RETURNING THE SHELLS TO THE BEACH

DEVELOPMENT OF A BEACH-CLEANER ADD ON, ENABLING THE MOBILE SEPARATION OF SHELLS AND GARBAGE

Master Thesis Report

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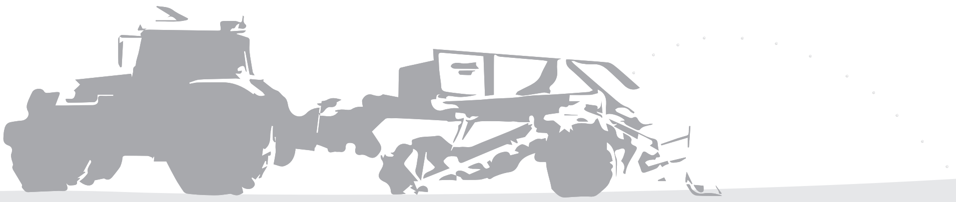

"Returning the shells to the beach"
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Preface

This thesis shows the development of an add on for the beachtech-3000, a beach cleaner that rakes and screens garbage from the beaches. The add on makes it possible to separate the shells that are collected along with the garbage and return them to the beach where they belong.

This thesis was generated to conclude my master Integrated Product Design at the faculty of Design Engineering. I can say with certainty that this was the most challenging and fun project I did during my masters. I think the project has a good balance between research, ideation, prototyping and embodiment. A combination you like to see in an integrated product design project.

I would like to thank my mentor and chair for their feedback, input and help during the project. And my company mentor, Sander Minnoye who gave me the opportunity to do this project and was a great help during the entire journey.

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1 INTRODUCTION

1.1 BACKGROUND OF THE ASSIGNMENT

The beaches of the Hague are intensely visited during the summer months. Especially the beaches around Scheveningen are very crowded during warm summer days. A lot of recreational garbage is left by the visitors (plastic packaging, bottles, soda-cans fordable chairs etc.). In order to make the experience of the beach visitors as pleasant as possible, the municipality cleans the beaches multiple times a week. This clean-up is executed by use of so called beach cleaners. Beach cleaners are tractor pulled screening machines that collect garbage from the beach. Although thorough, the machines fail to effectively take in the smaller garbage. The amount of glass/plastic pieces, bottle caps and cigarette buts is therefore increasing slowly but steadily. A side effect of the cleaning process is that the beach cleaners take in large quantities of shells.

Not only do shells contribute to the natural appearance of the beach but they also prevent the beach erosion the Netherlands is so desperately trying to avoid. The municipality pays per ton of material that is disposed at the dump-site, a lot of disposal costs can therefore be saved if the shells are no longer collected by the beach cleaners.

Currently their is no effective way to clean the small garbage and leave the shells on the beach. Therefore the municipality is looking for a solution to this problem. The municipality has approached design studio DIDID to come up with a solution to the stated problems. Since the municipality is looking for more student involvement in these kind of projects, the faculty of Design Engineering in Delft got involved through this graduation assignment.

This report will first of all analyse the amount and composition of beach pollution, problems with current cleaning methods. Secondly it will investigate possible separation methods, capable of separating small garbage, large garbage and shells. In the second phase the found solution will be build, tested and analysed to see if it is fit for application on the beaches of the Hague. The assignment stated for this graduation assignment is as follows:

“Research and develop a system capable of removing small garbage (shards of glass, small pieces of plastic ,bottle caps and cigarette buts) of the beach in a efficient way without affecting/taking away the shells.”

1.2 APPROACH
APPROACH PER PHASE

Analysis
In the first phase of the project, the analysis phase, the assignment as described by the municipality will be completely dissected into its relevant aspects. Three main blocks will be analysed:

The amount and type of garbage that can be found on the beaches of the Hague. Where are the most polluted areas and what does the garbage exactly consist of. What are the effects of the garbage to marine flora, fauna and humans. What current cleaning techniques exist and what problems occur with these techniques.

The importance of shells to the beach and the problems that arise when shells are taken of the beach will be discussed in order to confirm the need of the design.

The problems currently existing with the BeachTech-3000 (beach cleaner used by the municipality) are found out by testing the machines on different categories of garbage. And by analysing the techniques used within the machine. The problem and source of the incapability of removing small garbage is also analysed.

These three blocks are then combined into a problem definition that gives a good overview of the entire problem. By classifying the different components of the garbage and shells on material, size and shape appropriate separation techniques can be found that are suitable for separating the shells from the garbage mixture. At the end of this phase the list of requirements, objective, demands and the design goal will be completely clear and will be used as a basis for the rest of the project.

Synthesis
In the Synthesis phase all gained insights of the first phase will be used to generate ideas that are capable of solving the problem. Quick principle testing, mock ups and morphological charts will be used to find suitable (sub) solutions to the problem. A first choice between these ideas will be made according to the requirements and demands of the first phase.

The best ideas will be combined into two concepts. In this phase mock ups will be build and tested in order to validate their individual working principle and to validate the concepts.

Embodiment
In the embodiment phase, a prototype will be built based on the chosen concept. The prototype should be able to separate the collected garbage of the beach cleaner into a garbage fraction and a shell fraction. Finally the implementation within the beach cleaner will be shown by use of a 3D model. It will explain how the found solution can be implemented within the beach cleaner and the current beach cleaning procedure.

The challenges in this project will lay in the mock-up, prototypes and test set ups that will be made to validate the working principles. Another challenge will be to find a solution that can be up-scaled and implemented so that is fit for application on the beaches of the Hague (length of 11km).

On the page on the right the different phases of the project and the process steps of each phase can be seen (figure 1.2.1).

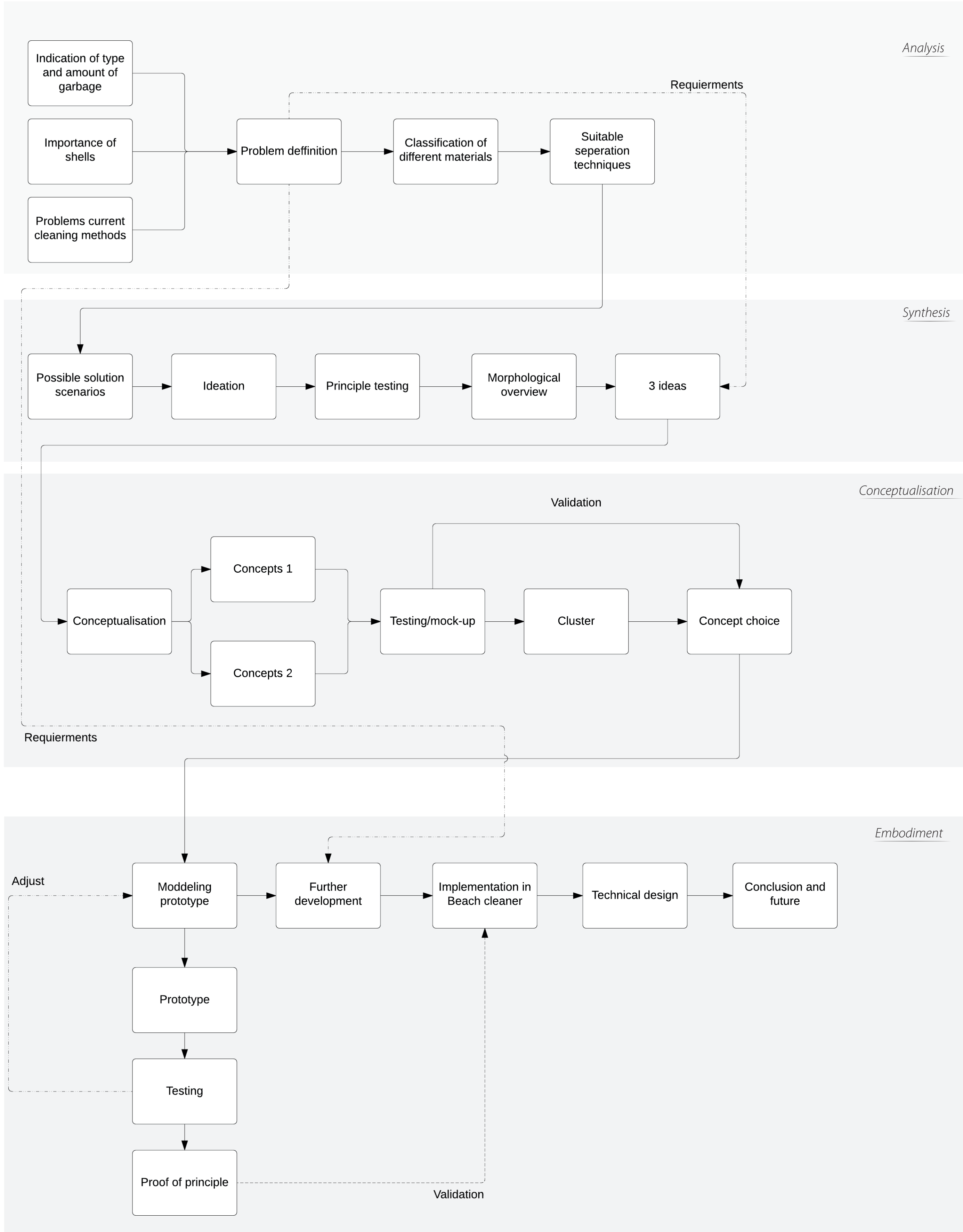


figure 1.2.1, Overview of the phases of the project

1.3 CONTEXT OF THE ASSIGNMENT

Keeping the beaches clean is not only a concern of the The Hague municipality, it is a concern of almost all touristy coasts around the world [1]. Most municipalities see the relevance of clean beaches as a way to draw more tourists to their cities but in the Netherlands incentives for clean beaches also come from higher up.

The Dutch government strives to reduce the amount of litter in the North sea, part of this plan is to reduce the amount of litter that ends up in the sea from the beaches [2].

KIMO is an association of coastal municipalities with common interest of local governments [3]. The organization is fighting pollution of the North sea, Irish sea North eastern Atlantic ocean and the Eastern Sea. Most of the Dutch and Belgium coastal municipalities are united under the Dutch Belgium department of KIMO (see figure 1.3.1). KIMO Netherlands and Belgium is also involved in the green deal Schone Stranden agreement. This deal is set up by the government (ministry of Economic affairs and the Ministry of infrastructure and Environment), The coastal municipalities and environmental foundations in order to communicate and elaborate on cleaner North sea beaches [2].

figure 1.3.1, coastal municipalities united under KIMO

The parties involved in the green deal Schone Stranden, collaborate around the following five themes: behaviour influencing of the beach visitors, facilitating of volunteers, cleaning up cigarette stubs, stimulating green key certification and monitoring of the beaches. This deal is focussing on a national level but since pollution of beaches is a global problem the results of this deal can be used worldwide.

The main goals of the green deal schone stranden are:
• Structurally cleaner beaches, in 2020 there will be less litter on the Dutch beaches
• In 2020 all Dutch coastal municipalities will be united under the green deal.
• Better behaviour of the beach visitors, the visitors will leave less garbage behind.

To accomplish these goals all parties involved (figure 1.3.2) have specific stakes and tasks to fulfil. Some examples of these activities are: placement of more garbage bins, initiating clean up and awareness initiatives, poster and sticker actions, Facebook campaigns, DropPits at the beach.

The individual municipalities are responsible to make sure their beaches are clean. Coastal municipalities bare great responsibility in the clean up process. Although a lot is done to change the behaviour of the beach visitors, mechanical cleaning is currently still very important and necessary to make the beach appealing to visitors [1]. Since cleaning a beach is a tedious job a lot of money is involved in the process. Yearly al coastal municipality spend a total of € 3,7 to € 5,3 million on keeping their beaches clean. Over 70% of these costs is involved in collecting of the beach litter [4]

Sand suppletion

The Dutch Department of Waterways and Public Works, is responsible for the sand nourishment of the Dutch coasts. A big project within this nourishment process involves depositing 21.5 million cubic metres of sand off the coast at Kijkduin. This sand is spread out over the coast by the tides. Because a lot of sand is deposited in one go, the ecosystem is not disturbed as frequently as in normal sand depositing [5].

Beach cleaners are known to disturb the ecosystem because they loosen up the sand and take in large quantities of shells and natural materials that normally help in clinging of the sand and thus preserving the beach [1]. (figure 1.3.3) If shells would not be removed as frequently by beach cleaners, the deterioration rate of the beach would decrease, meaning less costly sand supplementation is needed.

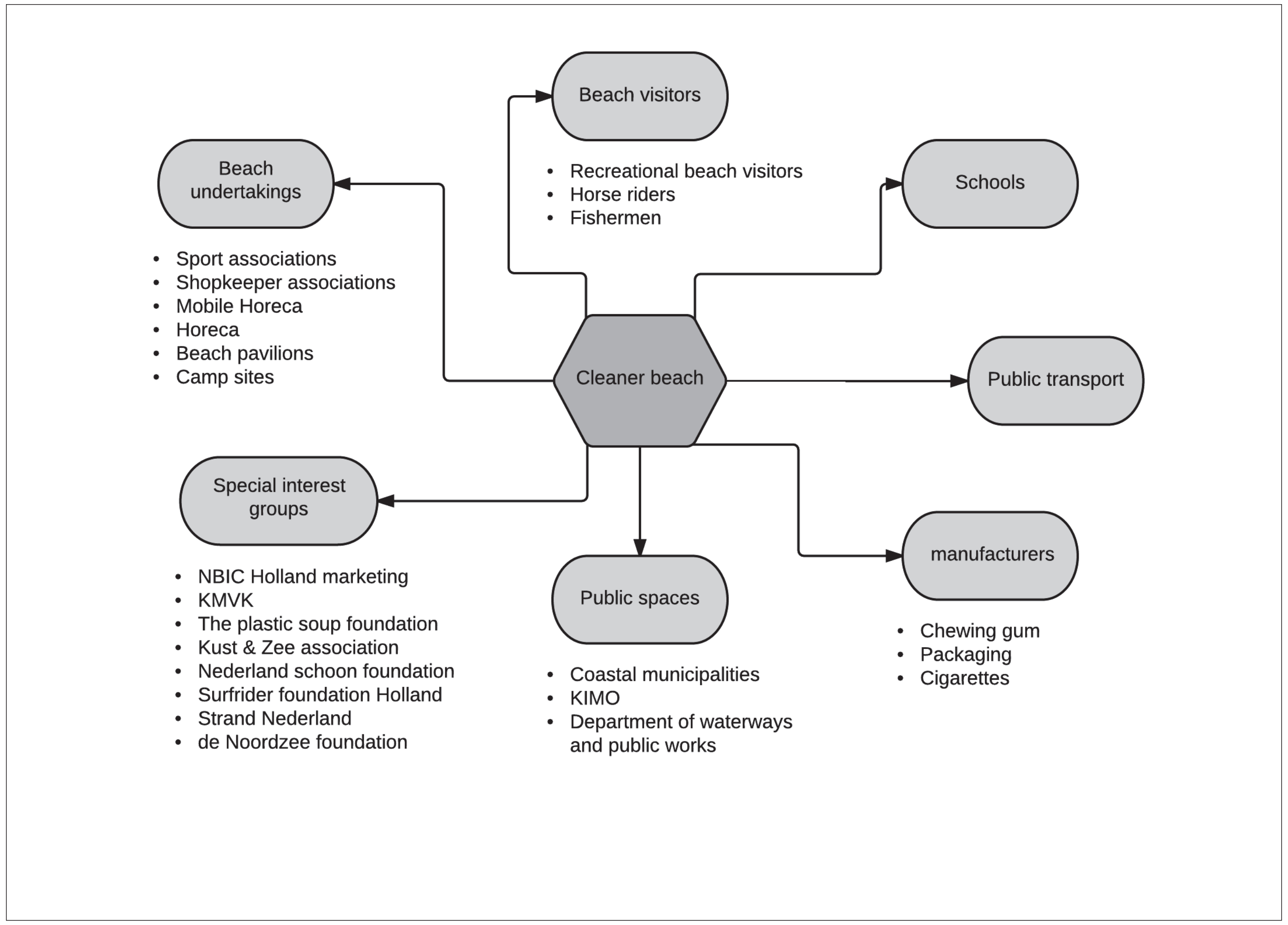


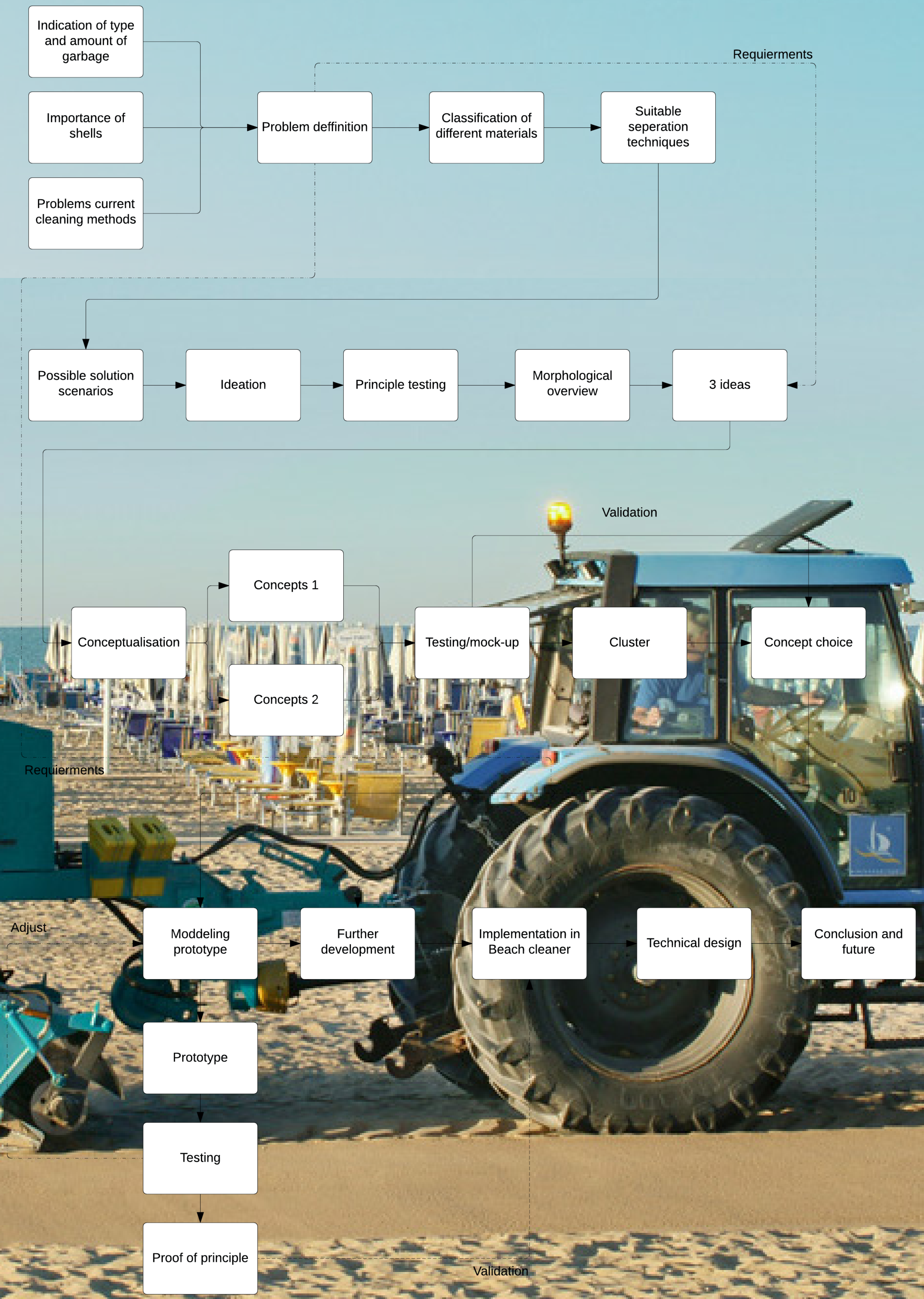
figure 1.3.2, Involved parties in a cleaner beach

figure 1.3.3, beach cleaners take in the natural materials along with the garbage.

figure 1.3.4, the 'zandmotor' near Kijkduin

2.ANALYSIS

Now the background, the structure of the thesis and the assignment itself are clear, the analysis phase will elaborate on all relevant aspects of the problem definition. It will investigate the type, sort and location of garbage on beaches, classify the different material fractions and search appropriate separation techniques that can be used to separate the different fractions from one another.



2. POLLUTION OF SEA AND BEACH

2.1 POLLUTION OF BEACHES WORLDWIDE

Pollution of the worlds oceans is the second largest environmental problem after global warming. [6]. Estimates of a 2005 research indicate that on average 13.000 pieces of plastic float on every square kilometre [7]. In so called gyres, marine litter is concentrated by tidal currents and high concentrations of marine litter are measured here [8] In 1999 the concentration of plastics was measured inside the North Pacific gyre, the result was a measurement of 334.271 particles per km2. The oceans are polluted by marine litter form the pole regions to the equator. On the total amount of marine debris, multiple studies have been executed, differing in predictions from 6.4 million tonnes annually to even 7 billion tonnes of garbage annually ending up in the ocean [8]. Even though the outcomes of these studies vary significantly, assuming actual number lies somewhere in between gives enough reason for concern.

According to (Allsopp,Walters, Santillo & Johnston, 2009) "At least 267 different species are known to have suffered from entanglement or ingestion of marine debris including sea-birds, turtles, seals, sea lions, whales and fish."

Sources of marine debris

The marine litter in the oceans originates from two sources, land based and ocean based sources. Estimated 80% of the marine debris is land based the other 20% is ocean based [9]

Land based marine litter has the following sources (also see figure 2.1.1):

• Storm water discharges: Litter traveling through storm drainage systems finally ends up in the sea. (US EPA 2002c)
• Littering: Beach goers that leave behind packaging material of food and beverages or fishers that dispose their fishing gear [9]
• Solid Waste Disposal: Located near seas or rivers, spillage of garbage from these landfill sites can end up in the ocean. Directly or through rivers [10]
• Industrial Activities: During transport or loading/unloading of materials, debris can end up in the sea. [11]. Especially pellets used as a raw material for production of plastic products are commonly found on beaches and in the sea [12].

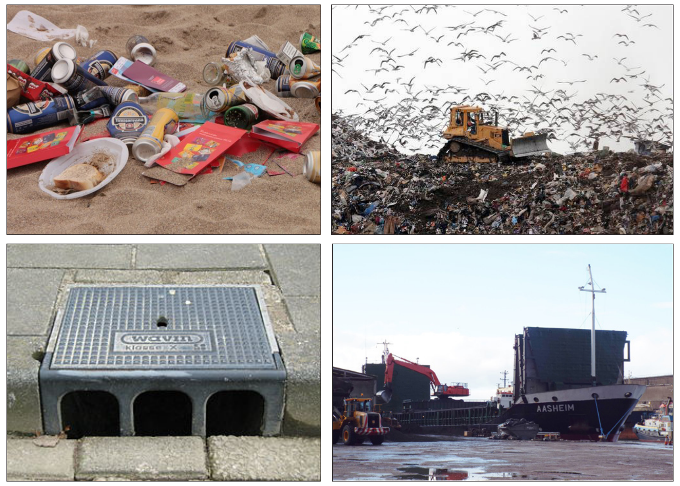


figure 2.1.1, Sources of land based marine litter

Ocean based marine litter has the following sources [9] (see figure 2.1.2:

• Commercial fishing: Originates from fishing gear that is not retrieved or disposal of garbage from fishing vessels. Most common items being disposed are: fishing nets, lines, strapping bands, bait boxes trawl float and galley and household trash.
• Recreational Boaters: Most common items disposed of are bags, food packaging and fishing gear.
• Merchant and Military Vessels: Since they carry food and drinks for the employees on board, garbage is produced everyday. If not correctly stored this can end up in the ocean.
• Offshore Oil and Gas Platforms and exploration: Helmets, gloves storage drums and materials used for research also end up in the ocean. Under water research can also contribute to the marine litter.

figure 2.1.2, sources of ocean based marine litter

Movement pathways

The amount and kind of debris found on the beaches corresponds to both land based and ocean based debris. Figure 6 shows the different movement pathways of marine litter in the marine environment. Close to urban areas the on shore concentration of marine litter can be very high. A 1997 study on islands on the eastern side of Indonesia, showed that 90% of the beach and strand line was covered with litter. Also on remote, non touristy coasts the build-up of marine debris can be large due to coastal tides bringing the garbage to the beaches [13].

Various studies on debris found on the beaches, in the oceans and at the ocean floor have been done, each with varying outcomes (see table 2.1.1). Although it is difficult to compare the data since the studies use different measurement strategies, some conclusions can be drawn:

• The amount of marine debris seems to decrease the more you go to the poles [14]
• Shipping lanes, fishing grounds and in gyres, higher concentrations of garbage are found. [15]
• Areas near urban centres, recreational and industrial sites are also more likely to have high concentrations of marine debris [9].

Figure 2.1.3 shows the different movement pathways of marine litter in the marine environment.

