover mix fraction of plastic domestic waste, PMD, are researched. The mix, with DKR350 standards, is one quarter of the total amount of plastic waste and there is still an open field of possibilities and challenges with this material. The material consists out of polyolefins(90%), PE/PP, and impurities (10%). The composition and quality of the mix fluctuates which makes it a challenging material to work with. Additionally, the composition of the material will change in the future because of the ongoing optimisation of plastic separation techniques. Therefore, the quality of the mix likely to decline since the good plastics are separated out of the mix. The percentage of mix is also likely to decrease because more material will be separated into the mono streams. However, the technology for this separation is not developed enough yet. This results in challenges for the current leftover mix.

The initial goal in this project was to develop a valuable product with the mix to show its potential. It appeared that the mix was not processed with rotational moulding yet. By doing some tests, both with producing powder out of agglomerate and rotomoulding this powder, the potential of the material using rotational moulding has been proved.

Besides proving the potential of the leftover mix, a product is developed that responds to two aspects regarding a circular economy. At first, using waste as a resource, and secondly creating a product that responds to climate adaptation.

6.1.2 Rotational moulding

Testing showed that it is possible to process the leftover mix fraction with rotational moulding. Using rotational moulding for the left over mix fraction of plastic packaging waste opens new possibilities in form freedom compared to extrusion and injection moulding (or intruding). It possibly opens a new market and besides that, this material could find its way in the current rotomoulding industry where it might substitute virgin plastics partially. The potential of this project was also noticed by the KVG programme. The project was rewarded with a subsidy of €48 000, which is half of the budget, to do further research in processing the mix using rotomoulding, during a pilot. KVG (Kunststof verpakkingsafval als grondstof, Plastic packaging waste as a resource) is a programme initiated by KIDV and 'Rijkswaterstaat'.

The characteristics of the material processed with rotomoulding is still unknown. According to Pieter van 't Veer, the material does not have the required strength and stiffness in order to be self supportive yet. Additives will stabilise the material, but further research needs to be done to see its influence.

Powder

Making powder out of the agglomerate is the most important and the most crucial step in the process of rotational moulding. The powder tested within this research does not have the right shape and characteristics yet. Tests showed that The fluctuation in composition and impurities are creating extra challenges. Within the innovation pilot the powder is the most crucial and will be developed and optimised further.

6.1.3 Product possibilities

Research showed that products made out of the mix tell a good story. Using plastic waste as a resource is one of the major themes in working towards a circular economy. Combing this theme with creating products that respond to other aspects that work towards a circular economy, like climate adaptation and energy transition, makes this story even stronger. Municipalities appear to be interested in products like these. With help of municipal subsidies, these products could also compete in the price range of products made out of virgin plastics. However, the story of the product will be the most important and unique selling point of these products.

CirculEm

CirculEm is a small rain barrel, partially made out of the mix, that responds to local heat stress. Municipalities, Breda and Rotterdam, seem to be interested in this product, because they are looking for solutions regarding water management on private area. Since 60% of urban area is private property, solutions on private property could have a significant impact. CirculEm might be the missing link between municipalities and the commonality by starting the collaboration in tackling climate adaptation on private areas. An estimation shows that CirculEm could be produced in a price range of €95,- and €160,-. The price is highly dependent on the production costs of moulding the barrel.

6.2 Discussion and recommendations

What is next?

6.2.1 The mix in rotomoulding

The characteristics of the leftover mix processed using rotational moulding are still unknown, and further testing needs to be executed to research these characteristics. Also the durability has to be tested and how this could be influenced by additives. When all characteristics, a new range of products could arise in which the unique characteristics of this material could be used. Characteristics like the residue moisture which will boil during processing which causes pinholes. This creates a unique surface finishing and material expression which reminds of concrete.

It is discussable to blend the mix with virgin material regarding to the end of life aspect of CirculEm. On the one hand, something has to happen with this material right now. On the other hand the problem is only postponed and relies on the development of chemical separation, hoping it is further developed in ten to twenty years. When the characteristics of the mix are known, the layer of virgin material needs to be minimized if possible. Another option would be to collect discarded rain barrels to make sure the material of the barrel goes back into the recycling chain.

In the current rotomoulding industry, almost nothing has been done with recycled content, only their own production waste is reused again. Therefore, it could be interesting to look at verifying the potential of mono streams out of the separation of plastic waste as well.

The mix, when rotomoulded, currently is brittle and not completely solid. Looking at the cross section, pinholes can be seen, which could mean that the material is not watertight, or cannot guarantee that it is watertight. It could be interesting to look at applications that ask for the material to 'sweat'. Additionally, it is uncertain whether this is influenceable with additives. During the innovation pilot of KVG, this potential influence will be researched.

Besides rotomoulding, also other processing techniques could be investigated. One of the techniques could be thermoforming. With thermoforming, sheet material is the input. When sheets could be produced out of the mix fraction, for instance with pressing, thermoforming might work. Looking at the influence of impurities in injection moulding and extrusion, tolerances will be likely less accurate, but testing should be done to research the behaviour of the mix.

6.2.2 Product possibilities

If rotational moulding proves to be a success, a scala of new products could be developed using the leftover mix fraction. In an ideal situation, the mix partially replaces products made out of virgin. Further research and development (in the innovation pilot of KVG) of this material using rotational moulding has to proof to what extend this material might replace virgin plastics.

6.2.3 The design

Besides the development of the technique using the leftover mix fraction, also the design of this project could be developed further.