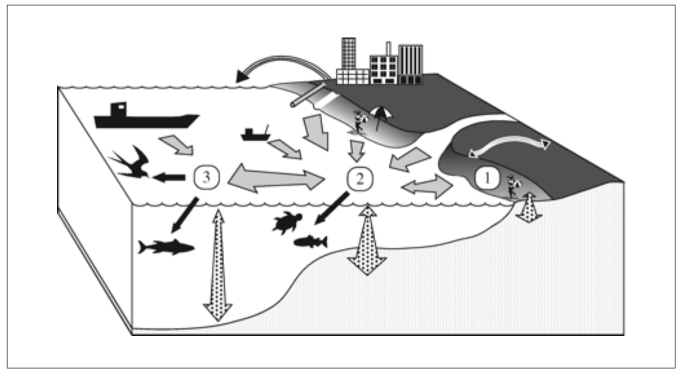


figure 2.1.3, 1 sink occurring on beaches, 2, in coastal waters and their sediments and 3, in the open ocean. Curved arrows depict wind blown litter, grey arrows water born debris, stippled arrows vertical movement through the water column (including burial in sediments) and black arrows ingestion by marine organisms.

Kinds of marine debris

Marine debris can be divided into multiple categories. [16].

- Fishery related garbage; Nets, rope, gloves and fishing crates.
- Food and drink related garbage; bottle-caps, cans, plastic bags, disposable cups, cutlery, plates, straws, candy wrappings, chips bags, plastic/glass and bottles
- Smoking related garbage; Cigarette filters and packs, cigar ends and lighters.
- Sanitary related garbage; ear-picks, ovulation bandages, condoms, diapers and tampons.
- Offshore related garbage; domestic garbage, packaging and work related materials.
- Shipping related garbage: Straps, pallets, industrial packaging and work materials
- Industrial and transport related garbage; pellets, plastic sails and straps.

Location	Mean or range of number of items	Mean number of items of debris per km	reference
Northern Atlantic shores	0.15 - 70.9 per m		Barnes and Milner 1995
UK, Edinburgh (1994)	0.8 m2		Velander and Mocogni 1998
Mediterranean			Barnes and Milner 2005
Croatia (200) Sicily (1988) Spain (1991 Cyprus (1988) Israel (1988/9)	6.4 per m 9 - 231 per m 33.2 per m 10.4 pet m 7.3 - 8.7 per m		
Gulf of Oman, Omani coast (2002)	1.79 per m		Claereboudt 2004
Gulf of Aqaba, Jordanian coast	3 per m2		Abu-Hilal and Alnajjar 2004
Southern Atlantic			Barnes and Milner 2005
Tristan da Cunha (1984)	0.3 - 0.8 per m		
Gough (1984)	0.019 per m		
USA Hawai (1989) California Texas Mexico		262 814 1712 8000	Jones 1995
NE Brazil, Costa dos Conquers (2002-4)		14.6	Santos et al. 2005
Caribbean St. Lucia (1991/2)		4500 - 11,200	Corbin and Singh 1993
Caribbean Dominica (1991/2)		1900 - 6200	Corbin and Singh 1993
Indonesia (23 islands)		range 0 - 29,100	
Tasmania (1990/1)		300	Jones 1995
Western Australia (1992)		3660	Jones 1995

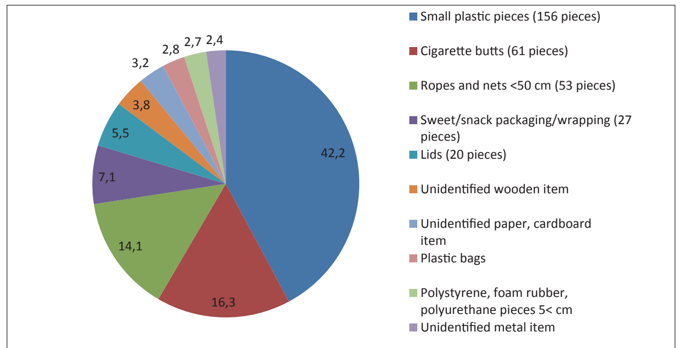
table 2.1.1, results of studies on amounts of marine litter

2.2 POLLUTION OF DUTCH BEACHES

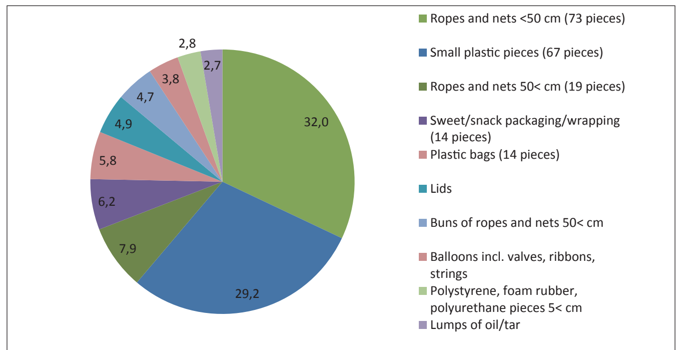
The Dutch beaches are a total of 450 km of which half is often used recreational. An increase in garbage on the beaches is caused by an elongated beach season, beach pavilions that stay opened all year round and an increase in the amount of festivals and events that take place on the beach [17]. The beaches in the Netherlands are cleaned by the municipalities, often in cooperation with the local beach pavilion owners. The estimated cost of cleaning all the beaches is 3.7-5.3 million annually (15.000 to 48.000 €/km/year) around 70% of this money is used to clean litter that is spread on the beach. 20% on garbage container management and 10% on garbage-processing [4]. Different sources are used to give an indication of the kind and amount of litter on the Dutch beaches. The main division in the measurements on beach pollution is between measurements done on recreational and non-recreational beaches.

Boskalis beach clean-up tour

The annual Boskalis beach clean-up tour was used to gather data on both types of beaches using volunteer civilian monitoring. In a total of 28 measurements (13 recreational and 15 non-recreational beaches analysed) were monitored. The average amount of litter items on recreational beaches was 409 (4kg) and on non-recreational beaches was 266 (20kg) [18]. The composition and item count of the garbage on each type of beach can be seen in pie charts 2.2.1 and 2.2.2.



pie chart 2.2.1, top 10 most found litter items on recreational beaches (%)



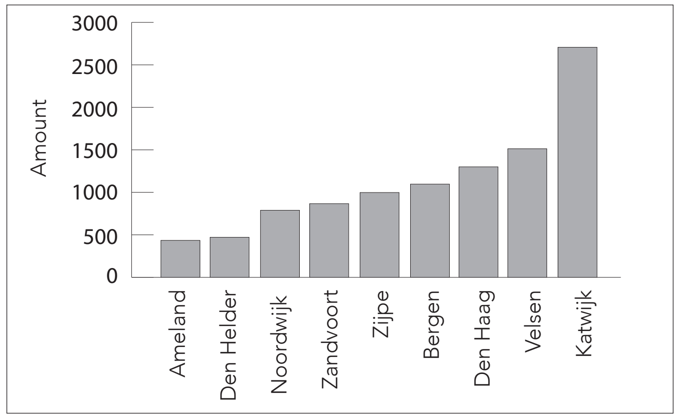
pie chart 2.2.2, top 10 most found litter items on non-recreational beaches (%)

Zwervend langs zee

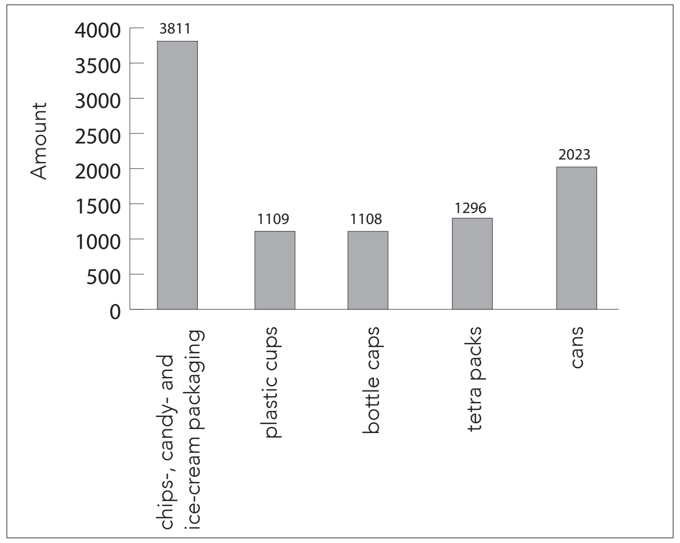
On recreational beaches the three main categories of garbage are:

- Food and drinks packaging, lids, cans, bags disposable cutlery, cups, plates, straws, candy wrappings, chips bags and bottles.
- Smoking related garbage: cigarette buts, cigar ends, lighters and cigarette packages.
- Sanitary garbage: ear picks, ovulation bandages, diapers, condoms and tampons

In order to get insights in the garbage left by recreational visitors and to clean the beaches, the Zwervend langs zee project was launched. This project was done in cooperation with KIMO, Rijkswaterstaat and Stichting de Noordzee. A total of nine coastal municipalities participated in the monitoring of strips of beach varying between 500 - 1000 m. A monthly monitoring combined with a 15 day straight monitoring session gave good insights in the garbage left by the beach visitors (see bar graph 2.2.1). As can be seen in bar graph 2.2.2, the top five most commonly found items were: chips-, candy- and ice-cream packaging, plastic cups, bottle caps, tetra packs and cans [19].



bar graph 2.2.1, amount of litter items per municipality



bar graph 2.2.2, top 5 most commonly found litter items

OSPAR Beach monitoring

To determine the amount of marine litter washing ashore, the Noordzee foundation commissioned by OSPAR Beach Litter monitoring program measures the amount of garbage found on more quiet beaches that are not cleaned by a municipality. The beach is inventoried over a length of 100 meters. Most of the garbage is found on the high-water mark because this is where the marine debris is left by the tides. Between 2002 - 2012 on average 395 pieces of garbage were found on a 100 meter stretch of beach. After the measurement, the beach is cleaned, the measurement is repeated every three months. Table 2.2.1 shows the top 10 most found items on non-recreational beaches between 2002 - 2012 [20].

RANK	Item or item cluster	% of total	n / 100m
1	All Nets & ropes etc	38%	147.3
2	All Plastic/Polystyrene pieces	19%	72.6
3	All plastic bags	6%	23.6
4	Plastic Caps/lids	5%	20.2
5	Plastic Crisp/sweet packets and lolly sticks	4%	15.1
6	Rubber Balloons, incl valves ribbons, strings etc	3%	12.7
7	Plastic Drinks Bottles, containers, drums	2%	8.4
8	Wood Other < 50 cm	2%	7.9
9	Plastic Food Bottles, container incl fast food	2%	7.1
10	Plastic Industrial packaging, sheeting	2%	7.0
	ALL Debris	**100%**	**395**

table 2.2.1, top 10 most frequently found items in the OSPAR beach monitoring

Pollution of The Hague beaches

Treasure hunt is a clean up initiative in the Hague that challenged themselves and others to clean the entire beach of Scheveningen every day during the summer months. By using volunteers, the initiative also confronts the participants and recreational beach visitors with the amount of garbage on the beach. Although not scientifically executed the monitoring of their clean ups gives a good indication of the scale of the pollution of the beach in the Hague [21].

The most common found items are listed in table 2.2.2. It is interesting to see that even though the municipality cleans the beach thoroughly by use of beach cleaners, vast amounts of garbage are still found in these kind of clean up initiatives. An explanation for this is that the beach cleaners mainly operate during the night and the clean up initiatives take place during the day.

Item	*Amount*
Cigarette buts	4352
Plastic bottle caps	3237
Shards of glass	Thousands
Facial cleaning wipes	884
Cans	1323
Straws	1256
Plastic bottles	723
Underwear	131

table 2.2.2, top 10 most frequently found items in the Treasurehunt monitoring in The Hague

2.3 EFFECTS OF MARINE LITTER

Garbage in public spaces is perceived as annoying and disturbing and can be seen as a factor that is degrading society. When people encounter garbage in a public space they will be more inclined to litter as well. According to the world health organization, a clean beach is one of the most important aspects sought after by beach visitors [6]. Consequently a polluted beach will attract less tourists.

For coastal municipalities around the world tourism is an important source of income and marine garbage has a negative influence on this sector. Marine debris influences animals, habitat and humans in other ways as well (figure 2.3.1) [19]. These effects will be discussed per category:

Fauna
Sea birds and other marine animals can get tangled up in the marine debris and get wounded or die. Next to that some species mistake the marine debris for food, ingest it and this will lead to malnutrition of the animals and finally death. Chemicals and toxins get attached to pieces of plastic floating in the ocean. When consumed by marine animals, the toxins end up in the living organisms and accumulate within the body, if the animal is a prey to other species, the toxins make their way into the food chain and can eventually end up in humans as well [22].

Flora
Coral reefs and coasts can get damaged by the impact of floating debris and in this way damage the habitat of sea/beach animals [23]. Organisms can attach themselves to floating debris and in this way be transported to areas where they naturally do not occur. This can cause disturbance of the ecological balance in a certain area [12].

Humans
Beach visitors can get hurt by stepping into glass, needles or other sharp objects that are hidden beneath the sand[19].

figure 2.3.1, overview of the effects of marine debris on flora, fauna and people.

2.4 WHAT IS CURRENTLY DONE TO TACKLE THE PROBLEM?

Legislation, conventions and agreements
In order to tackle the marine debris problem at the source, laws, conventions and agreements have been made globally and worldwide. The MARPOL convention and the Cartagena convention developed legislation that made dumping of waste from ships illegal [24]. Enforcement of these laws however is difficult. The zero waste strategy focusses on redesigning product life cycles in order to make a resource from waste. It is about reuse recycle and reduce products and their material sources. By reducing the amount of packaging, less garbage will end up in the marine environment [7].

Clean ups
All over the world clean up initiatives have been set up to rid beaches of the accumulated garbage. A beach clean up can be very expensive but by using volunteers the costs are brought down [7]. One of the largest clean up initiatives is the international coast clean up (ICC). It was initiated by the ocean conservancy in Texas in 1986 but today all American states and over 127 other countries have joined the initiative. One day each year volunteers clean their local beaches. Next to cleaning, this initiative also gathers data about the garbage found at the beach. This data can be used to indicate if there is an improvement between subsequent years.

Originated in Australia as; Clean up Australia day but now involves 40 million people world wide. They have a special department focussing on cleaning beaches [7]. Next to these global initiatives lots of municipalities and local organizations have their own clean up initiatives. Often a combination of municipal paid clean ups and clean ups using volunteers is used. For a clean up to have a sufficient effect, a good recycling and collection system of the garbage should be present otherwise the garbage can end up back in the environment and finally in the ocean.

Education
To solve the problem of marine debris it is also important to educate the people about the problem. A large part of the marine debris consists out of litter left behind by recreational beach users. By educating children in schools, they learn about the problem and they can spread the word to relatives and other people. Users of ships should also be educated in order to prevent ocean based marine debris.

Dutch clean up initiatives
In the Netherlands various clean up initiatives exist.

Boskalis beach clean up tour
The Boskalis beach clean up tour is held every year and cleans up 350 km of North Sea beach. The clean up is divided into 30 stages, starting August 1st. Two teams each starting at a different location and work towards each other. In 2016 the clean up gathered 19.203 kg of garbage. The idea behind the clean up is not only to clean the beaches but also to confront a large public with the amount of garbage [25]

Treasure hunt
In the treasure hunt clean up initiative, volunteers clean up the beach of Schevingen during the summer. Children are motivated to participate by a role play in which the children are treasure hunters and the garbage is their treasure. After the garbage is collected, it is used to create pieces of art. The creations are displayed in the treasure hunt museum on the boulevard of Scheveningen [21].

Grondstof jutters
Beach visitors are asked to take along a bag and to collect the garbage they encounter during a walk on the beach. The collected garbage is separated and used as a recourse to make new products. Participants are rewarded by giving them a drink when they hand in the collected garbage at a nearby beach pavilion [26]

CONCLUSION, CHAPTER 2

Pollution of oceans and beaches worldwide is a large problem. Large amounts of garbage float in the oceans and end up on the beaches or vice versa. Not only is this an aesthetic problem, it is also dangerous and harmful for marine species, coasts and people. In spite of legislation, clean ups and education their is not a decline in the amount of marine litter in the marine environment.

3. BEACH CLEANING TECHNIQUES
3.1 CURRENT WAYS TO CLEAN THE BEACH

A lot of different methods and techniques exist for cleaning the beach. From very simple to very advanced techniques. In this section an overview of the most common techniques of cleaning the beach will be discussed. Each method/technique will be explained and analysed on its pro's and con's.

Hand picking
The most basic and simple way to clean the beach is by hand (sometimes using a trash picker). A person or a group of people swipe the beach and collect whatever garbage they can find in garbage bags. All garbage bags are collected at a central point (see figure 3.1.1). This method is often used in clean-up initiatives. These campaigns are also used to confront the participants and beach visitors with the large amount of waste on the beaches and educate the participants in this way. So the benefits are twofold [21].

+ Educates and confronts participants with the amount of garbage
+ Cheap method, if volunteers are used

- Slow process
- Smaller garbage, and garbage that is buried under the sand is not taken in.

Hand raking/sieving
In order to comb/sift smaller debris from the beach rakes, sand-combs and hand sieves can be used. This is especially useful to clean smaller debris that would take to much time to pick up by hand (shards of glass, cigarette buts etc.). Manual versions and versions with wheels exist to increase the work-flow and speed. Some rakes have small vibrating motors incorporated in order speed up the screening process (see figure 3.1.2).

+ More effective in cleaning smaller debris

Sand raking and screening using ATV or a small tractor
In order to speed up the process even more, ATV's or small tractors can be used to pull a sand screen or rake through the sand. Some have small ploughs attached, to scoop up a layer of sand and clean up buried garbage as well (figure 3.1.3). By using a tractor or ATV a larger area can be cleaned. The problem with this method is that the screen/rake becomes clogged with garbage when a lot of garbage is collected since it is not transported to a collection container. This material has to be removed before the clean up can continue.

+ Faster process
- Screen gets clogged and has to be emptied manually


figure 3.1.1, hand picking garbage

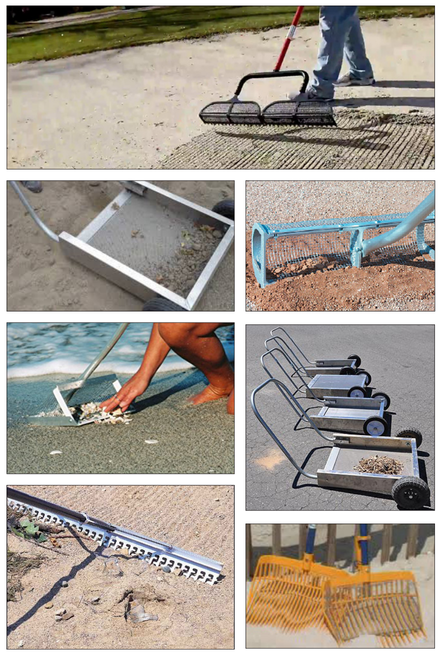


figure 3.1.2, hand raking/sieving

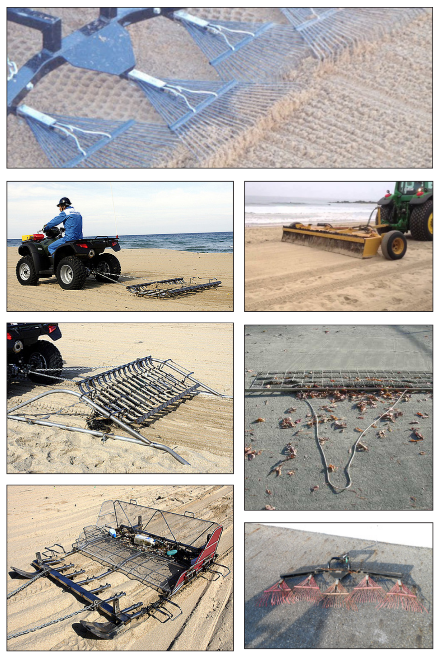


figure 3.1.3, ATV pulled raking and sifting screens

Walk behind beach cleaner
Walk behind beach cleaners often have a rotating rake that scoops sand on a vibrating/rotating sand screen. The screen is tilted and through the shaking motion small debris is transported to the top of the screen where it is collected in a collection container. The machine can be equipped with different screens with different mesh sizes. This way the size of the picked up garbage can be chosen. The propulsion of these machines are either by wheels or caterpillar-tracks (figure 3.1.4).

+ Faster process
- Mechanical cleaning disturbs the ecosystem on the beach

Beach cleaning machines
The largest scale beach cleaners come in different types. Either they are autonomously vehicles or they are suspended behind a tractor or ATV (figure 3.1.5). The raking or sifting device is moved through the sand during operation. The beach cleaner collects the sand by scooping or dragging the sand into the device. Raking, sifting or a combination of both methods, separates the garbage from the sand. The screen mesh of the beach cleaner determines the size of material to be sifted out of the sand. A collection container in the beach cleaner collects the material. When full, hydraulics make it possible to empty the content into a garbage truck or on a dumping site directly [27]. The larger scale beach-cleaners suitable for the larger beaches will be discussed in more detail in the following section.

+ Fasted way of efficiently cleaning the beach
- Expensive
- Disturbs the ecosystem of the beach
- Noisy
- Potentially dangerous


figure 3.1.4, walk behind beach cleaner

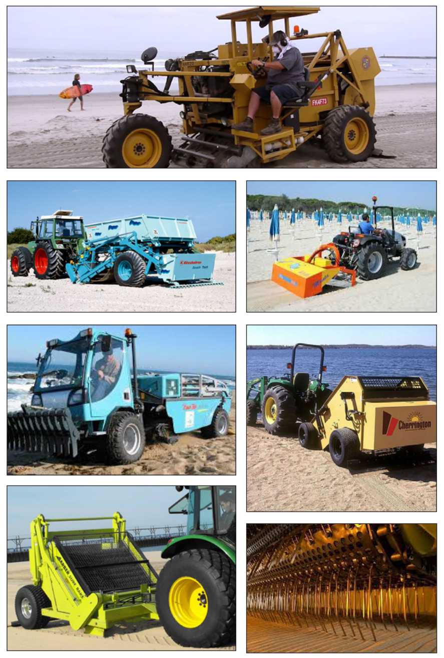


figure 3.1.5, beach cleaners for large beaches

3.2 PATENT ANALYSIS

A patent analysis has been executed in order to research the different kind of beach cleaners on the market. All patents can be found in appendix 1.
The patents analysed, all use raking, screening or a combination of both techniques to clean garbage from the beach.

Raking
Patent 3,362,480, H.S.Barber
This patent describes a beach cleaner that uses rakes in order to comb unwanted materials from the beach. It uses a screen equipped with tines that rotates, picks up unwanted material and transports it to the back where it is finally collected in a container. It is towed by a tractor and the propulsion of the system is by the tractor's hydraulic power take off shaft (PTO) (figure 3.2.1, top)

Patent 3,000,448 L.H.Platt, JR et al
This patent describes a beach cleaner that uses a rotating drum equipped with tines. By the rotating movement unwanted material is combed out of the sand and is thrown into the collection container. The propulsion of the system is done by a drive chain that is connected to the wheels of the machine (figure 3.2.1, bottom).

Screening
Patent 5,197,211, W.Hang
Sand in scooped onto a rotating screen that sieves the unwanted material out of the sand. The garbage is transported to the back in a collection container that can be emptied into a larger container on top. This is a self propelled machine (figure 3.2.2, top).

Patent 2,976,936, L.L.Fry
This patent is comparable to the patent above, it differs only on the fact that it has only one collection container. (figure 3.2.2, bottom).

Combination of screening and raking
Patent 3,596,717, V.Knudsen
This beach cleaner scoops up sand by a conveyor belt, drops it onto a vibrating screen that sifts out the sand and the unwanted material is dropped into the collection container. This machine is self propelled (figure 3.2.3, top).

Patent 4,014,390, A.S.Texselra
This patent is comparable to the one above, the only difference is that this one is suspended behind a tractor in order to move. The propulsion of the conveyor belt is by a drive chain connected to the rear wheels (figure 3.2.3, bottom).

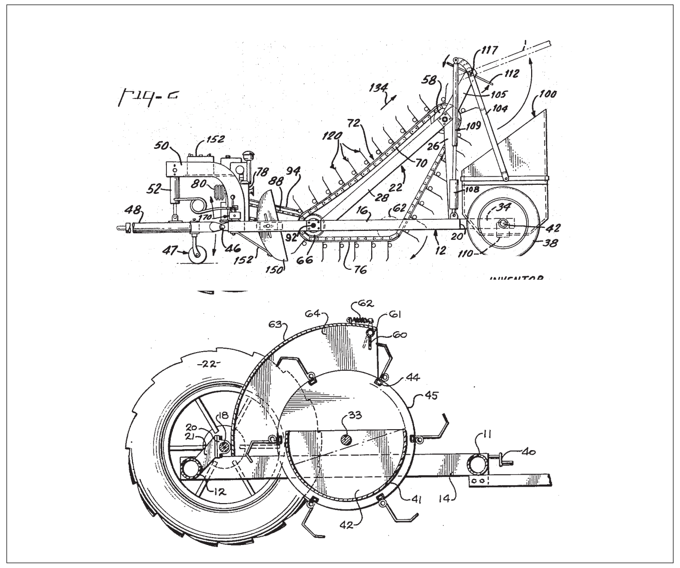


figure 3.2.1, patents using a raking mechanism

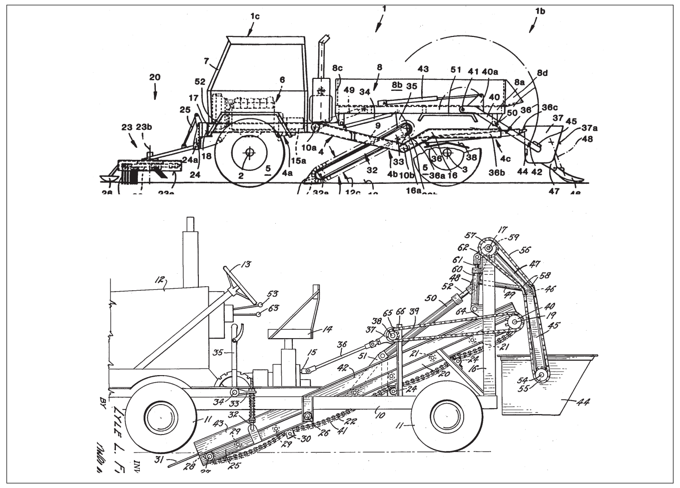


figure 3.2.2, patents using a screening mechanism

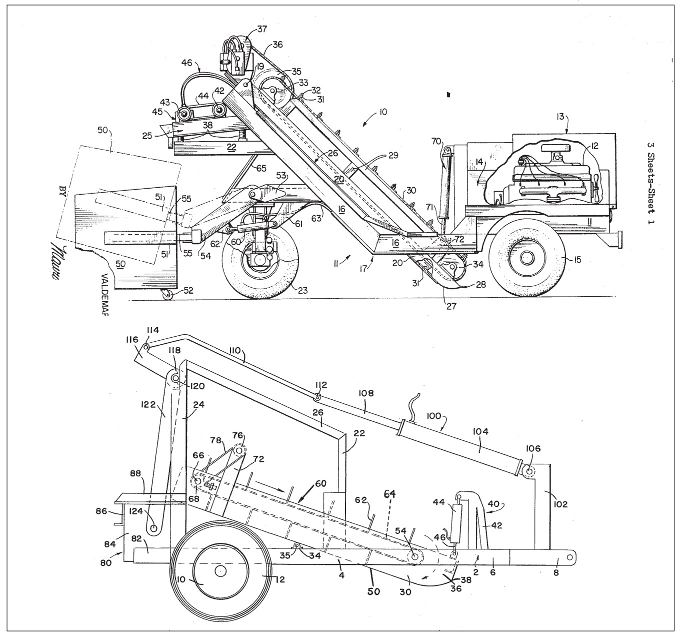


figure 3.2.3, patents using a combination of screening and raking

3.3 BEACH CLEANERS ON THE MARKET

Due to the large demand of beach cleaners, a lot of companies produce beach cleaning equipment. An overview of all the companies can be found in figure 3.3.1. Most companies produce beach cleaning equipment for different beach sizes. Ranging from the smallest, walk behind beach cleaners for the smaller beaches to the largest tractor pulled types used for the most vast and large beaches (figure 3.3.2).The absolute market leader in this sector is the Germany based Beach Tech company, which recently acquired the Cherrington company in the USA [28]. Beachtech also supplies the beach cleaners used by the municipality of the Hague. The beach cleaner market is a saturated one with a lot of different players active. However, all companies mentioned, produce beach cleaners that are not capable of effectively ridding the beach of small garbage while leaving the shells on the beach.
If a suitable solution to this problem will be found the product will have a competitive advantage compared to other beach cleaners.

Cherrington – USA
BeachTech – Germany
Beach Trotters – Spain
Barber – USA
Zaintoudis – Greece
Rockland – USA
Scam – USA
Metaljonica – Itally
RAM Europe – Greece
unicorn – Spain
dhooghe beachcleaners – Belgium
P.B.G. – Itally
Canicas – France

figure 3.3.1, companies producing beach cleaning equipment

CONCLUSION, CHAPTER 3

Different methods and techniques exist to clean garbage from the beach. From clean up initiatives that use volunteers to hand pick the garbage of the beach to more advanced techniques that use raking, screening or a combination of both. Most beach cleaning equipment companies produce beach cleaners of different sizes suitable for a large range of beaches. No beach cleaners currently on the market is capable of cleaning small garbage and leaving shells on the beach.

figure 3.3.2, different beach cleaning machines from Beach Tech.

4. THE THE HAGUE BEACH

4.1 GENERAL

The beaches of the Hague consist of the Northern beach (Scheveningen) and the Southern beach (Kijkduin) which are both intensively visited during the summer months. The total length of the beach is 11 km and the total area surface is 0,175KM^2 (figure 4.1.1). In total there are 77 beach pavilions on the beach of which 54 are on the northern beach (figure 4.1.2). The beach pavilions exploit an area of 20 meters wide. The rest of the beach is not leased to the beach pavilions but the owners are allowed to place beach beds and chairs on it. The beach pavilion owners are obligated to clean the 25 meters surrounding their premisses. Situated in front of Scheveningen the boulevard, the Kurhaus and the pier are situated. The beach of Scheveningen attracts mainly younger visitors and the Southern beach attracts more families. The Southern beach is recently broadened as part of a strengthening of the Dutch coasts [5].

Amount of visitors

On busy days the beaches of the Hague are visited by 100.000 - 300.000 visitors daily (12.000.000 annually). Especially on the northern beach a lot of events are organized [29]. The beach pavilions are responsible for keeping the parameter of their pavilions clean, the municipality is responsible for the cleaning of the rest of the beach.

The areas with the highest densities of visitors are around the beach pavilions and beach entrances. Especially on the northern beach near Scheveningen it can be very crowded, consequently it can be assumed that these areas are the most polluted.

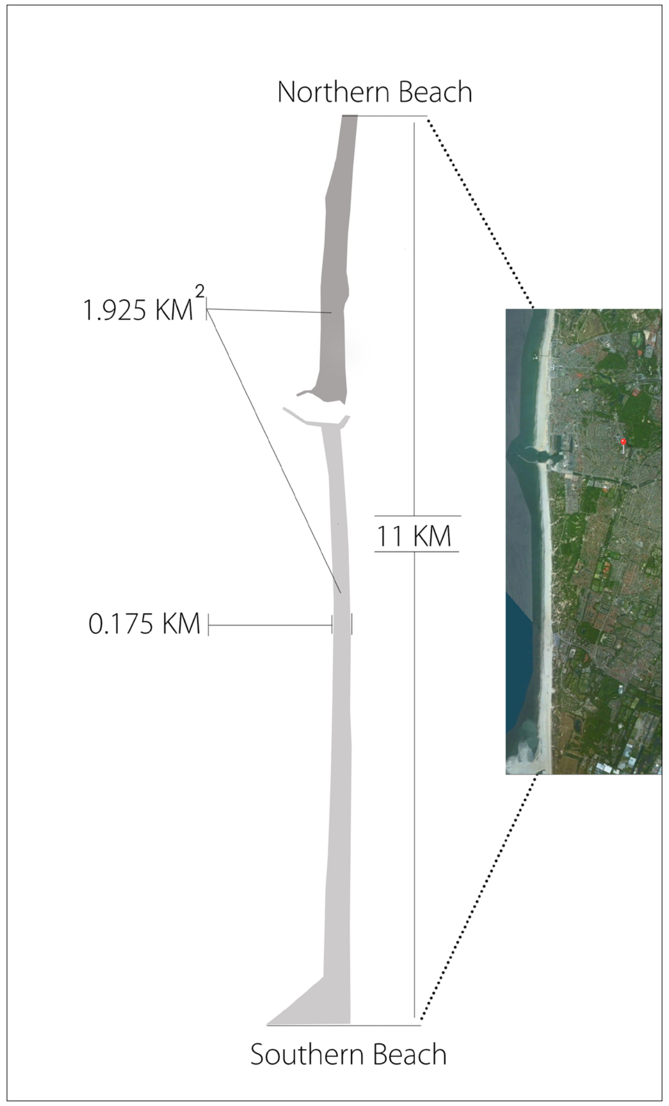


figure 4.1.1, the northern and southern beach of the Hague

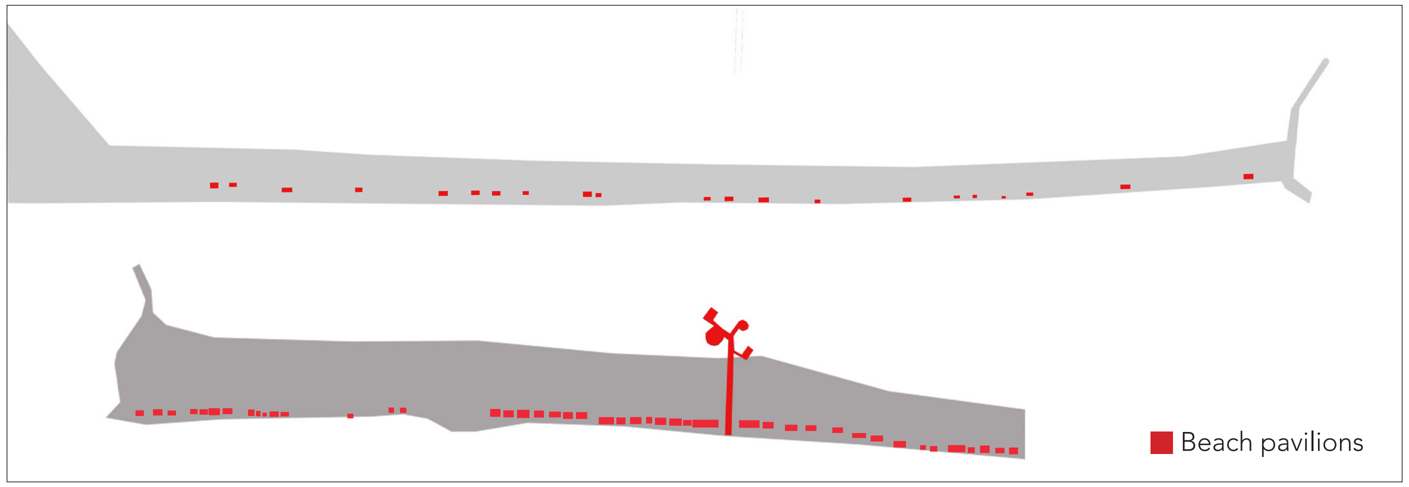


figure 4.1.2, the location of the beach pavilions on the northern and southern beach.

4.2 CONCENTRATIONS OF GARBAGE

As described before, the garbage on the beaches originates from two sources. On one hand there is the garbage coming form ocean based sources which is left on the high water mark (figure 4.2.1 (no 1)). This garbage can get spread out over the beach by wind and sea birds picking it up and dumping it along the beach. Most of the ocean based garbage forms a line on the beach where it is left by the flood. Next to that there is the land based garbage which is mostly left behind by recreational beach visitors. This garbage either gets left scattered over the beach on places where the visitors have been sitting (figure 4.2.1 (no 2)), left around the garbage bins when these are full (figure 4.2.1 (no 3)). Or around the beach entries (figure 4.2.1 (no 4)). During the summer months over 450 garbage bins are placed on the beach.

On the northern beach a double row is placed (figure 4.2.2) and on the southern beach a single row of garbage bins is placed. Only in front of the beach pavilions a double row of garbage bins is placed because these areas are more intensely visited (figure 4.2.1). In general it can be assumed that the areas of the beach where beach pavilions are situated, most garbage can be found. The northern beach is more polluted than the southern beach since it is more frequently visited [29].

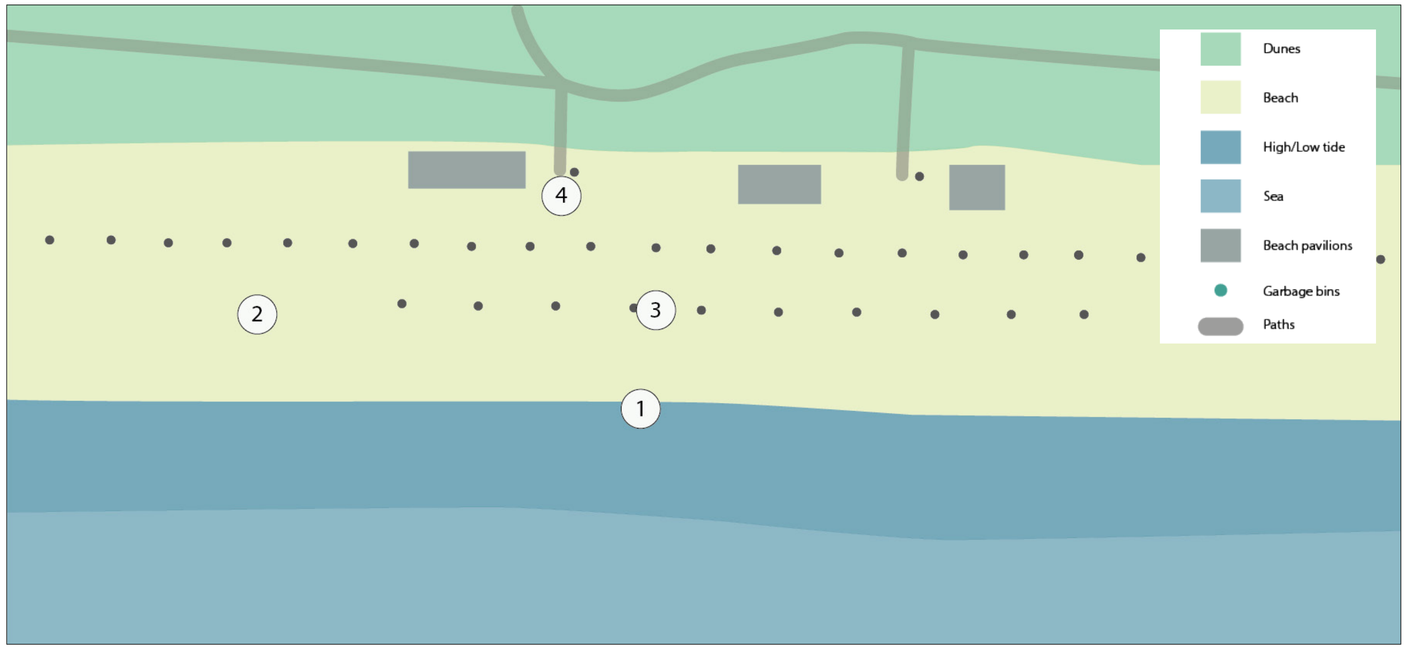


figure 4.2.1, part of the southern beach near a beach entry, the numbers indicate the different locations of the garbage

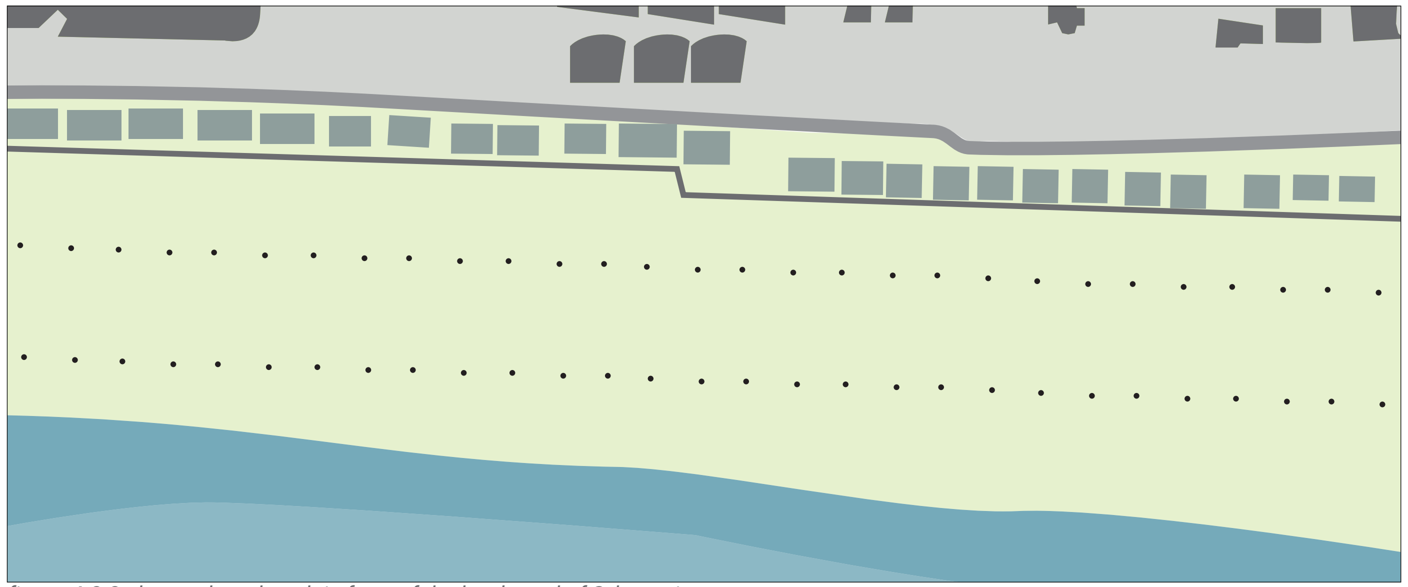


figure 4.2.2, the northern beach in front of the boulevard of Scheveningen

4.3 THE HAGUE BEACH CLEANING

The clean up of the beaches of the Hague is executed by the clean up team of the municipality. A total of 6 tractors equipped with so called beach cleaners (BeachTech 3000) clean the bigger pieces of garbage from the beaches. The beach cleaners can excavate 10-30 cm of sand from the beaches. A rotating screen filters out the garbage, which is collected in a collection bin while the sand falls back on the beach. Garbage trucks are used to empty the 461 garbage bins that are present all over the beach and to collect the garbage from the Beach Cleaners when their collection containers are full. When full, the trucks dispose the garbage at a nearby disposal site. Municipality workers collect the garbage that is scattered around the garbage bins and at the locations the beach cleaner can't reach (around the beach pavilions, stairs etc.). On normal summer days a total of 20 - 30 m3 of garbage is collected form the beaches. On busy summer days this amount can increase till 80 - 100 m3 per day. 16-20 municipality are active per shift and the costs per cleaning shift (cleaning the entire beach) are 18.000€ [30]. An overview of all information can be found in figure 4.3.1. During the off season, the beach is inventoried on the degree of pollution. According to the judgement of the municipality workers a clean up is scheduled. During the winter months the garbage consists mainly of ocean based litter which is removed periodically.

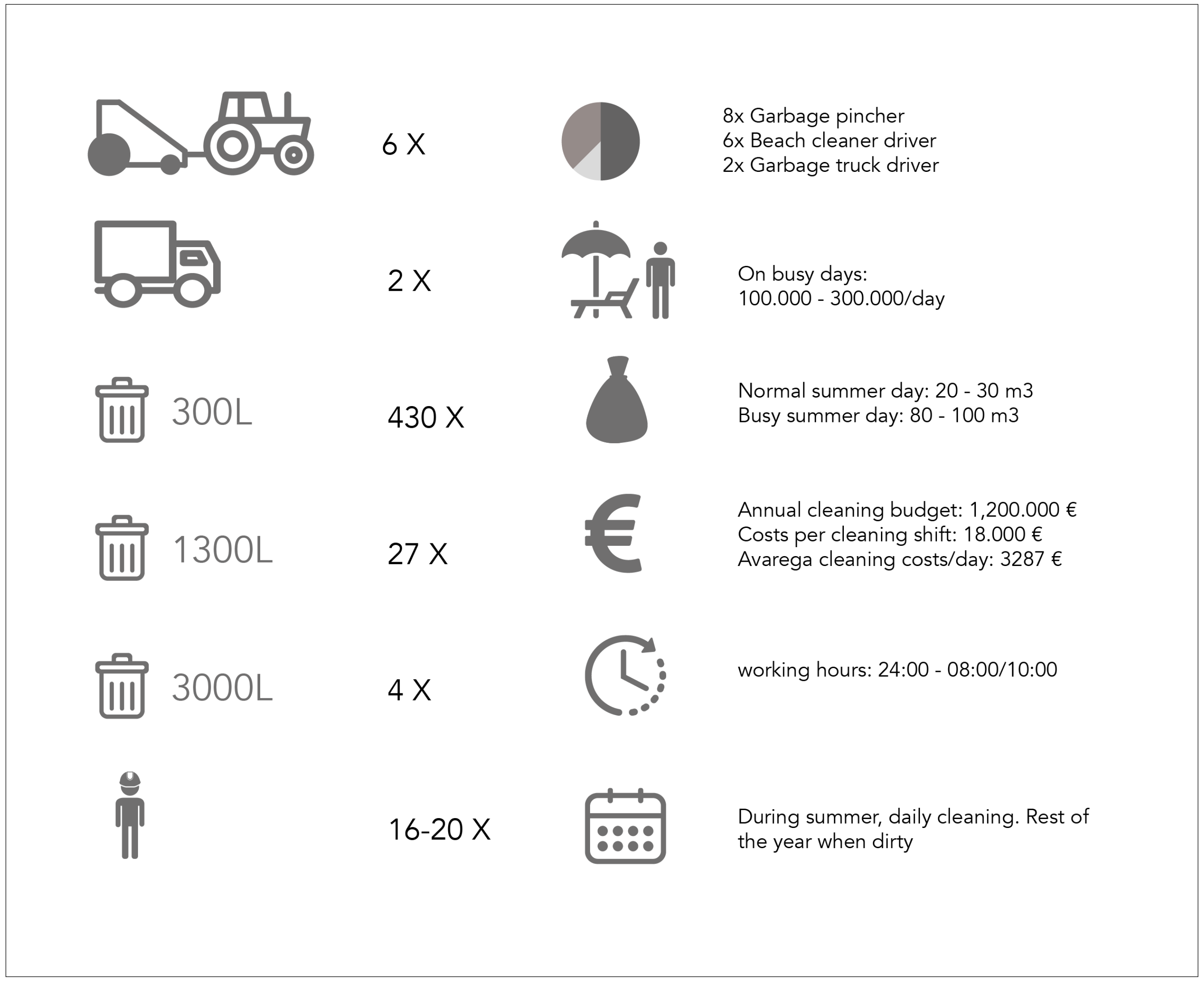


figure 4.3.1, overview of the clean up activities of the municipality of the Hague

4.4 IMPORTANCE OF SHELLS AND AN ECOLOGICAL BEACH

On a lot of places along the coast of the Netherlands, more shore is washed away than is added through natural beach supplementation. The sand banks in front of the coast are getting smaller and during heavy storms, the sea reaches the base of the dunes more easily. This has a negative influence on the forming of new dunes and consequently on the protection of the ground beyond them.

Rijkswaterstaat is trying to counter this process by depositing sand along the coast. The biggest project within this process is the 'zandmotor' that is located in front of the coast of Kijkduin [31].

Since the demand on the cleanness of the beach are high in order to get the BlueFlag award [32], the larger municipalities are forced to use mechanical cleaning. Mechanical cleaning takes in large amounts of shells as can be seen in the sample taken from one of the beachcleaners collected material (figure 4.4.1).

The diminution rate of the beach is decreased by shells. Shells help in preventing beach erosion because they clinch the sand and prevent wind from blowing the sand away. It helps in forming banks that hold down the sand during strong winds. The role of shells and shell fragments in forming a lag surface and preventing the underlying sand from blowing away was shown in research of van der Wal, D. Aeolian transport of nourishment sand in beach-dune environments [33]

Next to that the municipality of the Hague is striving for a more ecological beach. Shells belong to the natural materials present at the beach and offer shelter and food to marine species and thus it would be better if the shells would remain [1].

Lastly the municipality pays per ton they dispose at the garbage disposal. Since over half the weight of the material collected by the beach cleaner consist of shells, it would save a lot of money if these were not collected anymore. Since no concrete data is yet available on the exact amount of garbage collected from the beach and the percentage of shells within this material no exact figures can be given. The municipality did however start keeping track of the amount of garbage since August 6th 2016. In the period between august 6th 2016 till December 2016, 164 tons of garbage was deposited at the dump site. Considering this period is outside of the peak season the total amount of garbage collected yearly will be at least three times this amount. The following calculation gives a rough estimate of the amount of shells disposed at the dump site and the revenue that could be made (figure 4.4.2).

figure 4.4.1, Sample taken from one of the beachcleaners

garbage disposed annually: 500 tons
% shells within the disposed material: 60%
amount of shells disposed: 300 tons
cost per ton disposed material: around 80€/ton
300x80=24.000€ saved annually

figure 4.4.2, estimation of costs saving by not disposing the shells

4.4 BEACHTECH-3000

The Beach Cleaner used by the municipality of the Hague is a BeachTech 3000 from the German, Beach Tech company. The Beach tech-3000 is the biggest beach cleaner available and is suitable for larger and expansive beaches (see figure 4.4.2). Beach Tech claims that under the right circumstances (dry sand) the Beach tech-3000 can clean up to 30,000 m^2/h [27]. Two screening belts placed in series can clean large quantities of sand. The cleaning depth can be adjusted by changing the height of the raking-screening unit (figure 4.4.2 (1)). When set to a deeper cleaning depth, the Beach cleaner will collect garbage that is buried beneath the sand, the range is 10 - 30 cm. The garbage is collected out of the sand by a rotating rake that combs the garbage onto the screening belt (figure 4.4.2 (2)).