User research

At first, more research is required, in a larger group of people, in order to verify if CirculEm meets the needs and expectations of potential users.
It influence of the price on buying a rain barrel needs to be verified and besides that the price from CirculEm needs to be set. People might perceive CirculEm differently since it is made out of waste and tells a story, which might influence the price people want to pay.
A higher segment would pay more for a rain barrel, but a larger part of this group also have a larger outside space available.

Wall thickness

Additionally, the technical development of the barrel could be optimised. At first, the wall thickness of the barrel. Since the characteristics of the mix are unknown, all the strength and stiffness of the barrel is based on the virgin layer. The best way to optimise this is by doing tests with moulding in different wall thicknesses. This might be combined with a final element analysis.

Modularity

During this research, modularity in rain barrels came up to provide more flexibility in placement and size. It was stated that for the major part of the target group, one barrel was enough. However, it could be interesting to verify if modularity is something potential users need and want. In an ideal situation, the barrels are connected with integrated or standardised parts. Therefore, more research in how the barrels connect is required.

The insert

The insert of CirculEm is made out of brass. It could be interesting to research possibilities that does not require a brass insert, which optimises the recycling possibilities of CirculEm. Another opportunity is developing a connection between the tap and the barrel in which an insert is not required. This would make the mould cheaper and the production time shorter.

The barrel shape

CirculEm uses the advantage of curved walls to both prevent and hide possible warpage. However, testing is required to see if these curves are optimal. Additionally, the ground surface of CirculEm is now based on theoretical design parameters. An expert should verify if this ground surface is optimal.

6.3 Evaluation

Looking back at this project

6.3.1 Introduction

In this section, I want to reflect on the project. There is reflected on some specific aspects which are the assignment, the process, the meetings, the design, the notebook I was using throughout the project and the coaching.

6.3.2 The reflection of this project

The assignment

The assignment of this project was broad, which made it hard to get focussed in the beginning of the project. When the focus towards rotational moulding would have been the starting point, the project could have gone more into depth. Besides showing the potential of the technique, more time could have been spent with testing the characteristics of the material and looking at the influence of additives. Moreover, besides the technique, more time could have been spent into the detailing of the product and testing with users. On the other hand, it is very valuable that this project leaded towards rotational moulding, something which was one of the results of the analysis phase. It was also good to have a back-up plan of using injection moulding during the project in case rotational moulding would not work out.

The process

During this project, I have developed myself is presenting myself. I noticed that sometimes, the way of presenting myself was interpreted as being insecure. However, I intended it differently. It felt more pragmatic in which I would gave the team the opportunity to disagree with the things I was doing and continue. It was very informative to get feedback about how I was approaching certain things and why I did it that way. It gave insight about myself and about how I approach situations and/or problems. The awareness helps me to develop myself towards a more independent designer into which you search for a balance between making your own choices as a designer, and asking people what they think.

During this project, I have seen almost all the different parties involved in making a new product out of domestic plastic waste. First, I have seen the separating factory Suez, afterwards I had the chance to see the sorting plant of Hubert Eing and lastly I have seen two rotomoulding factories of Zweva. Unfortunately, I did not see the powdering process of the agglomerate. It was very helpful to see everything to get an idea of how everything really works

Meetings

It was nice to prepare a presentation before every team meeting to discuss as many as possible during these meetings and profit from the moment everyone was in the same room as much as possible. However, I could have tried something different in the structure of these presentation to see what would work the best. In the beginning, too much focus was on the report, which I might could have avoided if this part was at another phase in the meeting.

The design

It was a challenge to come up with a valuable product in this project since the subject was broad. Everything was possible which made it hard to make decisions and finding the right direction. It was very helpful to talk with municipalities in this case, since they are the potential buyer. At

a later stage, it was important to approach the target group to verify if the product design would fit the target group. An additional questionnaire with extra interviews provided information how CirculEm should look like. The interviews gave insight to go back to the essence of the product and provided argumentation for design choices and overruled assumptions.

The black little notebook

During this project, I had a notebook to write down everything that was passing during the project. This varied from phone calls, to insights, ideas, mind maps till todo's. It was really helpful to look back once in a while to see how my thoughts and thus the project was evolving. Besides that, the product that could be made out of the leftover mix fraction was constantly on the background in which ideas were written down in this notebook.

Testing

IIt was a tough road in finding a partner to do some testing during this project. During summer, a lot of companies are on holidays which did not help. I found out that rotational moulders do not make the powder themselves so an extra step was needed. Companies who make powder, also do not do this on lab scale so more material was required. I was depended on the goodwill of other parties, which was frustrating sometimes. I am glad that I pushed myself to look further until I found something and I am even more grateful that Zweva was willing to do some testing and that they shared their experience. A special thanks to Stefan who came up with Zweva as a possible party.

Innovation pilot

Applying for a subsidy was a good learning experience. Already in the beginning, we all knew that this innovation pilot programme was existing, but it was decided to focus on the graduation project. Close to the deadline of the pilot deadline, it turned out to fit the project, so we applied. It was a good experience to do such an application and to see how these procedures could work. When we raised the subsidy, I had the honour to present the project at the kick-off of this programme in which the other projects that raised a subsidy also presented their project. During this kick-off day, it was inspiring to see what other project are going to do and it really showed the possible value of this project.

6.3.3 Conclusion

Overall, I am happy with the result of this project. It is always interesting to look back at the starting point of the project and see the results which are almost always surprising and unexpected in the beginning. I learned a lot about managing an independent project and about myself. I am very grateful for the guidance the team gave me during this project and challenged me to get the best out of it.

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