Because the axis on which the sifting screen rotates, are non symmetrical the screen vibrates, resulting in a better removal of sand from the collected material (figure 4.4.2 (3-4)). The machine can be equipped with three different screens (figure 4.4.2 (5)), each with a different mesh size. The collected waste is transported over the second screening belt into the collection container (figure 4.4.2 (6)). The smaller collection container can be emptied into the second, larger container (4 m3 loading capacity)(figure 4.4.1). A couple of factors influence the cleaning process: Speed of the tractor/beach cleaner, rotational speed and depth of the raking unit, angle and mesh size of the sieving screen,. See table 4.4.1 for the effects of these factors on the cleaning process.

In order to speed up the cleaning process, municipalities choose a larger screening mesh size and mainly use the raking setting, however this results in inefficient removal of the small garbage.

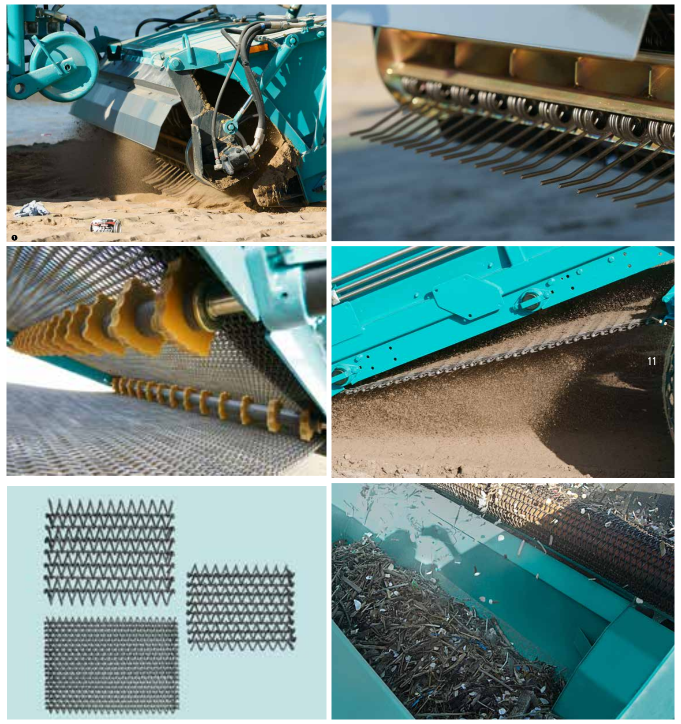


figure 4.4.2, different steps in the cleaning process

Setting	Effect
+ Raking speed	+ Sand, + garbage on screen, + cleaning speed
+ Raking depth	+ Sand + garbage on screen, -cleaning speed
+ Screen angle	- Sand collected in container
+ Screen speed	+ Sand in container + cleaning speed
+ Screen mesh size	- Sand in container, - (small) garbage in container, + cleaning speed
+ Driving speed	+ Sand on screen and container, + cleaning speed, - cleaning effect

table 4.4.1, factors influencing the cleaning process

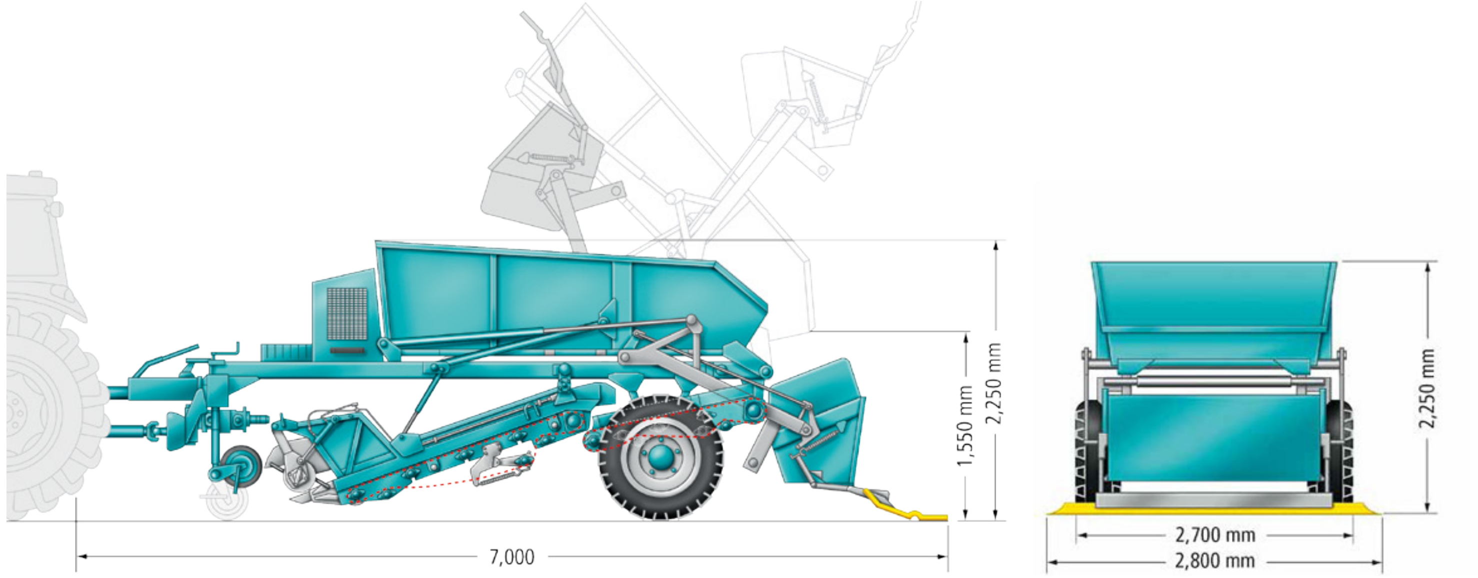


figure 4.4.1, the Beach Tech 3000 used by the municipality of the Hague

Problems with BeachTech 3000

The BeachTech 3000 uses raking, screening or a combination of both techniques to clean the beach (figure 4.4.3). With screening, a layer of sand is ploughed of the beach and sifted on the screen. This technique gets all garbage on the screen but significantly slows down the process and is even impossible when the sand is whet because large quantities of sand end up in the collection container.

Most of the time, mainly raking is used to clean the beach. The raking mechanism that combs the garbage onto the screening belt uses tines. These tines rake through the sand and material that is large enough, gets combed from the beach. Nets, plastic wrapping and ropes can get stuck in the raking unit and have to be removed manually if the rake gets jammed (figure 4.4.5). Garbage that is smaller than the distance between the tines is mostly left on the beach. Because of the counter clockwise motion of the raking unit, smaller garbage gets pushed in the sand and is not collected (personal observation).

Even when screening is applied, the screen of choice has to big a mesh size to clean the smallest garbage (cigarette buts, shards of glass and plastic). (figure 4.4.4). Because of this, the small garbage accumulates on the beaches of the Hague.

Finally, the raking device of the beach cleaner sometimes brakes glass bottles and softer plastics into smaller pieces that pass through the screen and fall back on the beach. Glass also gets broken when stones inside the beach cleaner crush glass that remains at the bottom of the screen (figure 4.4.6). Figure 4.4.7 gives an overview of the process and the through flow of garbage

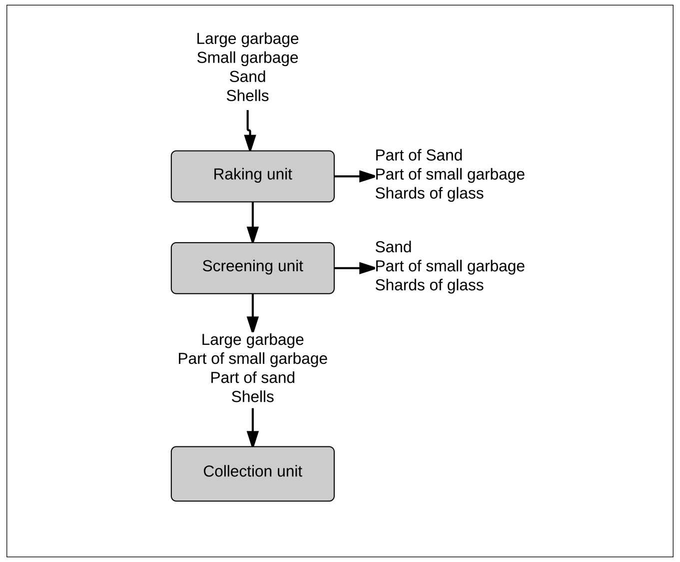


figure 4.4.7, through flow of the different materials

figure 4.4.5, ropes get stuck in the raking unit.

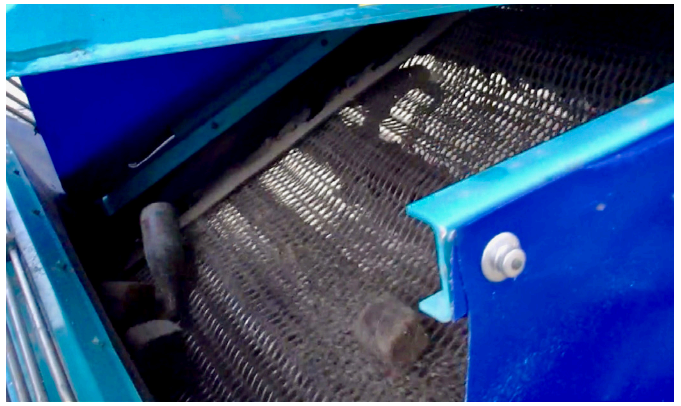


figure 4.4.6, stones inside the beach cleaner brake glass

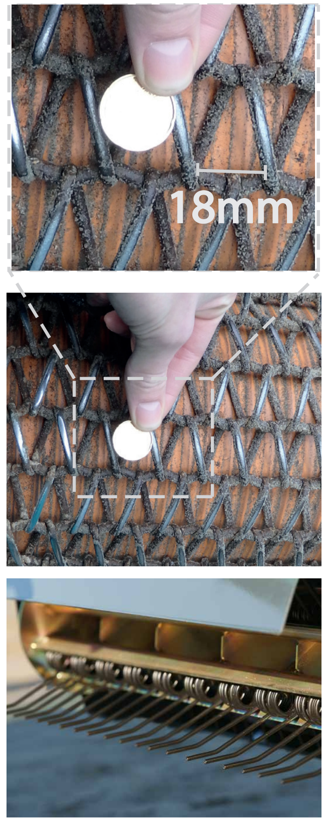


figure 4.4.4, the mesh size of the sieve and the distance between the tines

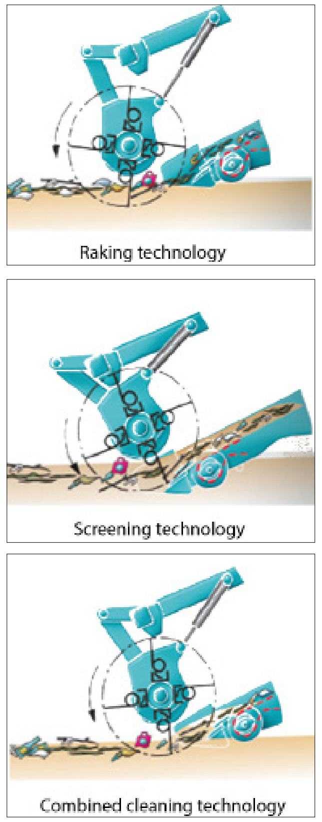


figure 4.4.3, raking, screening or a combination

4.5 PROBLEM DEFINITION

What
The BeachTech 3000 currently used to clean the beach is not capable of cleaning small garbage (plastic pieces, cigarette buts, shards of glass and bottle caps) from the beach. This has two reasons; first of all the tines of the raking unit are to far apart in order to comb the small garbage from the beach. When the screening technique is used, the mesh size of the screen is to large to filter out the small garbage (pieces smaller than 18mm fall through the screen back on the beach). Finally, the current beach cleaners on the market take away shells which should actually be left on the beach. The cleaning method is not selective between garbage and shells (figure 4.5.1). This results in graph 4.5.1, shown on the next page.

Where
The beaches of The Hague are large, vast beaches with a combined surface area of 0,175km2. The entire beach needs cleaning since it is all recreational used.

Who
Coastal municipalities worldwide. (but for this assignment the municipality of the Hague is taken as a pilot study)

What is the goal
The goal is to find a solution to this problem of efficiently removing the smaller garbage while leaving/retrieving the shells on the beach. It should be usable behind a tractor currently used by the municipality.

Why
Small garbage is negatively influencing the experience of beach visitors, it is dangerous for people and animals and is harmful for the marine environment. Shells should remain because they belong to a natural beach, help in preventing beach erosion and generate high garbage disposal costs since they form over half the weight of the collected material.

The way the BeachTech-3000 is currently used does not rid the beach of the smaller garbage and the amount of small garbage is therefore increasing. If the machines are equipped with a smaller mesh size screen and if the plough is lowered, more small garbage will be collected. Thorough cleaning takes longer and the cleaning could not be finished in the given time.

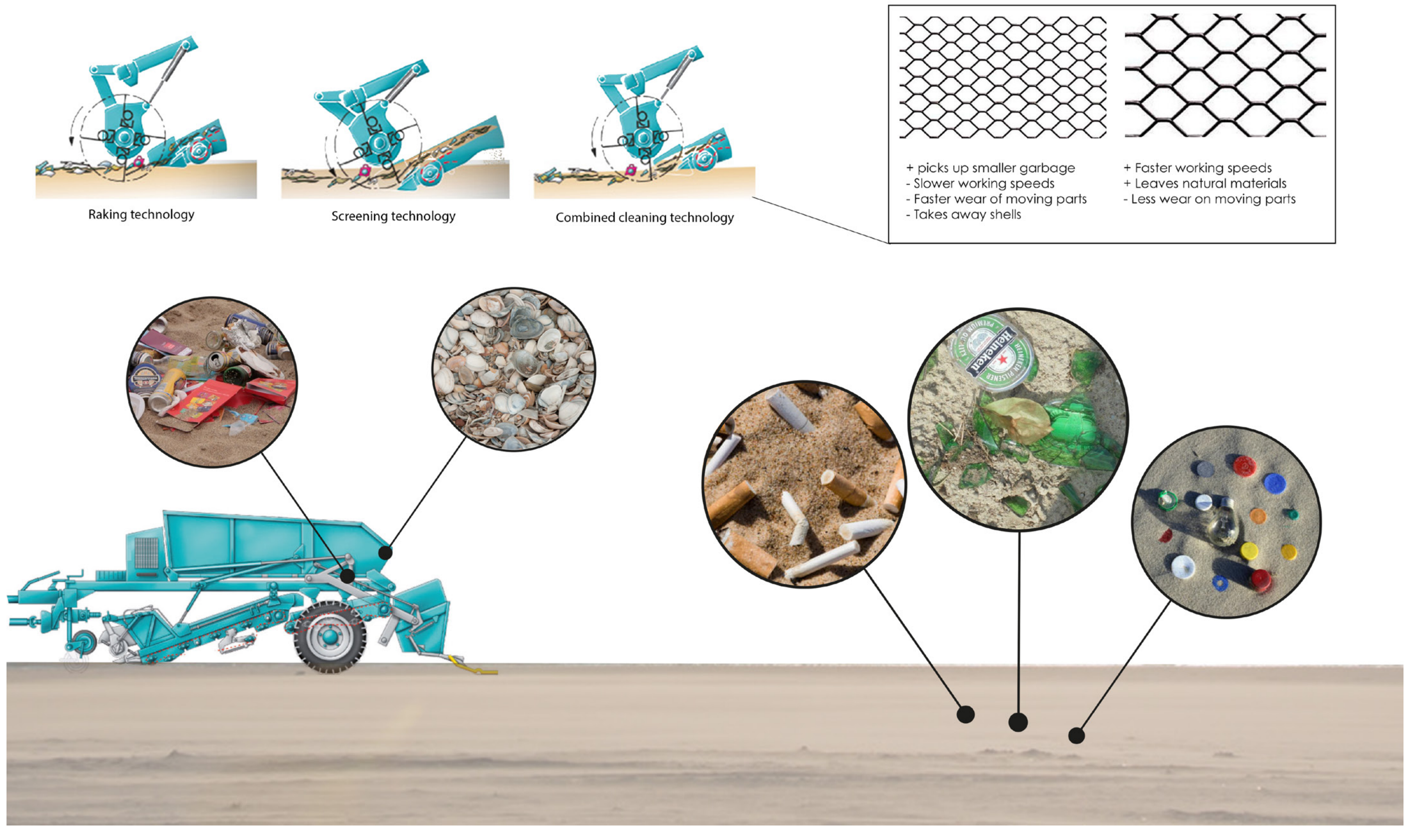
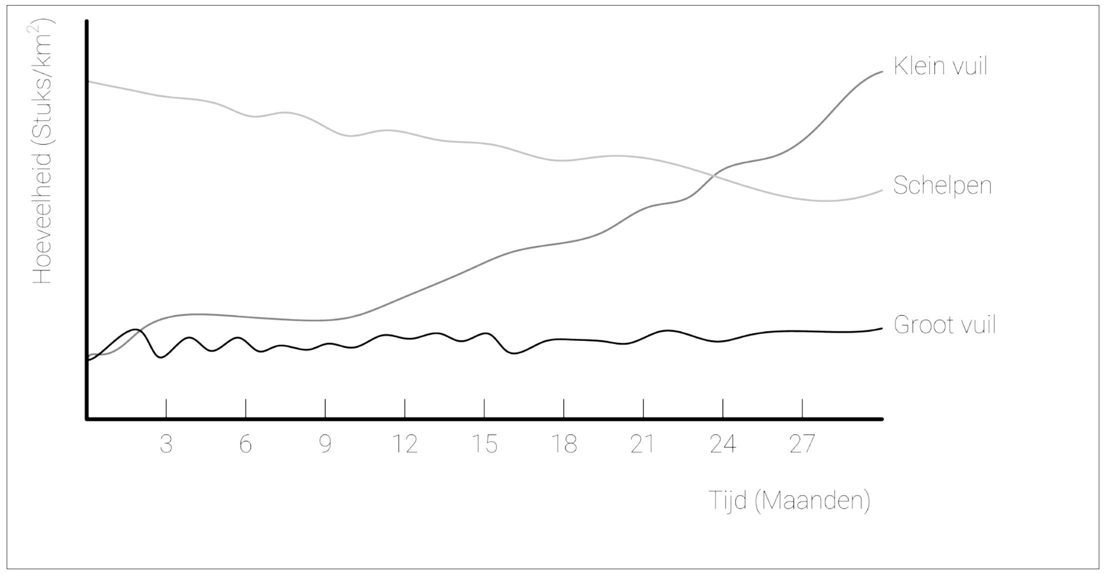


figure 4.5.1, visual of the problem definition

CONCLUSION, CHAPTER 4

The beach of the Hague is a broad and long beach with a total surface area of 0,175KM^2. The cleaning of the beach is done every night during the summer months and when necessary in the winter months. The costs per shift are 18.000€. 6 BeachTech 3000 are used by the municipality to clean the entire area. Although this machine takes away most of the larger garbage, part of the smaller garbage is left on the beaches because the raking device and the chosen screening setting are not capable of cleaning the smallest garbage. The goal of this project is to develop a device that is capable of cleaning the small garbage while leaving the shells on the beach.



Graph 4.5.1, increase/decrease of the different materials on the beach due to the current cleaning method.

5. CLASSIFICATION OF DIFFERENT MATERIALS

5.1 SAND AND SHELLS

In order to decide upon the separation techniques suitable for separating the sand, small garbage, larger garbage and the shells an overview is needed of the different components of these groups. To characterize and finally separate the different materials the different components of the garbage will be analysed on size, shape, colour, material, (specific) weight.

Sand

The sand on the coasts of the Netherlands consist of two main types of sand. The sand south of Bergen consists of mainly reworked Rhine sands with an admixture of late pleistocenene-holocene Rhine sands [34] The sand consists of a mixture of garnet minerals which have a red-pinkish color and Siliciumdioxyde. The average width of the beach is 150 meters with a mild shore face slope (1:300) The average grain size of the sand is 1/4mm. This size of sand is classified as medium sand (1/4 mm - 1/2 mm) according to the ISO 146688 grades.[35]. When considering the density of the sand a couple of factors are important. The sand can be compacted, non-compact, whet and dry, each factor influencing the density of that specific part of the beach. Figure 5.1.1 shows a cross-section of the beach with different regions. It can be assumed that the sand in the regions 2,3 and 4 is whet sand with a density of 1600 kg/m³ and the sand in region 5 is dry sand with a density of 1400 kg/m³.

Shells

The sea in front of the coast of North and South Holland is shallow with sandbanks tideway's and tide currents. The strong current influences the fauna on the sea floor, especially when strong waves occur, a lot of sand is moved, making it a harsh environment to survive. The shellfish living on the seabed near the coast need to be capable of burying themselves quickly in order to survive in this environment. The fresh water coming from the Zeeland delta is rich in nutrients. Because of the shallow and nutrient-rich water vast shellfish crags developed near the coast. The most prevailing species are: the Atlantic jackknife clams, Cut through shells and false angel-wings. The shells are mainly found at the wrack line (figure 5.1.1) These will each be discussed below

Spisula subtruncata - subtruncated surf clam
This is the most common shell prevailing on the beaches of the Netherlands. The shell is thick and strong and one of the smaller species (up to 35mm) Sub triangular but distinctly asymmetrical; umbones close to mid-line. When fresh, the shell has a creamy white colour with a grey-yellow periostracum (top layer). The shape is flattened out near the sides and has fan shaped grooves. Older valves can be yellow-brown, dark brown, blue-grey or black [36].

figure 5.1.2, subtruncated surf clam

Ensis americanus - American Jack knife clam
Very common in the North Sea. Thin shell, has a clear curvature and the edges are rounded. Maximum length 160mm and width 30mm. Colour: shiny brown-green and creamy white inner surface. (naturalis biodiversity centre, n.d.)

figure 5.1.3, American jack knife clam

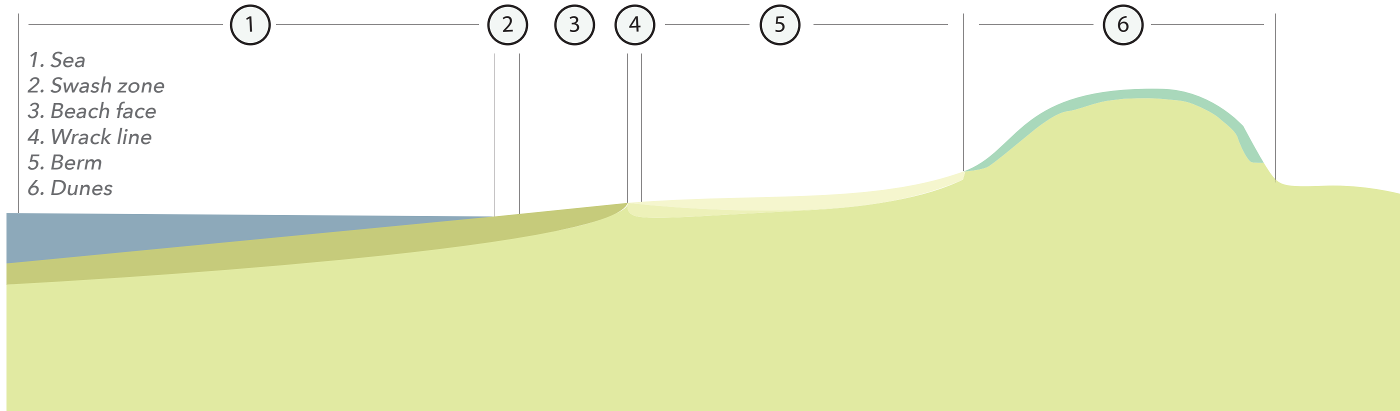


figure 5.1.1, a cross section of the Dutch coast

Petricola pholadiformis - false angelwing
Strong and elongated shell. Umbones far from the mid-line. Ribs from the centre to the edges. Maximum length 80mm and width 35mm. Colour: Creamy white, older specimen are often brown-yellow [37].

figure 5.1.4, false angelwing

Composition of shells
Mollusc shells are mainly build up out of calcium carbonate (CaCo3). Cells in the mantle tissue of the mollusc secrete protein and minerals in order to form the shell. The shell is constructed from the bottom up and has to grow together with the mollusc since the shell is not shed. Because of this, three distinct layers can be identified in the shell (see figure 5.1.5). An outer uncalcified periostracum, a prismatic calcified layer and an inner calcified nacreous layer [38] (figure 5.1.5).

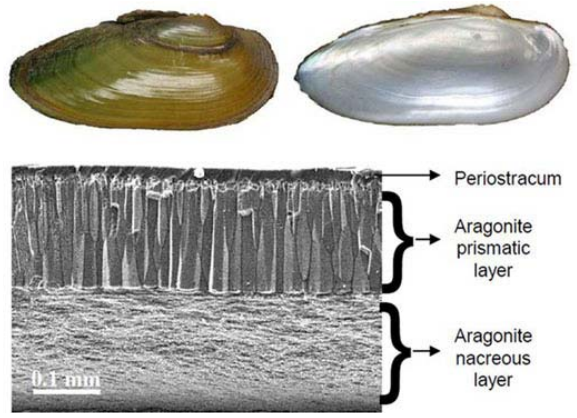


figure 5.1.5, Composition of a mollusc shell

5.2 SMALL GARBAGE

The main categories of small garbage that is currently not being picked up by the beach cleaners consists of the following categories: shards of glass, pieces of plastic (including plastic wrappings and caps) ,cigarette buts and crown caps.

Shards of glass
It can be assumed that the glass chards present at the beaches of the Hague originate mainly from bottles and jars (packaging glass) brought to the beach by the beach visitors. The different types are: green, clear brown and blue glass. The most common kind of glass is Soda-lime glass which has as main component silica dioxide (SiO_2) The different colours are created by adding different chemicals before melting. The density of most glass ranges between 2,4 and 2,8 g/cm3 [39]. When broken the shards are sharp but because of the movement through the sand the shards get blunt.

Pieces of plastic
As mentioned before, the most common item found on recreational beaches during the Boskalis beach clean up tour were small pieces of plastic (mean of 156 pieces/100meter). Since the source and therefore the material of these pieces is hard to determine, this had to be substantiated. It can be assumed that the biggest source of the pieces of plastic is plastic packaging of food and drinks left by the beach visitors. These deteriorate over time and become the small pieces of plastic on the beach. The most common packaging plastics are: PETE, HDPE, LDPE, V, PP and PS. Mainly 2d flakes [40].

Cigarette filters
95% of cigarette filters are made out of cellulose acetate. Cellulose acetate is made by esterifying bleached cotton or paper pulp with acetic acid. The resulting ester is spun into fibres, bundled and cut into the right size. The paper of the cigarette is glued around the filter forming the cigarette tube. The cigarette filters that remains after smoking the cigarette is most commonly referred to as a cigarette but. The cigarette but is around 30% of the size of a cigarette (20-30 mm) and consists out of the filter, paper and some tobacco remains. By smoking a cigarette, part of the chemicals end up within the filter which can finally end up in marine life by ingestion of the filter [41]. One filter (without tobacco) weighs around 0,175 grams. The weight of the filter can differ because of the amount of tobacco left on it and the amount of water absorbed by the filter [42]

Material	*Use*	*Specific weight range*
PETE	Soft drink, water and salad dressing bottles; peanut butter and jam jars;	1.38 g/cm3
HDPE	Five gallon buckets, milk, juice and water bottles; grocery bags	0.93 to 0.97 g/cm3
LDPE	Frozen food bags; squeezable bottles, cling films; flexible container lids	0.910–0.940 g/cm3
PVC	Clear food packaging	
PP	Reusable and disposable microwaveable ware; yogurt containers; margarine tubs; ; disposable cups; soft drink bottle caps; plates.	0.905 g/ cm3
PS	Egg cartons; packing peanuts; disposable cups, plates, trays and cutlery; disposable take-away containers, polystyrene foam	0.96–1.04 g/cm3
Glass	Wine/beer bottles, glasses, jars	2,4 and 2,8 g/cm3
Steel	Bottle caps,	7,82 g/cm3

Overview
The components of the mixture differ in size, shape colour and weight (see figure 5.2.1) so on these characteristics no separation is possible. The different components do however share the same specific weight and can be classified accordingly. The range of the specific density of each of the mixtures components can be seen in table 5.2.2. A gap exists between the specific weight of the plastics on one hand and glass and shells on the other.

CONCLUSION, CHAPTER 5

The different components within the material categories differ in size, shape, colour, and weight. They do however share the same specific weight and material type. The shells that should be left on the beach are the American Jack knife clam, sub-truncated surf clam and the false angelwing.

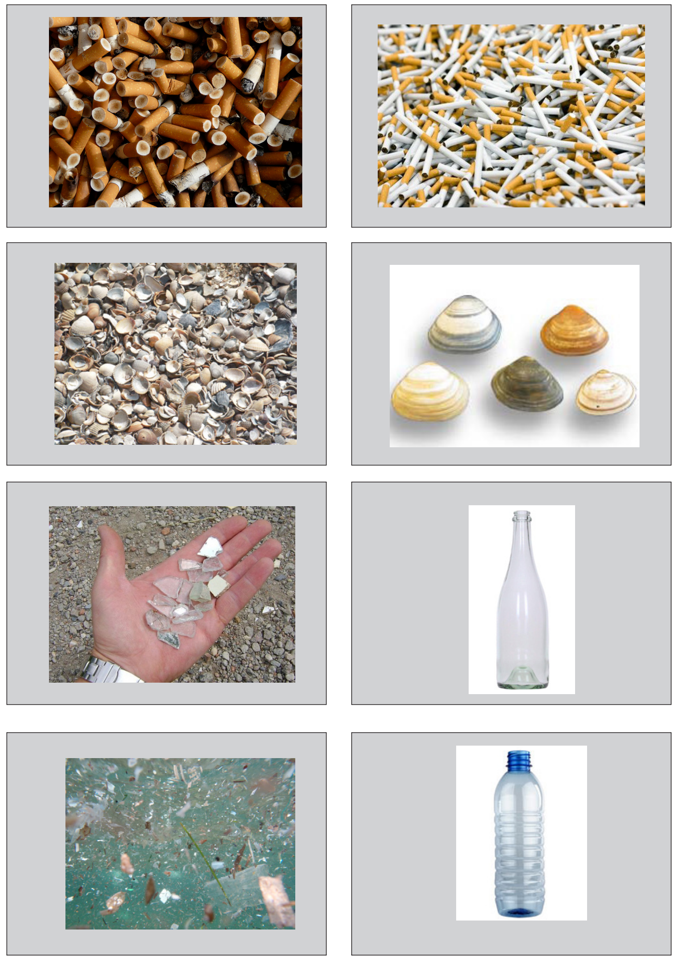


figure 5.2.1, different material categories differ in size, shape,weight and colour

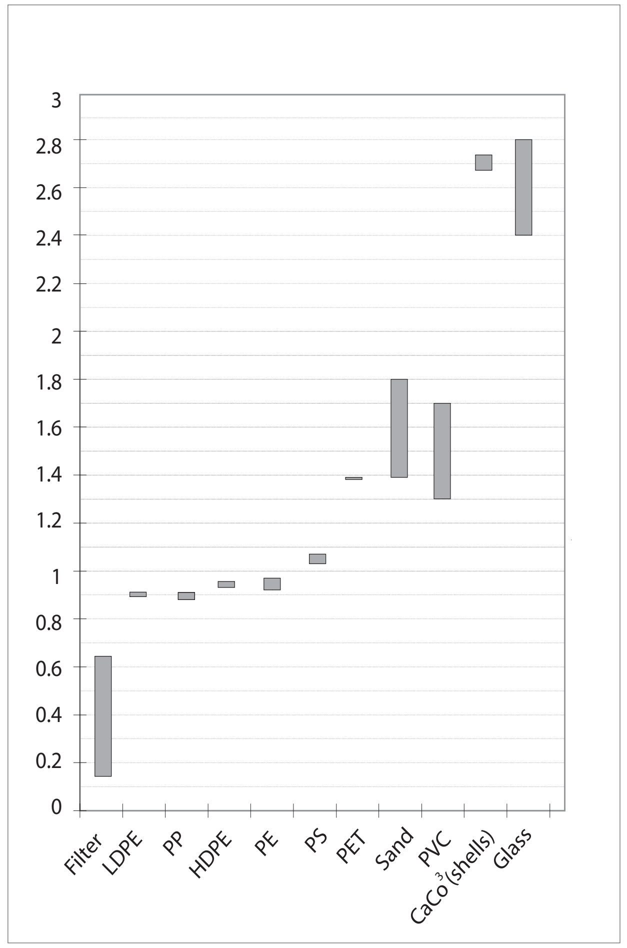


table 5.2.1, range in specific weights of different materials within the mixture

6. SEPARATION TECHNIQUES

6.1 OVERVIEW

A lot of different kinds of separation techniques are available to separate a vast range of different mixtures. In order to make a first selection within these processes it is important to have a look at the mixture that has to be separated. As can be seen in the previous chapter, the individual particles within each material category of the mixture are of different size, shape, form, material and weight. The one thing these components have in common is that they are all solids (Sand, shells, plastics, cigarette buts and glass) In order to determine appropriate separation techniques, research was done on separation processes used on solids. These processes can be found in the greyed out area of table 6.1.1 . From this selection the different kinds of separation methods have been analysed on its applicability to separate the mixture.

The three main analysed directions are density separation, mechanical screening, and sensor based sorting. An overview of the different applications of the three separation principles can be seen in table 6.1.2.

Each type of separation will be discussed individually in the coming sections. The working principle will be explained and the typical aggregates of the techniques will be discussed.

		MINOR COMPONENT		
		Solid	Liquid	Gas/Vapour
MAJOR COMPONENT	Solid	Sorting Screening Hydrocyclones Classifiers Jigs Tables Centrifuges Dense media Flotation Magnetic Electrostatic	Pressing Drying	
	Liquid	Thickeners Clarifiers Hydrocyclones Filtration Centrifuges Crystallizers Evaporators Precipitation Membranes Reverse osmosis Ion exchange Adsorption	Decanters Coalescers Solvent extraction Leaching Chromatography Distillation	Stripping
	Gas/Vapour	Gravity settlers Impingement separators Cyclones Filters Wet scrubbers Electrostatic precipitators	Separating vessels Demisting pads Cyclones Wet scrubbers Electrostatic precipitators	Adsorption Absorption Membranes Cryogenic distillation Condensation
The terms major and minor component only apply where different phases are to be separated, i.e., not to those on the diagonal.				

table 6.1.1, overview of separation techniques arranged according to material state

Gravity separation	*Mechanical screening*	*Sensor based sorting*
Shaking tables	Vibrating screens,	NIR cameras
Gravity separator	Bar screens,	IR cameras
Reichert cones	Wedge wire screens	UV cameras
Spiral separator	Radial sieves,	Monochromatic cameras
Winnowing machine	Banana screens,	Colour cameras
Sluices	Multi-deck screens,	Trichromatic colour cameras
Jig concentrators	Vibratory screen,	Lasers and sensor
In line pressure jigs	Fine screens,	Camera and laser combination
Multi gravity separators	Flip flop screens	XRT:X-ray transmission
Cyclones	Wire mesh screen	XRF X-ray fluorescence reflection
Zig Zag wind sifters	Drum screens	Radiometric sorting,
Cross flow separator		Inductive sorting

table 6.1.2, overview possible applicable separation methods

6.2 GRAVITY SEPARATION

Gravity separation uses the difference in specific weight of the components in order to separate them From each other. Some use only the gravitational Force As Driving Force Of The separation, others enforce separation by density by using a centrifugal force. Settling in water or separation by use of an airflow can be applied. The advantages of this method is that it is generally low cost and environmental friendly since no chemicals or heating is required. It is one of the oldest separation techniques (used in winnowing of weat) but the last 25 years the factors are enhanced [43].

Jigs (figure 6.2.1)
Jigs consist out of a bed that rests on a ragging screen, an inflow of hutch water that is pulsated by a moving diaphragm, in combination with a bed of intermediate specific gravity particles. The heavier particles sink through the bed and sink to the bottom. The lighter fraction forms a tailing overflow, hence enabling separation. Variations on this principle are the in-line Pressure jig and the Kelsey jig (using pressure and centrifugal force respectively).

Pinched sluices (figure 6.2.2)
Working principle The mixture is transported over a incline slope, due to gravitational force and narrowed sluices, segregation occurs. The finer, heavier particles sink and pass through the sluices while the lighter fraction passes over and is discarded. The two main types are trays and cones [43].

Spirals
Spirals use a combination of gravitational and centrifugal forces to segregate particles of different specific gravity. While rolling down the spiral, the segregation occurs. Some spirals use wash water in the process others depend on the particles rolling or gliding down.

Shaking tables
Working principle (figure 6.2.3):
Motion of particles due to difference in specific gravity and size. An oscillating inclined table, equipped with riffles holds back the parts that are closest to the table deck. Small high specific gravity particles are transported through the riffles to an outlet. The particles with a lower specific gravity move over the riffles. Air and water tables exist, air tables use low pressurised air to fluidize the mixture.

Cyclones
Working principle (figure 6.2.4)
The centrifugal force within the cyclone (air or water) makes the heavier particles go to the wall and downwards while the lighter fraction moves upwards through the vortex and is discarded as overflow.

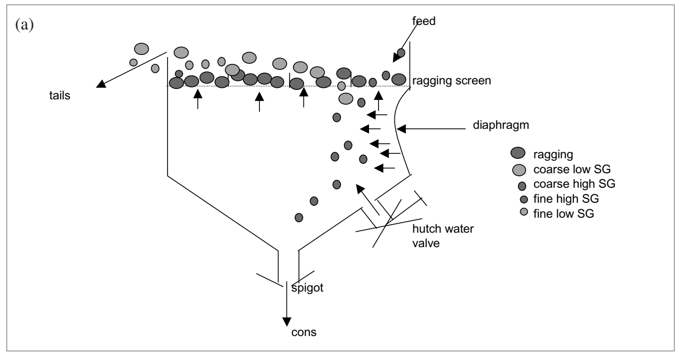


figure 6.2.1, hydraulic jig

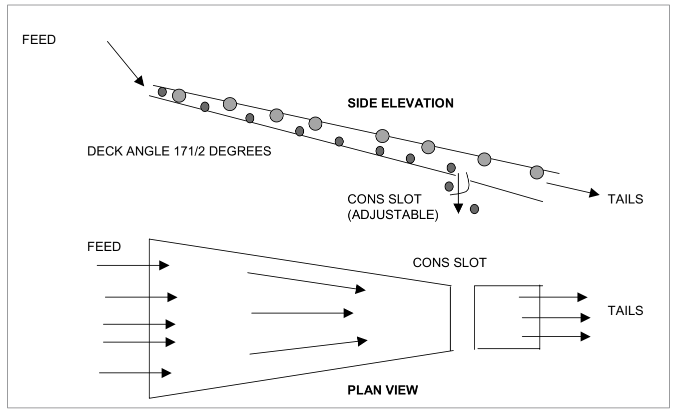


figure 6.2.2, pinched sluices

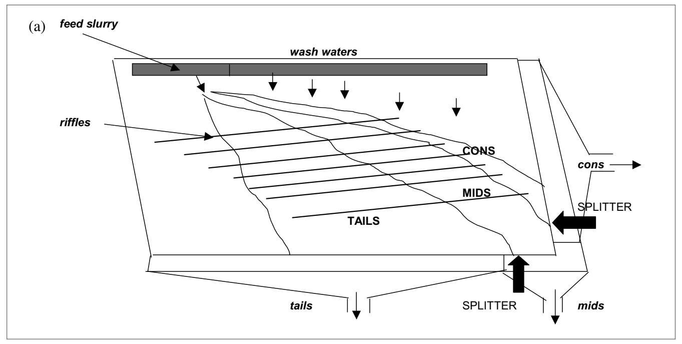


figure 6.2.3, shaking tables

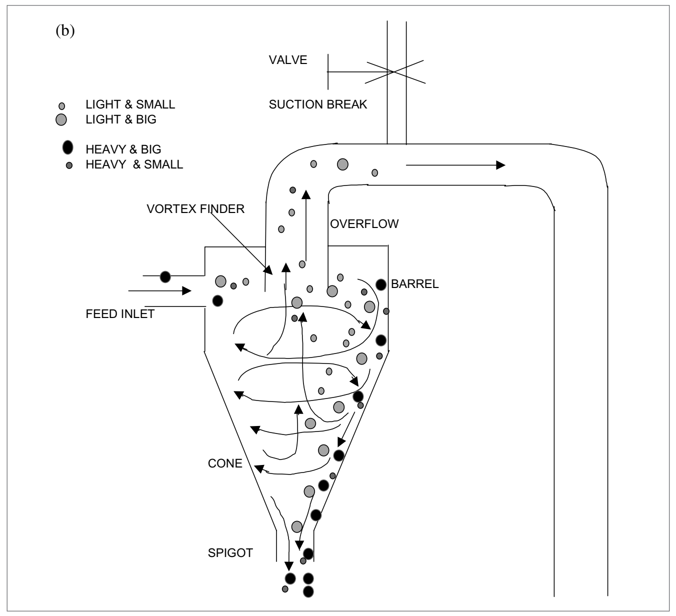


figure 6.2.4, cyclones

Zig-zag wind sifter
Working principle (figure 6.2.5):
The zigzag wind sifter consists of a multi-deck zigzag channel, which is fed from above or in the middle of the channel. Lights and fines are entrained in the upward-flowing air and heavy, large materials fall down by gravity. The air velocity is the main separating criterion of a zigzag wind sifter. In order to separate with multiple thresholds, multiple zigzag sifters can be used in series each with a different volumetric air flow (figure 6.2.6))

Cross flow separator
Working principle (figure 6.2.7):
Also known as air knife separator, indicating the elongated flow of air “cutting away” the lights from the main stream. Heavies are less affected by the air stream, while the lights are entrained and carried over to a separate collection container.

Suction Hood
This is a quite simple technology. The lightweight fraction is sucked out of the mixture from a conveyor, a vibrating screen or a drum screen. The major problem with this classifier usually is the poor separation efficiency

Cross-flow Air Classifier
In this kind of air classifier the air is blown perpendicular to the fall direction of the material. Because of the short contact time between the falling material and the air stream, there is a marginal separation (unless large differences in specific weight or surface exist. If there is a wide density range within the material mix (e.g. shredded automobiles) then there is a successfully use of these classifiers possible. When a focused high velocity air stream is used, the unit is called an impulse air classifier and this one is used successfully in the waste recycling industry.

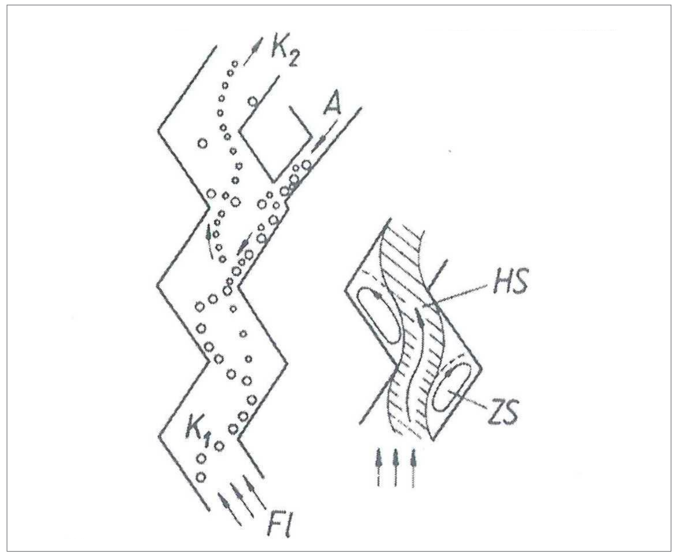


figure 6.2.5, zigzag air sifting, A: feed, K1: fines, K2: coarse, FL: air input, HS: main stream, ZS: circulating flow

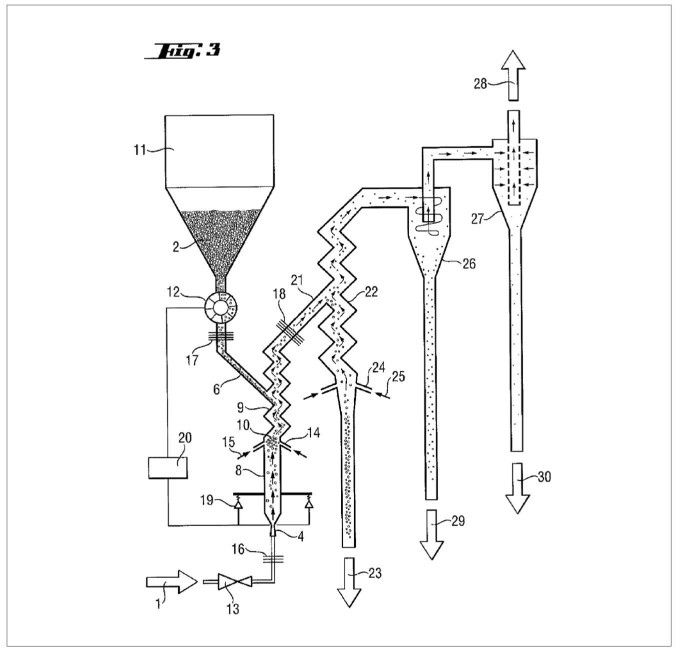


figure 6.2.6, zigzag air sifting in series.

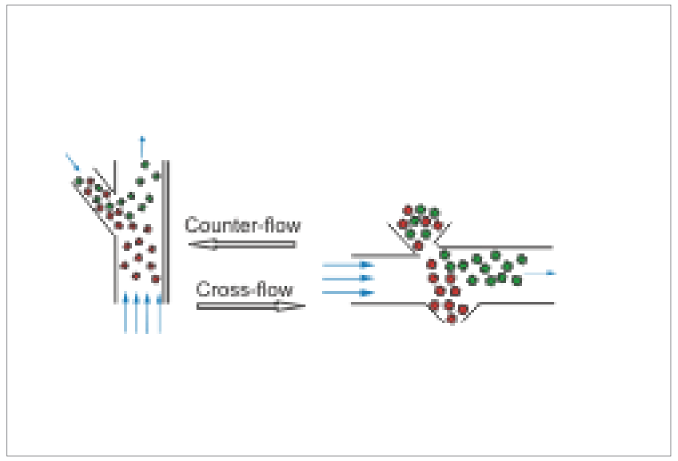


figure 6.2.7, counter and cross flow separator

6.3 AIR CLASSIFICATION PRINCIPLE AND TYPES

Wind sifting
Wind-sifting is a technique that is frequently used in the mechanical recycling process and in the waste treatment industry. It is a good durable and inexpensive method to separate a mixture on differences in size, shape and density characteristics. It consist of removing a light fraction out of mixed particle stream by use of an uprising air flow. It relies on a differential force applied by an air flow in the gravity field. The individual material flows coming out of the wind sifter are more pure on one of the three mentioned material characteristics than the mix that went into the separator. The main division in wind sifters is between static and dynamic sifters. If the particles are very small, separation out of the air flow becomes more difficult and a centrifugal force (cyclone) may be needed to separate the particles from the air flow.

In order to get a better understanding of the classification mechanism the motion of the particles and the accompanying force balance will be shortly discussed in the following section.

Motion of particles
A mixture of material that needs to be separated shows a variety in particle size, density and shape. Looking at a particle moving relative to the air-flow, the motion of that particle depends strongly on the three properties and can be predicted by setting up a force balance of all forces acting on the particle. By doing so, predictions about the classification result can be made if the property distribution of the feed is well enough known. Below the force balance is explained. The theory also applies on motion of particles that are suspended in water. Therefore we speak about a fluid medium which can be both air (or another gas) or water (or another liquid)

Force balance of a particle moving in a fluid
The stationary motion of a sphere in standing fluid is the simplest example of a interaction between the particle and a fluid. When considering a sphere of a diameter d and density Rho, settling in a fluid with destiny Rhof. When the different forces reach an equilibrium, the particle is at its constant velocity. This constant velocity is called the terminal settling velocity of the particle. The different forces acting on the sphere are:

Fg = Gravitational force
Fg can be determined when mass, volume and specific weight of the particle are known.

$$F_g = m_s g = \rho_s V_s g$$

Fb = The buoyancy force
The buoyancy force Fb is caused by the hydrostatic pressure gradient dP/dz of the fluid in which the particle is suspended. The fluid pressure at the bottom half of the particle is higher than at the top half, resulting in an upwards directed force. The hydrostatic pressure is given by:

$$P(z) = \rho_f g(z_0 - z)$$

$$F_b = V_s \frac{dP}{dz} = -V_s \rho_f g$$

Where z0 is the height of the fluid surface and z the height of the particle Fb is derived from P(z)

Fb depends on the volume of the particle. Fg and Fb are often combined as a nett effective gravity force Fgn:

$$F_{gn} = F_g - F_b$$

Fd = The fluid drag force
Fd is the drag force applied on the particle. Which opposes the direction of motion. It is caused by a build up of pressure difference between the front and the back of the particle at increasing velocities. In advance of to the establishment of Fd, three different Flows must be considered: laminar transitional and turbulent flow. the drag force for a sphere under laminar flow conditions is solved by the following formula:

$$F_d = 3\pi\eta d v_r$$

In general the desired volume of air needed can be estimated by:

$$v_0 = \frac{F_v}{WL} = \frac{F_v}{A_t}$$

Fv=volumetric flow rate
At is horizontal area

At is the horizontal area of the air classifier. Normally the actual needed area is larger due to concentration gradients and non ideal plug flow conditions that occur in wind-sifters. As a rule of thumb, the desired area is twice the theoretical calculated area.

Zigzag wind-sifter
The zigzag wind-sifter consist of a multi-deck zigzag channel fed from above or in the middle. Lights and fines are entrained in the upward flowing air and heavy large material falls down due to the gravitational forces that act on the particles. The air velocity is the main separation criterion within an zigzag wind-sifter, a higher air velocity will mean that a larger percentage of the mixture will end up in the “lights” fraction.

The zigzag can be considered as a sequence of single cross flow separators, the more zigzags, the better the separation sharpness that is reached. In every corner of the zigzag channel Eddy Rolls occur, in which the material circulates (at ZS), see figure 6.2.5. (HS) is the main uprising Airflow. The zigzags also cause the air flow to be less turbulent. A single zigzag normally has a poor separation efficiency so a zigzag normally consists of multiple of these zigzags.

4 and more decks are applied for application requiring a high separation sharpness, for example in the sorting of plastics. The length of the channel gives the mixture sufficient time to settle against, or flow with the uprising air stream. For high efficiency application usually cross sections do not exceed 1.2 by 0.8 m at a maximum air velocity of 10m/s.

The distributed properties of a typical particle mixture cause a spread in relative velocities, thus enabling separation. These properties are important to know if the maximum reached classification result should be decided.

Conclusions wind sifting

Some basic rules apply in wind sifting, if the particles have the:

- Same density and shape, mix can be separated on size
- Same size and shape mix can be separated on density
- Same size and density, mix can be separated on shape

These situations unfortunately almost never occur, the result of the separation will therefore be lower than 100%.

Partition curves

To get better insight in the separation of the wind sifter, partition curves can be made. In the waste recycling industry, property distributions vary a lot and are often difficult to describe.

A practical design procedure is required that is based on experimental data gathering. Instead of a single efficiency parameter the efficiency of wind sifter can be presented graphically, based on experiments. When the air classification is used for separation on size, a partition curve can be made.

Partition curves and its related efficiency parameter Ep and I are also useful for monitoring density separation by replacing the size axis by a density axis. A density partition curve shows the added overflow percentage or partition factor as a function of the density. In other words a point on the curve shows the percentage of that particular particle density that reports in the light fraction of the separator. Ideally under the cut density all percentages should be 100% and above it 0%. Resulting in a step function. In reality most partition curves look like figure 6.4.2 (right).

Other factors that influence the separating result of the wind sifter are:

- The degree of overload
- The distribution of the size of the feed material
- The amount of moisture in the mixture

A typical wind sifting process consists out of the following steps:

- Homogeneous and constant supply of the feed to the separation zone, in recycling practices the material is often shredded. To a certain size.
- The wind sifting step itself
- Separating the air form the coarse and the fine products, letting the particles settle.

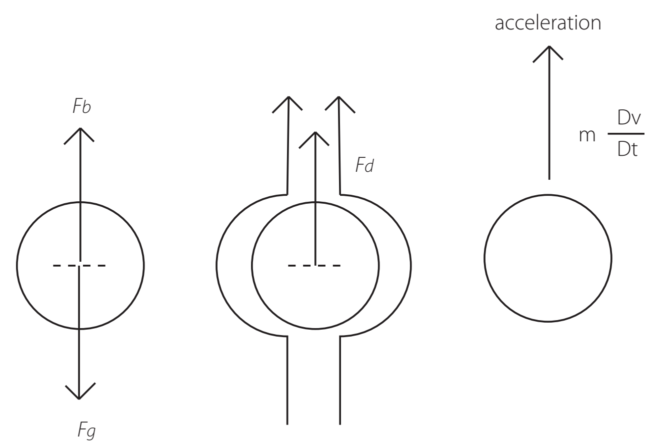


figure 6.4.1, forces acting on particle in windsifter

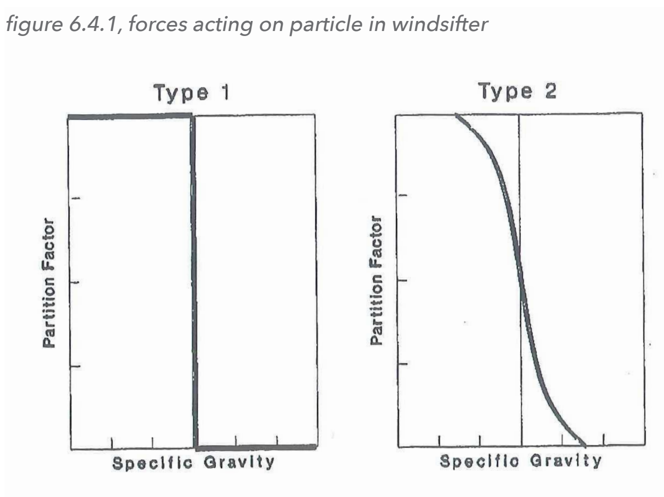


figure 6.4.2, partition curves

Types

In figure 6.4.3, different types of wind-sifters are explained. The zigzag wind-sifter offers the highest efficiency due to its multiple separating steps included. All types use the same principle of an air-stream taking along the lighter fraction, while the heavier fraction settles against the air stream.

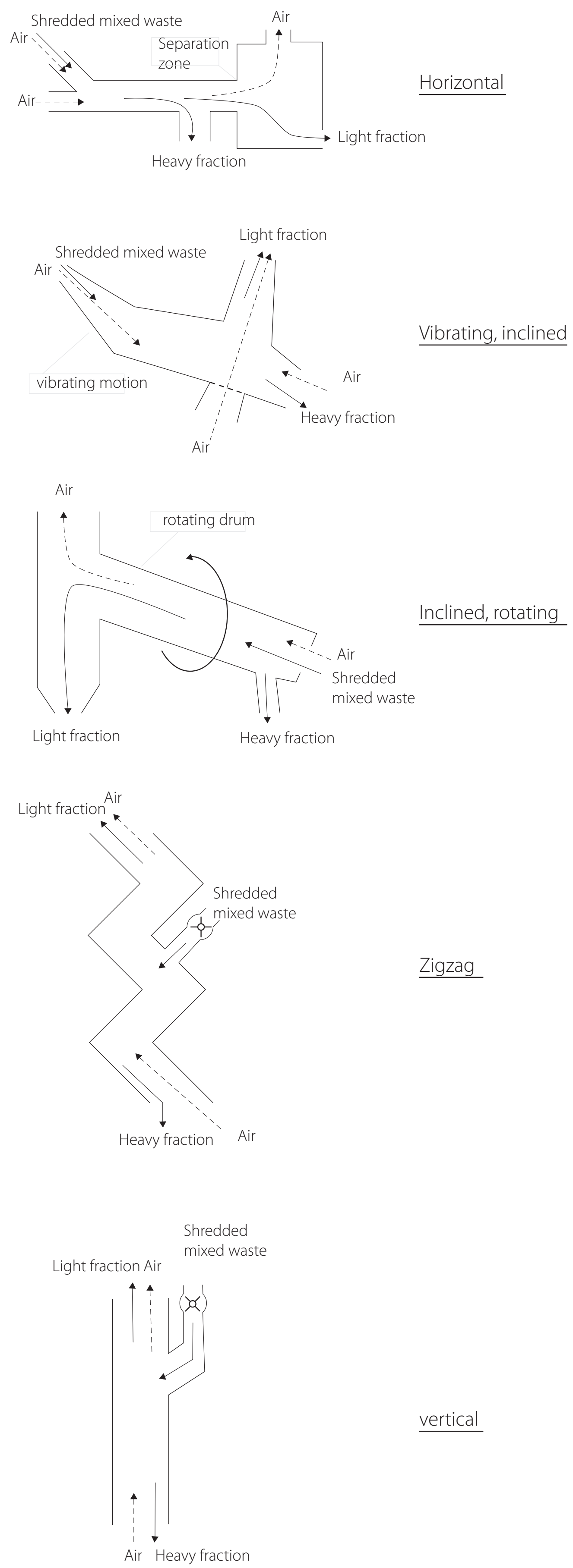


figure 6.4.3, different types of windsifters

6.4 MECHANICAL SCREENING

The beach cleaners currently used by the municipality, are not effective and efficient enough to clean all the garbage from the beach. In this section, mechanical screening will be discussed in order to get a better understanding of the factors and working principle of mechanical screening.

Screening is performed by separating the different components based on the size of the particles using different openings on the screening surface. The fraction that is smaller will fall through the opening (fine fraction). The oversized fraction stays on top of the screen and is discarded at the bottom. The screening efficiency is based on the rating between the fine fraction in the initial feed and the fine fraction that passes through the screen. The main division in screening is between dry and whet and static or mechanic screening. The factors that are influencing the efficiency of mechanical screening machines are:

Machine dependent factors:
- Angle, form and surface area of the screen
- Vibration frequency, amplitude and revolutions

Screen surface dependant factors:
- Surface type
- Surface opening size
- Screen material

Screening dependant factors
- Feed input
- Surface dampness
- Particle size and density
- Distribution and fibre content of the input

Typical aggregates of mechanical screening are:

Trommel/Drum/revolving screen (figure 6.2.1)
The mesh size, the type and number of baffles and the inclination of the drum are factors which influence the efficiency of the screening. Deflectors and other wall assemblies are installed to carry the waste up the drum's sides and enable maximum screening potential of the screen. In order to increase the screen efficiency, spiral shaped deflectors are installed in the drum to transport the material through, regardless of the angle of the drum. To classify multiple fractions with the same drum, multiple mesh sizes can be incorporated.

Multiple screen deck (figure 6.2.2)
In multi deck screens, multiple screens are situated above each other. Each screen taking out a different particle size. By doing so, the screening process is speed up and the material can be classified in different size fractions in one screen. This principle is applied in banana screens which are used to separate different grades of ore.

Ballistic separator
Two types of ballistic separators exist, the first version ejects the mix into standing air at high speed using a conveyor. If the set up has enough height (usually several meters) the heavy and light fraction are separated (figure 6.2.3). Advantages are the high throughput and the simplicity of the system but the downside is the amount of space needed to house such a system. The other type of ballistic separator uses a inclined rotating slope in which the 2D light fraction travels upward, the fine fraction is sieved out and the 3D heavy rolling fraction moves down (figure 6.2.4).

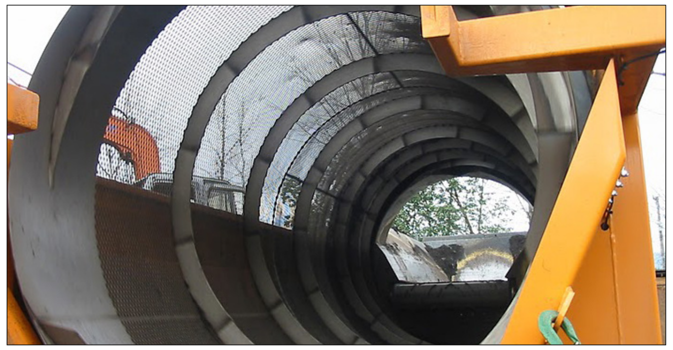


figure 6.2.1, drum screen

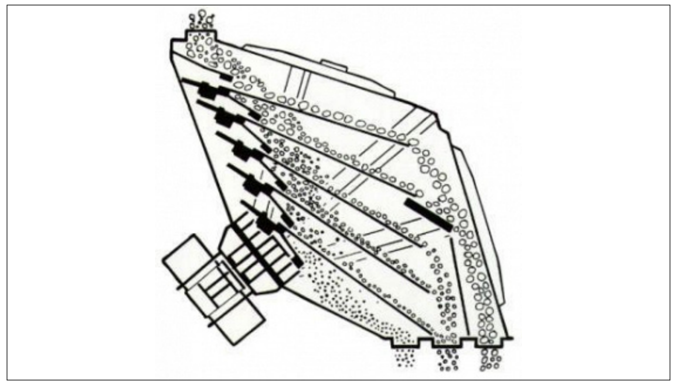


figure 6.2.2, multiple deck screen

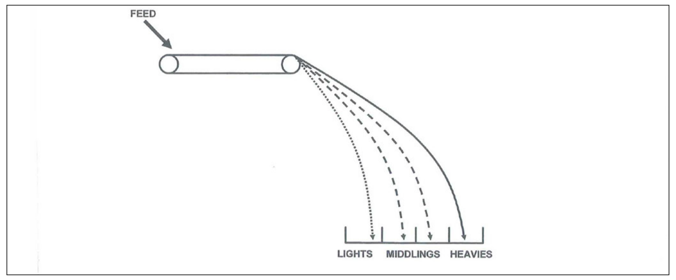


figure 6.2.3, ballistic separator

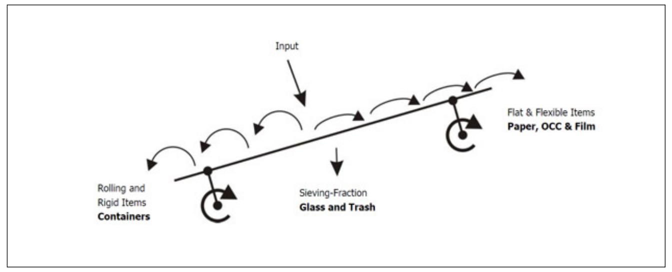


figure 6.2.4, ballistic separator

6.5 SENSOR BASED SORTING

Sensor based sorting uses different material properties to detect and sort materials. (on colour, size, shape, structural properties and chemical composition). A wide range of sensors can be used to define the scanned material (table x) Sensor based sorting is an umbrella term where the different particles of a mixture are singularly detected by a sensor and ejected out of the material flow by mechanical, hydraulic or pneumatic ejectors.

Sensor based sorting generally consist of the following sub-processes:
Presentation of the material:
Presenting the material in a predictable and stable manner. Typically, this is done by using vibrating feeders followed by a chute or fast-moving conveyor belt (figure 6.3.1 and 6.3.2).
Sensor detection:
This can be divided into two types. Reflection based systems use the difference in surface properties and use cameras to identify the different materials. Transmission types use for example X-ray radiation to determine the difference in density. The amount of absorption/ reflection of the radiation is measured.
Data processing:
The sensor input must be analysed in real time, the system makes the yes/no decision about individual particles and passes this decision through to the ejection system.
Ejection:
The pneumatic, mechanical or hydraulic ejection system ejects the refused particles out of the material flow.

Colour recognition
Cameras are used to detect the visible spectrum and beyond (Infrared, Ultraviolet and other spectra).

Sensor	*Material property measured*
NIR cameras	Reflection and absorption of NIR-radiation
IR cameras	Reflection and absorption of IR-radiation
UV cameras	Reflection and absorption of UV-radiation
Monochromatic cameras	Monochromatic reflection
Colour cameras	Reflection, absorption, brightness and transmission of visible radiation
Trichromatic colour cameras	Reflection, absorption, brightness and transmission of visible radiation
XRT:X-ray transmission	Transmitted X-ray radiation
XRF X-ray fluorescence reflection	Reflected X-ray fluorescence under X-ray radiation
Radiometric sorting,	Natural radioactivity
Inductive sorting	Electrical conductivity and susceptibility

Near infrared (NIR)
Materials can be identified by their unique spectral properties when shined upon with near infrared radiation. The reflected radiation is measured by the NIR sensors
X-ray transmission (XRT)
Difference in atomic density can be identified by releasing X-ray radiation on the material flow. The difference in absorption of the radiation is used to identify the different materials. The advantage of this technique is that it doesn't matter is the material is whet or dirty.
Electromagnetic sensor (EM)
Electromagnetic sensors use the difference in electromagnetic properties to identify different materials. Electromagnetic conductivity and permeability are used.
Photometry (PM)
Attenuation and reflectance of a monochromatic laser on the material are used to identify different materials. Often this sensor is used in combination with other sensors to complement and further optimize the separation. The PM sensor can identify material structure, size, colour and shape [44].

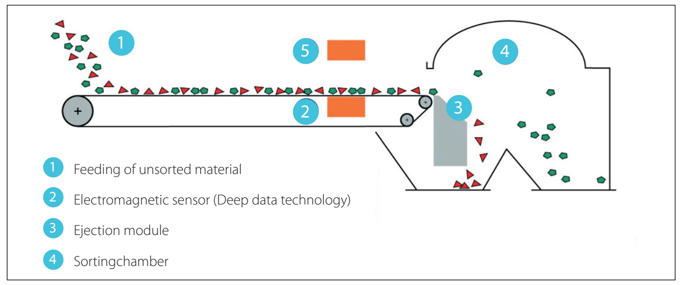


figure 6.3.1, conveyor belt type sensor based sorting

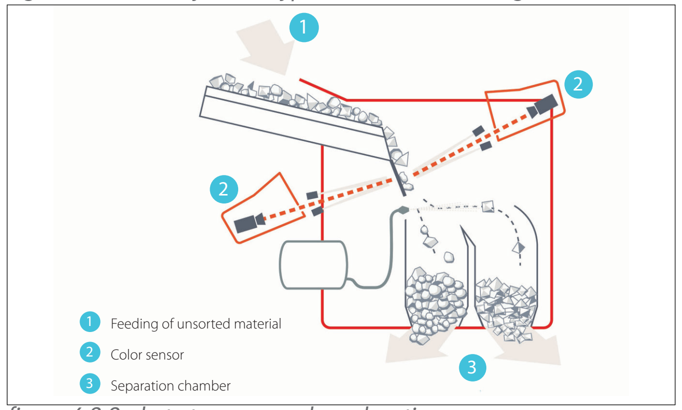


figure 6.3.2, shute type sensor based sorting

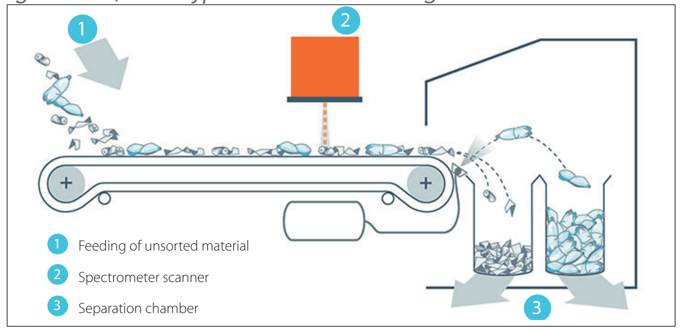


figure 6.3.3, spectrometer scanner

CONCLUSION, ANALYSIS

In the analysis phase, the amount and kind of garbage present at the beach was mapped out by analysing the monitoring executed during clean ups and by analysing a sample taken from one of the beach cleaners. Garbage in the marine environment is a big problem for humans and animals.

Most mechanical cleaning solutions for cleaning beaches use either raking, screening or a combination of these techniques. The BeachTech-3000 used by the municipality of the Hague uses a rotating rake and screen to collect the garbage. The BeachTech-3000 is not capable of effectively removing the smaller garbage and takes in large quantities of shells.

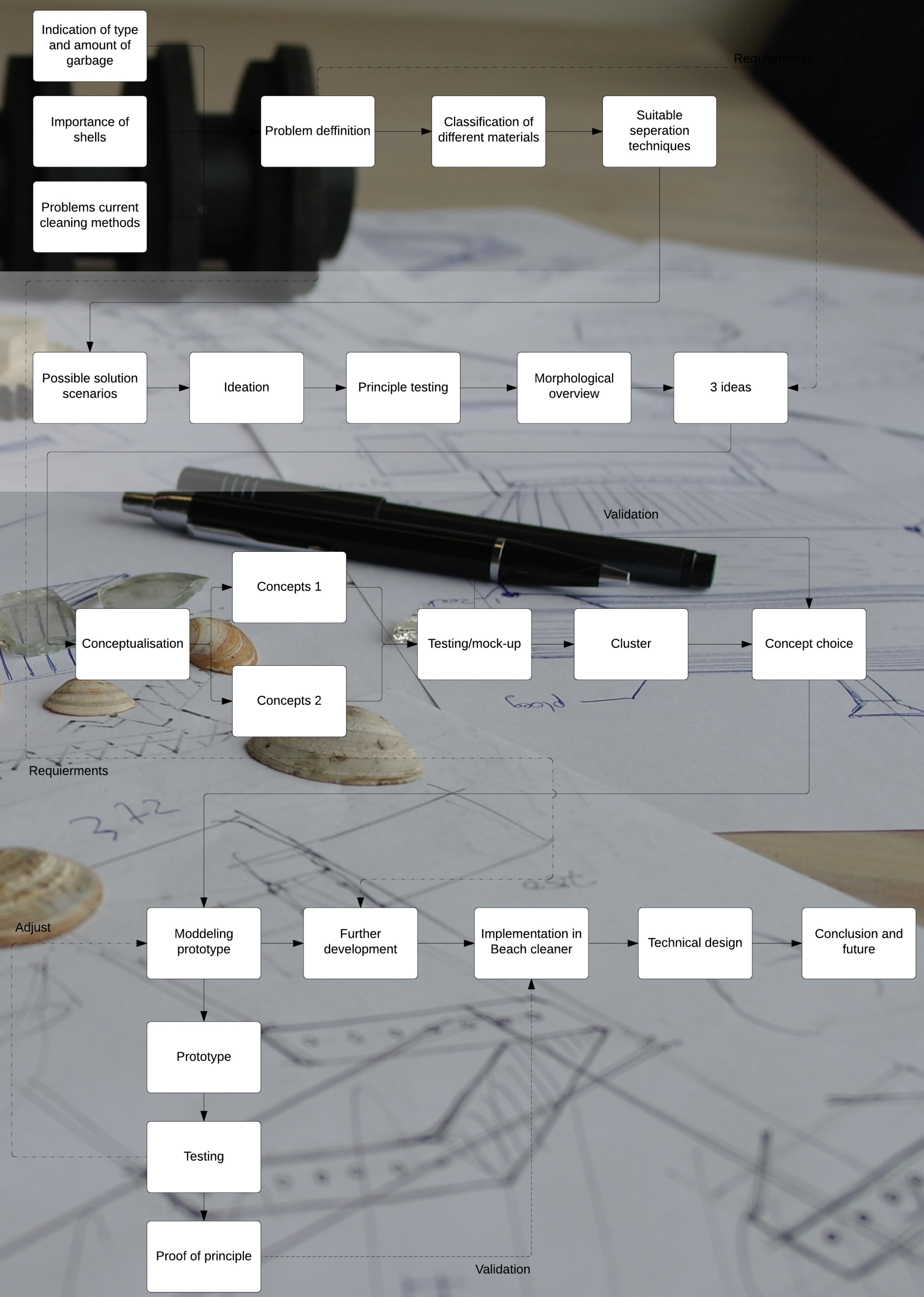
The different characteristics of the garbage components and the shells have been investigated. It became clear that separating garbage from shells can only be done on material type or specific weight since all categories are found in different sizes and shapes.

Different screening types have been analysed to explore the possibilities of more efficient screening and to see if the current rotating screening deck can be replaced by a different type of screening to increase the cleaning efficiency.

The only feasible possibilities to separate garbage from shells is either by using a type of gravity separation or by using a form of sensor based sorting. In the next chapter the applicability of these processes will be researched further and first ideas will be generated.

7.SYNTHESIS

In the Synthesis phase all gained insights of the analysis phase will be used to generate ideas that are capable of solving the problem. Quick principle testing, mock ups and morphological charts will be used to find, cluster and integrate suitable (sub) solutions to the problem. A choice will be made according to the requirements and demands generated in the first phase.



7. SYNTHESIS

7.1 SET UP OF THE SYNTHESIS PHASE

The problem definition in chapter 4.5 describes a problem that is twofold. On one side, the beach cleaner is not capable of collecting small garbage in an effective way due to the raking technique that is used and the mesh size of the screen (2cm). Secondly, the beach cleaners remove the shells from the beach, which is undesirable for the earlier stated reasons in section 4.4.

The desired outcome of the solution should be that the (small) garbage is removed more efficiently, while leaving/returning the shells to the beach (figure 7.1.1). In this phase, idea generation has been done in order to come up with first solutions to the problem statement.

Sketching, morphological overviews, quick prototyping and tests with different separation techniques have been done to discover and test possible concept directions. The process of this phase can be seen in figure 7.1.2. The results from this phase will form the base for the concept development and finally the detailed design.

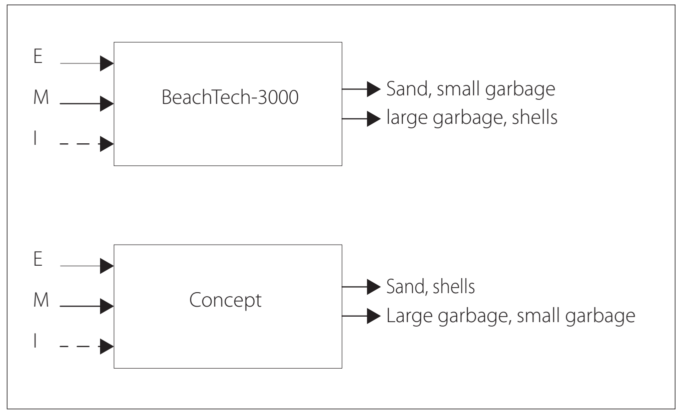


figure 7.1.1 current and desired material flow situation

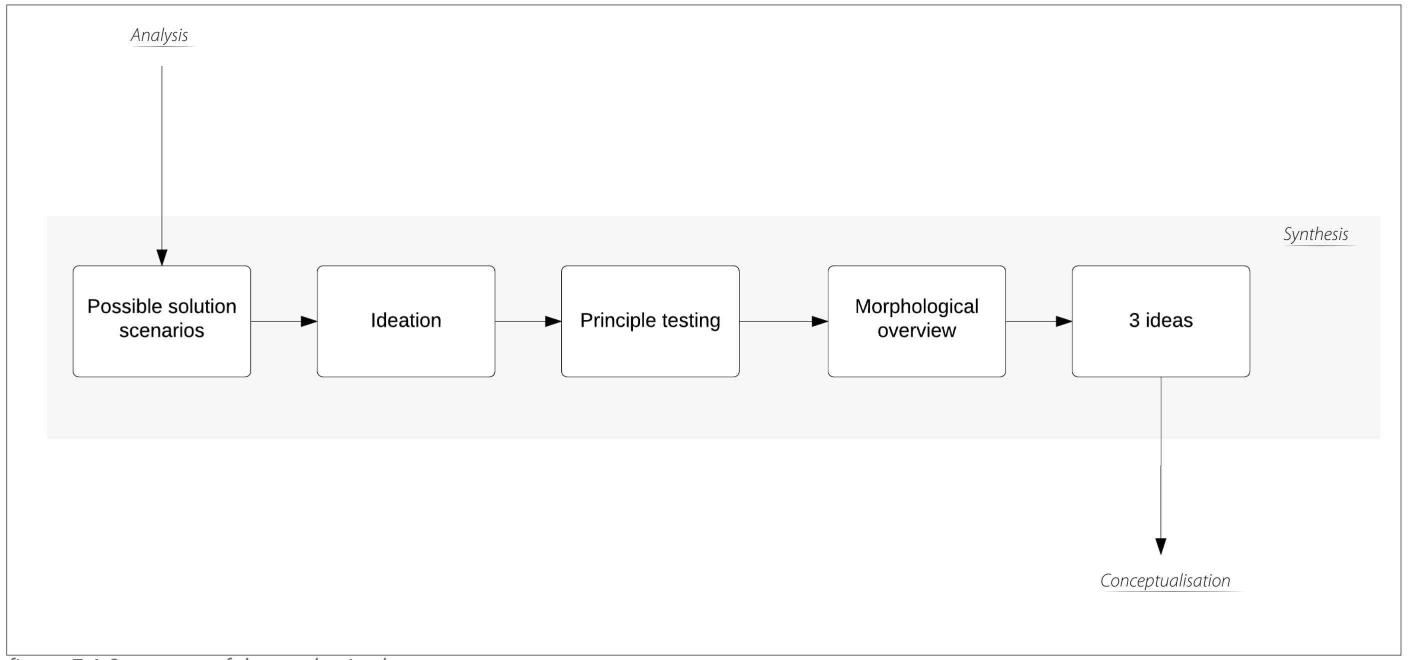


figure 7.1.2, process of the synthesis phase

7.2 SCENARIOS

In order to make a first selection on the direction of ideation, different possible solution scenarios have been developed according to the findings of the analysis phase (figure 7.2.1). Each scenario approaches the problem in a different way or solves a different part of the problem definition.

1A. New Beach Cleaner, sensor based
An entire new Beach Cleaner concept with an innovative principle solution. Using sensor based sorting to detect and take garbage directly from the beach instead of taking in the sand with the garbage and screen out the sand.

+Innovative direction with possibly drastic impact on the beach cleaner market and if successful, large market share.
+Significant decrease in power needed and wear of the device by eliminating intake and screening of material.
+Less impact on the beach's ecosystem because sand and shells are left on the beach.
- Very high prices of such systems (around 150.000€ in garbage recycling systems)
- Not realistic to develop working prototype within time span of graduation project, very complex system.
- Challenging to make robust system out of sensor based sorting that is usable within the beach environment. Very sensitive to movement.

1B. New Beach Cleaner, enhanced screening
Entire new Beach Cleaner concept with increased screening capabilities, taking in more material and executing a more efficient screening on the mixture with a smaller mesh size and thus cleaning the smaller garbage more effectively. The screening capacity will be enhanced by optimizing the relevant material, screen and screening element factors. Included within this concept is a separation unit that is capable of returning the shells to the beach thus offering a total solution to the problem definition.

+Effectively cleans small garbage from the beach
+Returns the shells to the beach.
-Detail design of such a large machine is not feasible within the time span of this graduation.
-Could not come up with a validated prototype before the end of the graduation project.
-Development of an entire new beach cleaner would take multiple years and a lot of resources.

2.Stationary Separation unit
A stationary separation unit on the beach where all beach cleaners dispose their load. The separation unit separates the shells and returns them to the beach or the beach cleaners are used to spread out the shells over the beach.

+Since the separation unit doesn't has to be mobile, the design of such a system is less bound by size restrictions.
-Driving the beach cleaners to and from the stationary separation unit will take more a lot of time and cause a complicated logistical situation.

Scenario 3.
Develop an addition to the current BeachTech-3000 (and possibly other beach cleaners).
If screening (with smaller mesh sized screen) is used with the current Beachtech-3000 and the right settings, significantly more small garbage is cleaned form the beach (despite of the cleaning speed). If a sifting device will be added to the current Beach cleaner, the shells can be returned to the beach and thus solve the problem of the shell removal.

+Could be solved within the graduation project
+Good prototype and demonstration opportunities because of use of BeachTech-3000 as showcase.
+BeachTech could use such an addition to offer increased value to their customers machines.
- Does not effectively solve the problem of the efficient removal of small garbage from the beach.

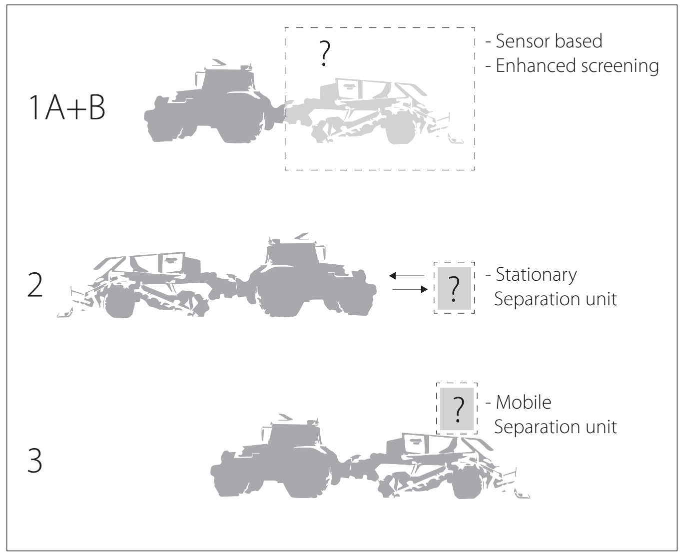


figure 7.2.1, different possible solution scenarios

Conclusion
Although sensor based sorting could mean a completely new disruptive solution to cleaning beaches, at this point it is to costly and complex to make such a system function on the beach. Other separation methods show enough potential to investigate further. Scenario 2 is not feasible because shells have to be spread out over the beach and a stationary separation unit would create a logistically complicated and time consuming solution. Scenario 1B and 3 can still be considered since both could deliver feasible solutions. Ideation will focus on both the increase of cleaning of small garbage by means of more efficient intake and screening of the material and secondly on separation of shells from the small garbage.

7.3 MORPHOLOGICAL OVERVIEW

Morphological overview.
After a first selection within the possible solution scenarios. Further research on screening and separation techniques has been done. Analysing current separation methods used in garbage recycling, mineral processing and food industry has led to an overview of suitable methods. Next to that, principle solutions to achieve more effective screening have been listed into the morphological chart shown on the page on the right (figure 7.3.1). Each column will be shortly discussed here.

Intake of sand garbage and shells (1)
In order to effectively screen material out of the sand, the mixture firstly has to be taken in. The first column of the morphological overview therefore focusses on solutions to take in sand, garbage and shells.

Enhance material conditions for screening (2)
In order to increase the capacity of the screen and therefore the cleaning speed of the device, the material factor is of importance. Lowering the moisture content and loosening bonded material, increases the material factor and therefore the capacity of the screen.

Spread out the mixture (3)
Most sensor based sorting techniques require a thin layer of material in order to detect individual particles, therefore ideation was done on ways to spread out the material. See column 3.

Separate sand from mixture or vice versa (4)
In order to return the sand to the beach and take in the shells and the garbage these have to be separated from one another. Multiple technical solutions have been generated, these are listed in column 4.

Separate small from large fraction or vice versa (5)
Most density separation methods require small size deviation of the mixture in order to create efficient separation. Therefore small garbage and shells need to be separated form the larger garbage. Column 5 focusses on appropriate separation methods for this purpose.

Separate shells from garbage (6)
To finally return the shells to the beach they should be separated from the rest of the garbage. The most viable solutions are listed in column 6.

Transportation of material (7)
To transport the material from one step in the process to the next, it needs to be transported. Commonly used bulk material handling principles have been analysed and the most suitable ones are listed in column 7.

Since enhancing the current BeachTech-3000 by adding a shell separating device is also still an option, there are two groups of ideas.
The greyed out area within the morphological chart visualises the first step within the process. These four columns show principle solutions that could be combined and used to more efficiently collect and screen material out of the sand. The left over three columns focus on feasible separation methods for shells and garbage.

Most feasible options per column
1, intake:
- Ploughing is the simplest and most efficient way to take in material. The absence of moving parts make it robust and reliable and the fastest way to take in lots of material.
2, Prepare for screening
- Raking with steel rakes seems to be the most suitable solution. Robust, fast and easy method to loosen up the mixture and prepare it for screening. Could be aided by blowing hot air on the mixture in order to lower the moisture content.
4, separating sand from garbage and shells:
- Best way to increase screening capacity and efficiency is by using a double deck screen with high acceleration on mixture. Screen, screen-element and material characteristics are of importance.
5, Prepare mixture for shell separation:
- Disc screens can be made small, are durable, do not use much power do not clog often and could be integrated within the current beach cleaner.
6, separate shells from small garbage:
-Sink-float and air sifting both (cross flow and zigzag separator) seem feasible and cheap. Further exploration of these techniques is necessary.
7, moving the materials within the machine
- For transportation of the material within the system both conveyor belts, screw conveyors, pipes and bucket conveyors seem feasible solutions to transport material.

In the next section, the morphological overview will be used to generate the first idea directions.

figure 7.3.1, morphological overview of the different techniques suitable for idea generation.

7.4 FIRST IDEAS
CONCEPT COMPOSITION

In this section the morphological overview will be used to show the different ideas that have been generated. By following each line, and adding the separate components, one will end up at the different ideas (figure 7.4.1). These ideas have been schematically visualised, showing the different material flows within the concepts on the next page.

Idea combination A
Idea direction A uses the current BeachTech-3000 as a base, therefore the first steps within the morphological chart are: ploughing; the contaminated top layer is taken in. Raking; loosens up the sand and transports material onto rotary screen, sand is screened out of the mixture by the rotary screen. Garbage and shells are first collected in the small garbage container and dumped into the larger container on top. (figure 7.4.2).

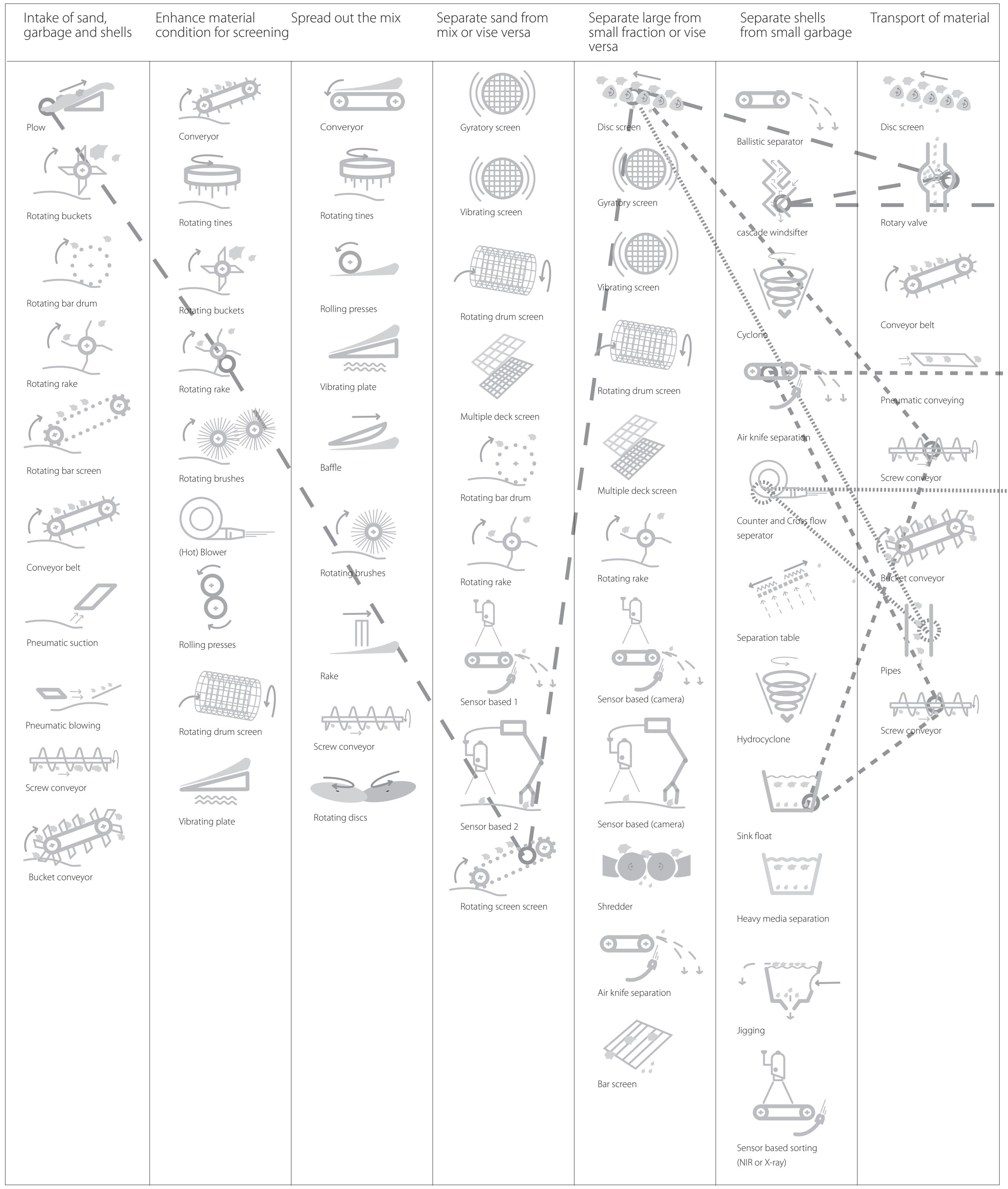


figure 7.4.1, idea directions

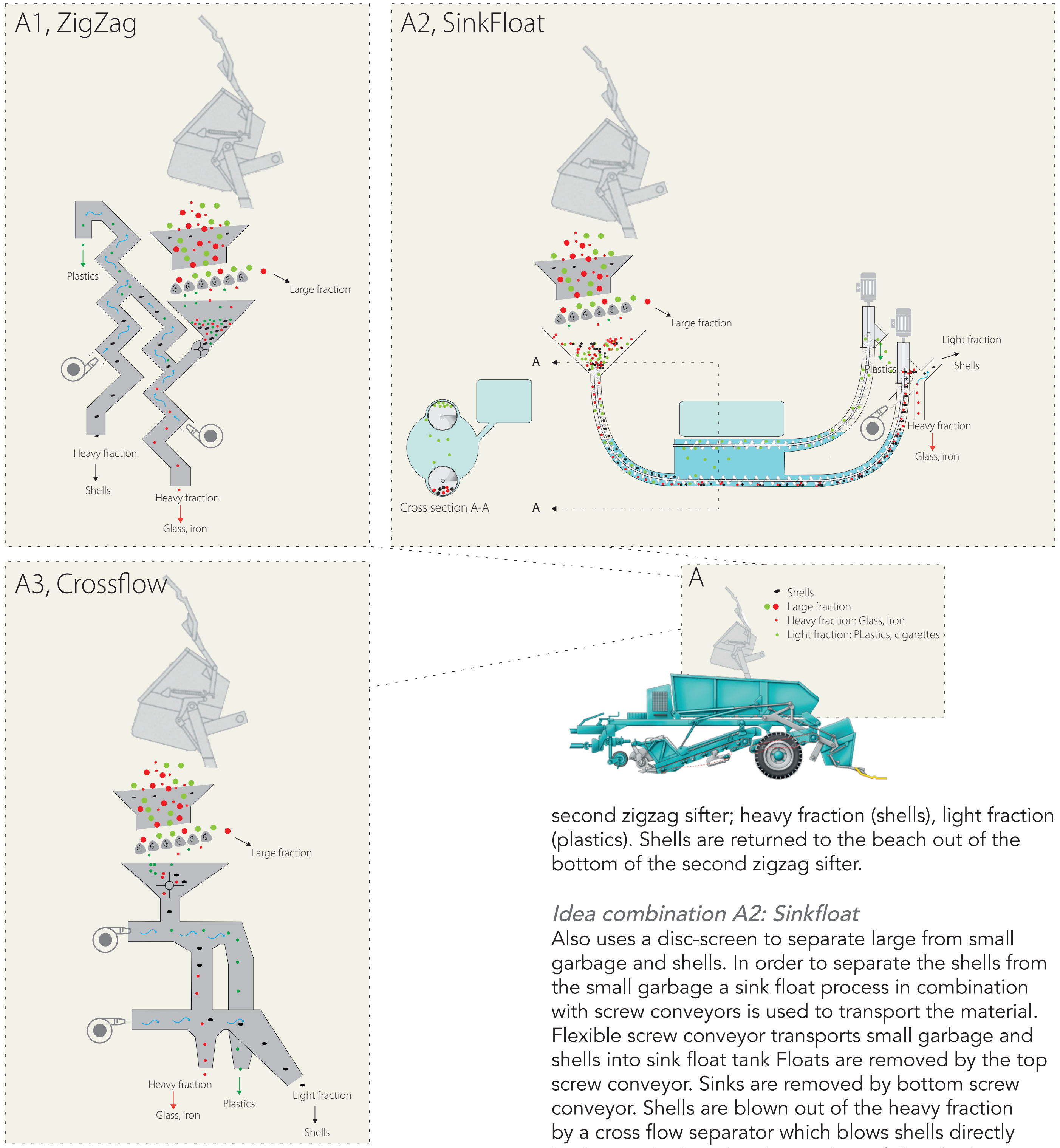


figure 7.4.2, idea combinations A1,2, and 3

Idea combination A1: Zigzag
Material from the small container is emptied into a collection hopper within the large collection container. A disc-screen separates larger garbage from small garbage and shells. Small garbage and shells are collected in a funnel under the disc-screen. Rotary valve feeds shells and small garbage into first zigzag sifter; heavy fraction: glass and iron, light fraction: shells and plastics. Light fraction moves to second zigzag sifter; heavy fraction (shells), light fraction (plastics). Shells are returned to the beach out of the bottom of the second zigzag sifter.

Idea combination A2: Sinkfloat
Also uses a disc-screen to separate large from small garbage and shells. In order to separate the shells from the small garbage a sink float process in combination with screw conveyors is used to transport the material. Flexible screw conveyor transports small garbage and shells into sink float tank Floats are removed by the top screw conveyor. Sinks are removed by bottom screw conveyor. Shells are blown out of the heavy fraction by a cross flow separator which blows shells directly back onto the beach. Glass and iron fall in the large collection container.

Idea combination A3: Crossflow
First steps are comparable with A1&A2. In the first cross flow, light fraction (cigarettes, plastics) are blown out of the material feed and end up in collection container. Second cross flow separator blows shells out from left over material.

Idea combination B
Offers a total new beach cleaner concept in which: a layer of sand is removed by a plough, loosened up before screening by rotating rakes, transported upwards to a double deck screen in which larger garbage is screened out on the first deck and small garbage and shells come out of the overflow of the second deck. Sand falls back on the beach. Because of the high acceleration of the eccentric motors on the double deck screen, the through flow of the screen is increased.

Small garbage together with the shells is then separated by using a sink float process in which the shells are removed from the bottom together with the glass and iron by a screw conveyor that scoops out the material. Subsequent cross-flow separation could take out shells from heavy-small garbage fraction (figure 7.4.3)

Conclusion
Four idea directions have been generated out of the morphological chart. Direction A consists out of an addition to the current beach cleaner while direction B is a complete new concept direction that also focusses on more effective screening by use of a conveyor belt and a double deck screen. Idea direction A uses wind sifting and sink float separation principles to separate small garbage from shells. In the next section the first ideas will be scored against the list of requirements.

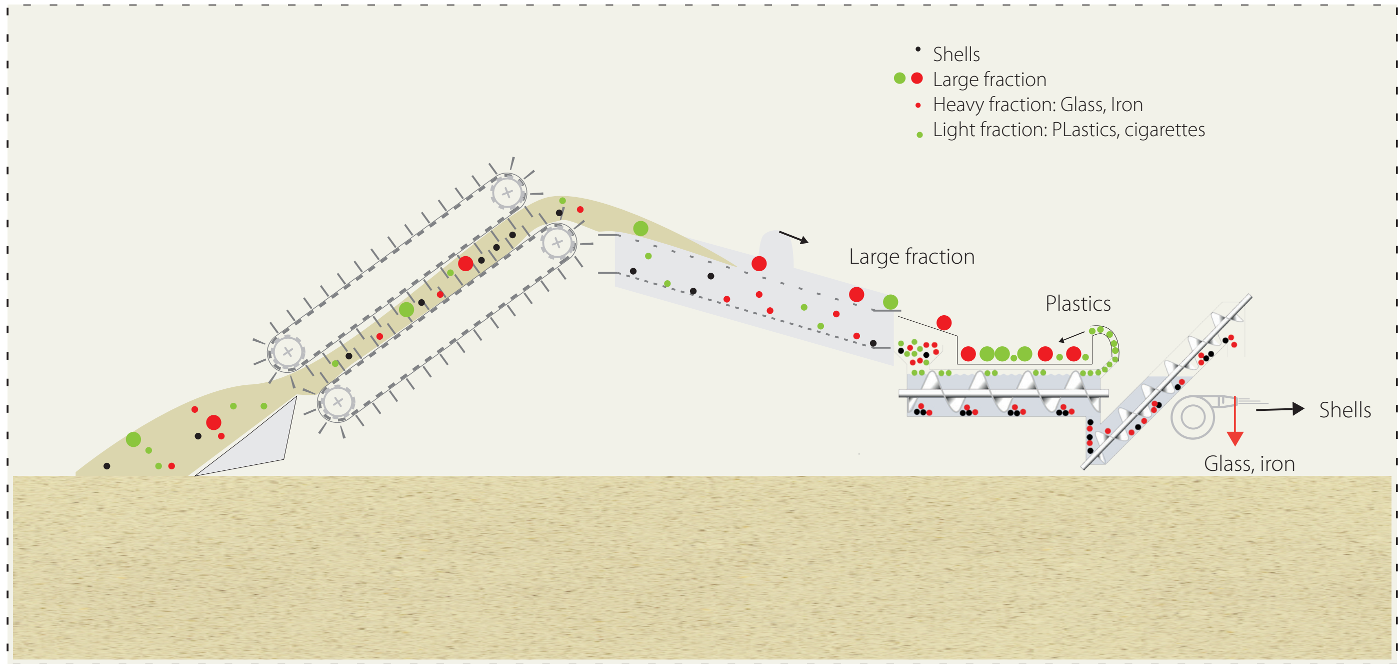


figure 7.4.3, total new beach cleaner idea.

7.5 SCORING THE IDEAS AND FIRST CHOICES

In order to make a first selection among the generated ideas, they are scored to the requirements generated in the analysis phase. The entire list of requirements (including explanation) can be found in appendix 2. The most important ones are listed in the table below. The ideas are scored -- (very bad), -. +/-, + to ++ (very good).

Costs
The integral new concept will of course be the most expensive while all three add on ideas will be less expensive. Among idea direction A1,2,3 the two wind sifting ideas will be cheaper than the sink float concept.

Small garbage removal
Since the assignment asked for a more efficient way to clean the smaller garbage, this requirement is taken into account. The add on concepts do not change the amount of small garbage <2cm that is collected but do however use the current beach cleaner for this, therefore they are not scored on this requirement.

Shell separation
It is difficult to say which separation technique will have the best efficiency since no tests have been done with the given mixture. However an estimation has been done based on the research done in chapter 6.

Robustness
The separation techniques have to still function properly while moving (shocks, different angles) since they are mobile and the surface of the beach is not flat. Both wind sifting techniques are seen as techniques that can function under these circumstances while a sink float technique will be harder to implement since a sink float tank is vulnerable to movement.

Durability
Since this is dependent on the type of finish the concepts will have all concepts score the same on this requirement the finish of the concepts will be discussed later.

Spreading of shells
Since concepts A1,2 and 3 are only active when the smaller container of the beach cleaner is emptied into the larger one, they will not generate a constant return of shells. Within the total new beach cleaner concept this could be integrated.

Feasibility
At this point it can be concluded that concepts A1,2 and 3 are the most feasible solution to the problem statement since they can be developed more quickly.

Requirement	A1	A2	A3	B
Low cost	++	+/-	++	--
Simplicity	+/-	-	++	--
Small garbage removal				++
Shell separation	+	++	+/-	++
Low energy usage	+/-	+/-	+/-	--
Robustness (withstand movement, working angle, shocks)	++	-	+/-	+/-
Durability (withstand abrasive salt water, sand, wind)	+/-	+/-	+/-	+/-
High tech (innovative solution)	+/-	+/-	-	+/-
Set-up time	+/-	-	+	+/-
Maintaining ecosystem on the beach	+	++	+	+
Spreading of shells	+	+	+	++
Feasibility	++	+/-	++	--
Does not require maintenance	++	+/-		

figure 7.5.1, all four idea directions scored on the requirements

7.6 TESTING SEPARATION TECHNIQUES

CROSS FLOW SEPARATOR

In order to test the separation methods mentioned in the idea directions. Two tests were executed. First of all a cross flow separator was built to see what the effect would be on the different materials within the mixture. A mixture of shells and small garbage was transported over a conveyor track and dropped in front of a fast flowing air stream (figure 7.6.1) see appendix 3 for a complete overview of the test.

Results cross flow separator

As expected the lighter fraction was blown away further than the heavier fraction. Thin plastic foils and lighter plastics were blown away the farthest while the glass and iron travelled less far. Particles with a larger projected surface perpendicular to the air flow travel further. Problem with the cross flow separator is that the distance the particle is blown away is strongly dependant on the orientation of this particle to the air stream. Because of this, the same particle can travel further when it has a larger projected surface to the air-stream resulting in an inefficient separation.

Results zigzag wind-sifter

The cascade wind sifter was tested at the lab of civil engineering with the same mixture of garbage and shells in order to see if separation was possible (figure 7.6.2). The complete set up of the test can be found in appendix 3.

The cascade wind sifter gave promising results. However with the given diameter of the zigzag and the compressor used, the sifter was not able to generate enough volumetric air flow to take the shells out together with the plastics (light fraction). See figure 7.6.3 for the results of the test. Out of the two wind-sifting techniques, the zigzag sifter gave significantly better and consistant results.

Since the different particles circulate within the vortexes of the zigzag sifter, the projected surface on which the wind blows is not dependant on the orientation of the different particles. In stead a dynamic constant projected surface is generated.

Conclusion

When separating shells form small garbage, the zigzag sifter has the most potential. However one zigzag sifting step is not capable of effectively separating the mixture. This is because there is a heavier and a lighter fraction that have to be taken out in multiple steps in order to be separated from the shells.

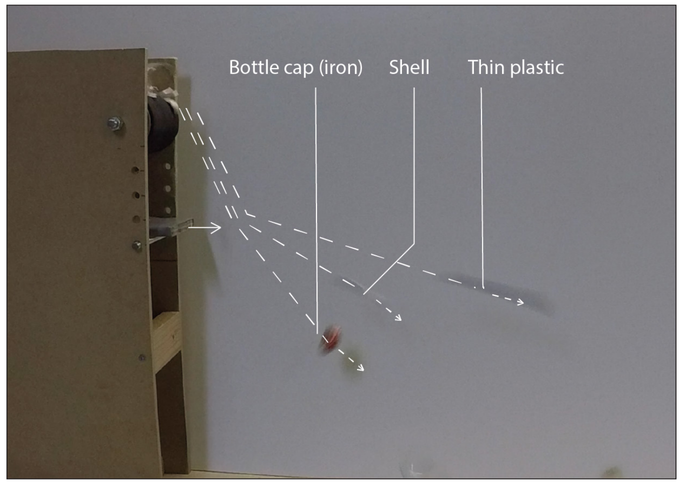


figure 7.6.1, testing the cross flow separator on the mixture

figure 7.6.2, particles rotating in the zigzag vortexes

figure 7.6.3, L. heavy fraction with shells, R. light fraction

7.7 PRE-SIZING THE MATERIAL

In order to effectively separate shells from the garbage in one of the proposed wind-sifting separation techniques, a pre-sorting step based on size needs to be executed. Plastic bags, cans and other large garbage could cause blockage and malfunctioning of the wind sifter so they need to be taken out of the material mix first. Since application on the current beach cleaner asks for a compact solution, that both moves away the larger garbage and lets through the smaller fraction, active screening options are considered. Appropriate screening techniques could be: ballistic separator, moving screens and disc screens.

Of these options, a disc screen seems most suitable for the application (table 7.7.1). The rotating discs convey larger material as an overflow to the end of the screen and agitate the mixture while doing so. The smaller garbage together with the shells pass through as the underflow (figure 7.7.1)

The disc screen is a simple but effective piece of equipment that is ideal for and commonly used in screening woody biomass and garbage. It consists of a series of rotating shafts that are mounted in a frame. Each shaft assembly has mounted discs at certain distances. The discs from one shaft inter-leaf with the discs of the next shaft, creating openings between the discs and the shafts which make up the discs screen openings. Disc screen openings have two dimensions: slot length and interface opening.
By placing the screen under an angle, the material takes longer to pass the screen thus the smaller fraction has more time to fall through the screen.

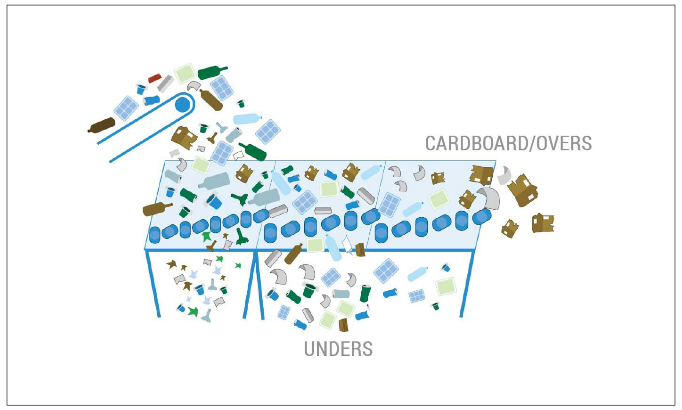


figure 7.7.1, disc screen working principle

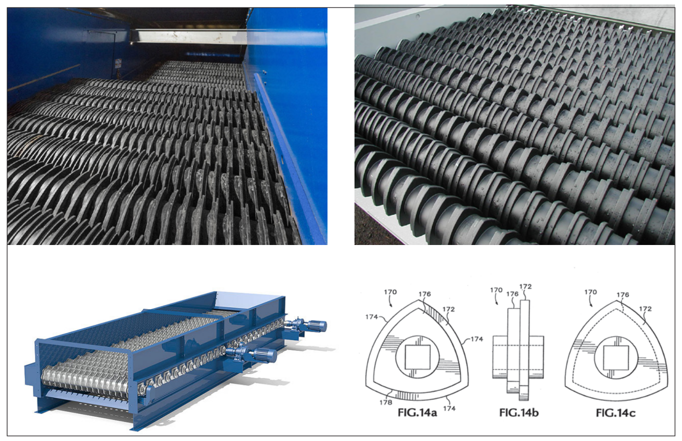


figure 7.7.2, disc screens explained

Screening technique	Disc screen	Ballistic separator	Drum screen	Multi deck screen
Footprint	++	+/-	--	--
Power usage	++	-	-	--
Maintenance	++	+/-	++	+/-
Effectiveness	++	-	++	+/-

tabel 7.7.1, ranking the different screening techniques

In order to test the working principle on the defined mixture and get insights into the possible application within the design, a mock up of a disc-screen was built and tested. It consists of seven shafts with a total of 112 wooden discs. The shafts are mechanically driven by a wooden gear configuration that is powered by a cordless drill. The mock up was also developed to demonstrate the principle. See appendix 4 for a total overview of the mock up.

Conclusions

The mock up was capable of separating the smaller garbage and the shells from the larger faction. Some conclusions could be drawn from the mock up.

The mock up was not robust enough. Sharp pieces of shell got stuck between the wooden discs and jammed the system.

If the shafts rotated to fast, the smaller material was ejected over the disc-screen and did not fall in between the shafts.

If the shafts rotated to slowly, the material was not agitated enough and the small material would remain on top of the larger fraction and would be transported to the end of the disc-screen together with the larger faction.

If the disc-screen was held under an angle, better agitation of the mix was reached and more small particles would be screened out. Only the particles in direct contact with the disc-screen would be transported up and to the end of the disc-screen.

The space between the discs could be reduced in order to separate more garbage from the shells. If more garbage is separated from the shells in this step less garbage as to be removed during either of the two separation steps

7.9 POWER SUPPLY TO THE SYSTEM

The different components that might be used in the concepts (blower, drive system of disc screen etc.) need power and a drive system in order to operate. This page shows an overview of the different appropriate actuators and power-sources that can be used. The main division is between power taken from the PTO of the tractor or by a separate power source.

Power taken from the tractors PTO

Hydraulic drive system

Most commonly used in agricultural machines is the hydraulic drive system. The drive system of a hydrostatic drive system consists of the following parts:
- Hydrostatic pump powered by tractors PTO generating pressurised oil flow to the system.
- Valves, filters, piping transferring and arranging flow of oil to the separate parts of the system.
- Actuators (hydraulic motor or cylinders) driven by the flow of oil.

Electrical drive system

An electrical PTO powered drive system consists out of the following components:
- Electric generator powered by tractors PTO
- Electric wiring, batteries and switches to transfer and store the power
- Actuators (electric motors)

Mechanical drive system

Mechanical PTO driven systems consist out of the following components:
- Mechanical connection to the PTO of the tractor
- Transfer of mechanical energy by chains, gears etc.
- Drive of the actuators by mechanical connections

2. Separate power supply system

Battery driven system
- Energy stored in (rechargeable) battery pack either by power grid or solar cells
- Electric wiring, batteries and switches
- Electrical actuators powered by stored energy

Generator driven system
- Gas powered Generator generates electric power.
- Energy stored in battery pack or directly used, wiring directs power to actuators
- Electrical motors power the different actuators of the system.

Separate engine which mechanically drives the actuators of the system
- Combustion engine drives mechanical connections
- Transfer of mechanical energy by chains, gears etc.
- Drive of the actuators by mechanical connections

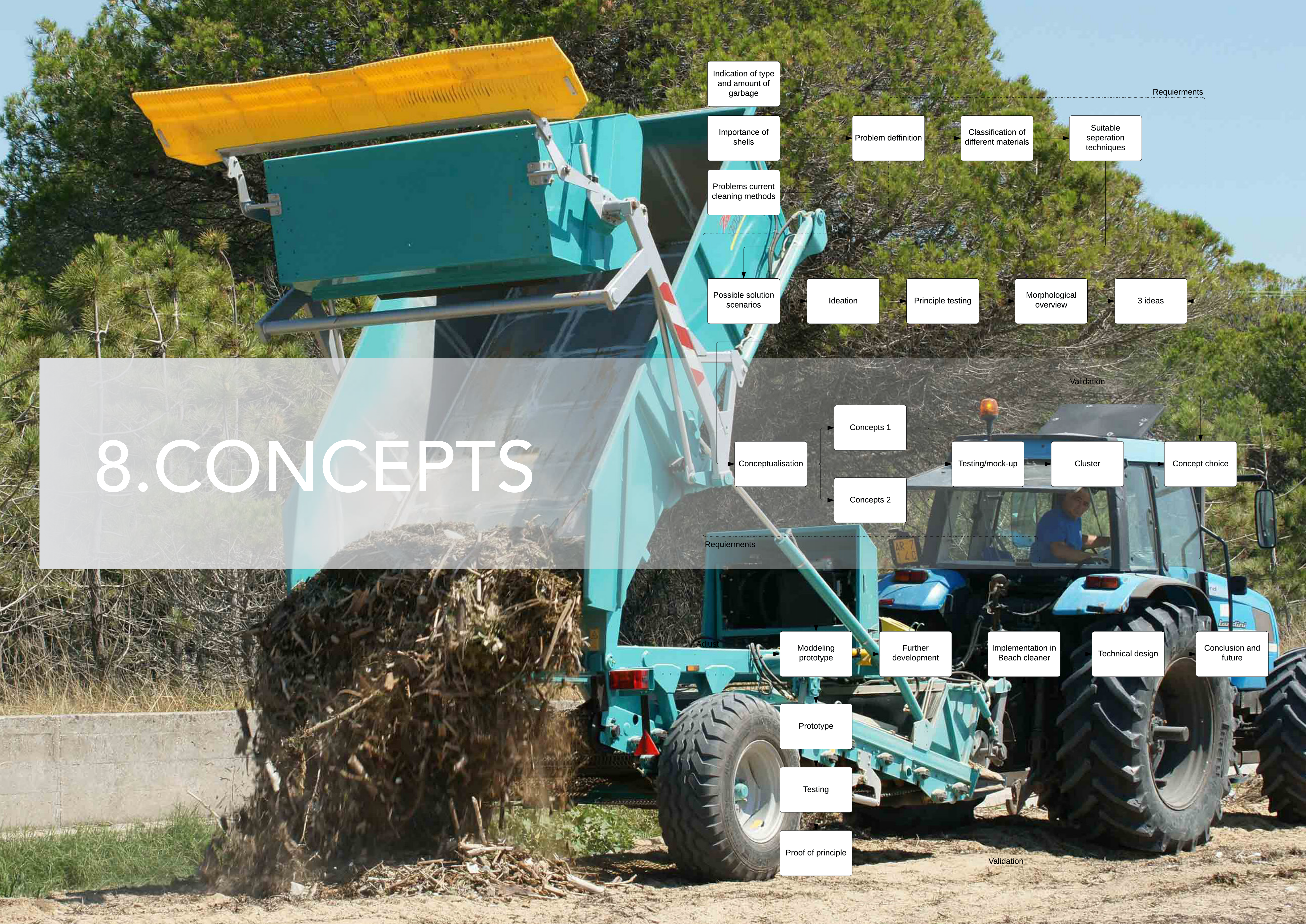
Since the most viable ideas at this point are add-ons to the current beach cleaner the most suitable power supply would be by the hydrostatic drive system of the BeachTech-3000. Adjustments should be made to the hydrostatic system. A larger hydraulic pump should be fitted to generate a higher amount of pressure and oil to the system. Next to that extra piping and hydraulic motors should be incorporated to drive the add-on. They hydrostatic drive system has three main advantages [45]:

- Fast response of the system
- Maintain precise speed under varying loads
- Allow variable speed controls
- Compact and agile system

figure , power supplied by PTO of tractor possibilities

figure, power supplied by separate power sources possibilities

8.CONCEPTS



Indication of type and amount of garbage
Importance of shells
Problems current cleaning methods
Problem deffinition
Classification of different materials
Suitable seperation techniques
Requirements
Possible solution scenarios
Ideation
Principle testing
Morphological overview
3 ideas
Validation
Conceptualisation
Concepts 1
Concepts 2
Testing/mock-up
Cluster
Concept choice
Requirements
Adjust
Modeling prototype
Further development
Implementation in Beach cleaner
Technical design
Conclusion and future
Prototype
Testing
Proof of principle
Validation

8. CONCEPTS

From the four ideas that were generated within the ideation phase, two will be further developed into concepts. The idea of an integral new beach cleaner that would use more efficient screening to better clean the small garbage was discarded. The main reason to do this was that the beach cleaner currently used by the municipality is actually capable of cleaning the smaller garbage if the raking screening unit is set to a greater depth and a smaller mesh size screen is used. Next to that it will be very costly and time consuming to develop an entire new beach cleaner and an appropriate solution to the problem statement is needed quickly. Finally, solving the problem of the shell removal will also offer great added value to the municipality.

During the tests with both types of wind sifters it became clear that the zigzag was better in achieving proper separation between the different fractions of the mixture than a cross flow separator. Therefore the concept development phase will focus on the SinkFloat and the Zigzag idea direction. On the page on the right the chosen ideas are shown once more.

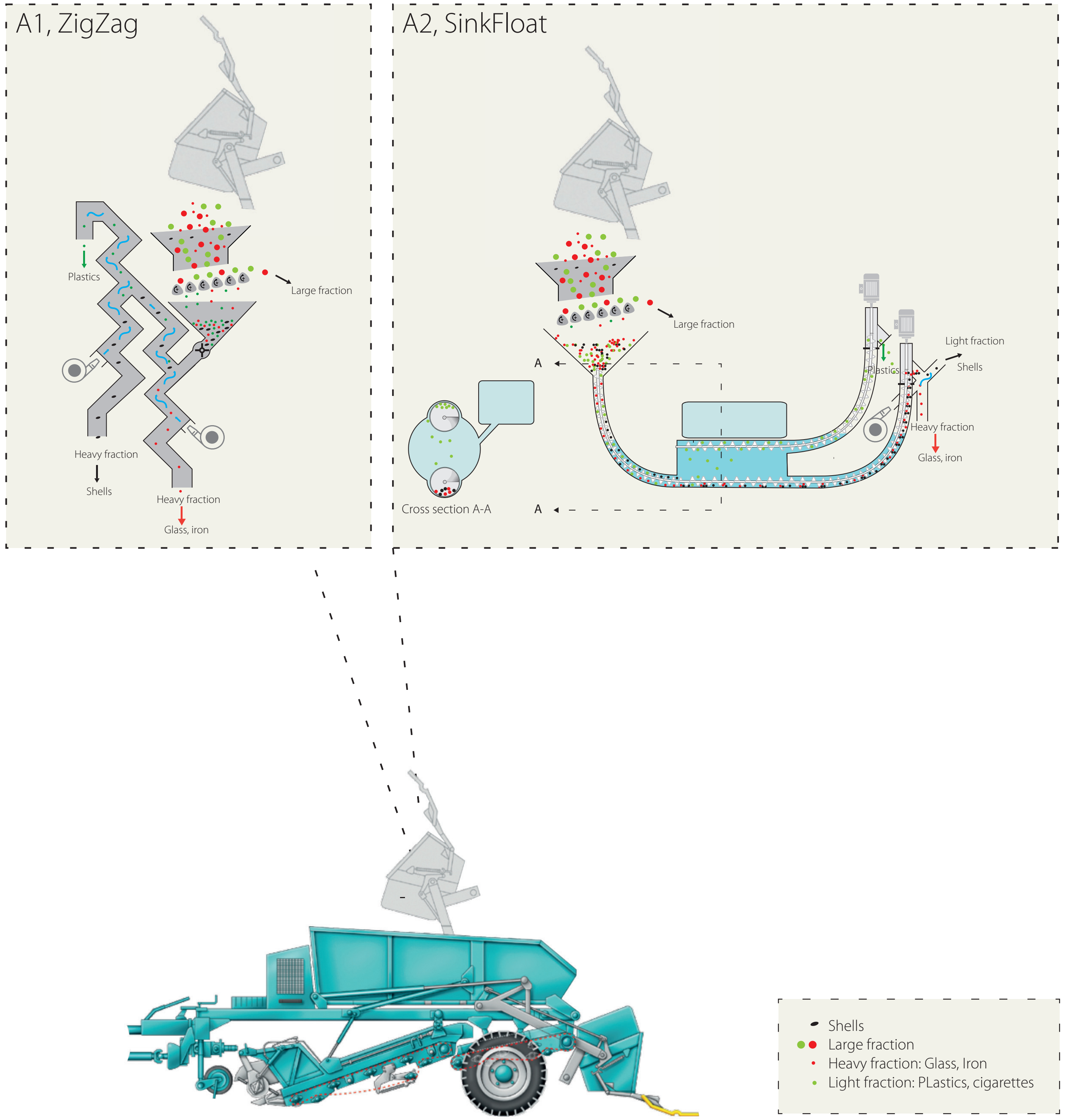
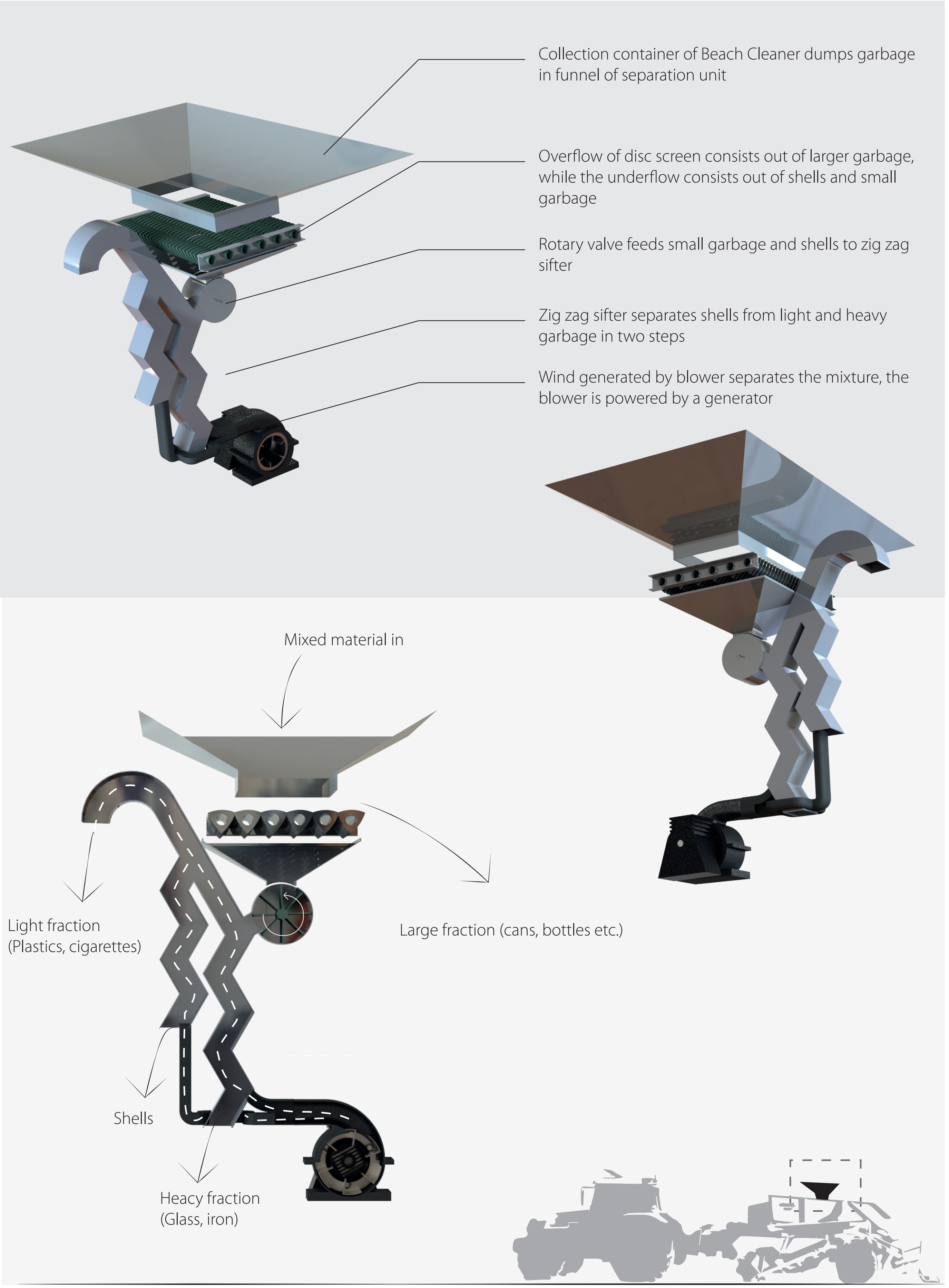


Figure 8.1, the two ideas chosen to further develop into concepts.

8.1, ZIGZAG CONCEPT



Disc screen
In order to prepare the small fraction and the shells for the wind-sifting steps, the larger material (cans, bags, bottles etc.) have to be removed. The disc screen has good potential because its low power consumption, low wear and amount maintenance required. The rotating discs pull the material out at the bottom of the collection hopper decreasing the chance of clogging of the hopper. Shells together with the small garbage fall in between the gaps of the disc-screen while the larger fraction is removed as overflow and is collected in the collection container.

The disc screen only has to be activated when the small collection container of the beach cleaner is emptied into the collection hopper of the machine. When all material has passed the disc screen it can be turned off. The direction in which the discs rotate can be reversed in order to equally fill the large collection container on both sides.

Small collection hopper
When the disc screen is running, shells and small garbage are collected within the hopper underneath the disc-screen. A sensor measures the material level of the particles within the hopper and activates the rotary valve when the maximum level has been obtained.

Rotary valve
The rotary valve regulates the amount of material that is fed to the zigzag sifter by its rotational speed, thus offering a constant flow of material. It makes an air tight closing between the smaller collection hopper and the zigzag sifter. By doing so, no air can escape and thus more wind is effectively used to separate the mixture within the zigzag.

Double zigzag sifter
The double zigzag sifter uses differences in size, shape and specific weight to separate the small fraction into three material fractions. The heavy fraction (glass and iron), mid fraction (shells) and light fraction (plastics, cigarettes). Tests with the zigzag sifter gave promising results. Further research is needed to determine the required volumetric airflow and the feed rate of the rotary valve to come up with the best possible separation. Since the zigzag sifter has no moving parts it is less vulnerable to failure and therefore requires minimal maintenance. A high separation sharpness can be achieved because each zigzag acts as a separate air classifier.

Blower
The blower that generates the air flow for the zigzag sifters is located at the bottom of the collection container of the beach cleaner. The air flow is separated into two pipes, both directed to the base of one of the zigzag wind-sifters.

Expansion chamber
In order to prevent the air flow of the second zigzag sifter interfering with the air flow of the first an expansion chamber with another rotary valve should be incorporated (see figure 8.1.1). The speed and pressure of the airflow of the first zigzag will decrease because of the larger volume of the expansion chamber. The baffle in the middle of the expansion chamber will direct the air flow downwards and the entrained particle will settle to the bottom of the chamber where they will be collected by the second rotary valve.

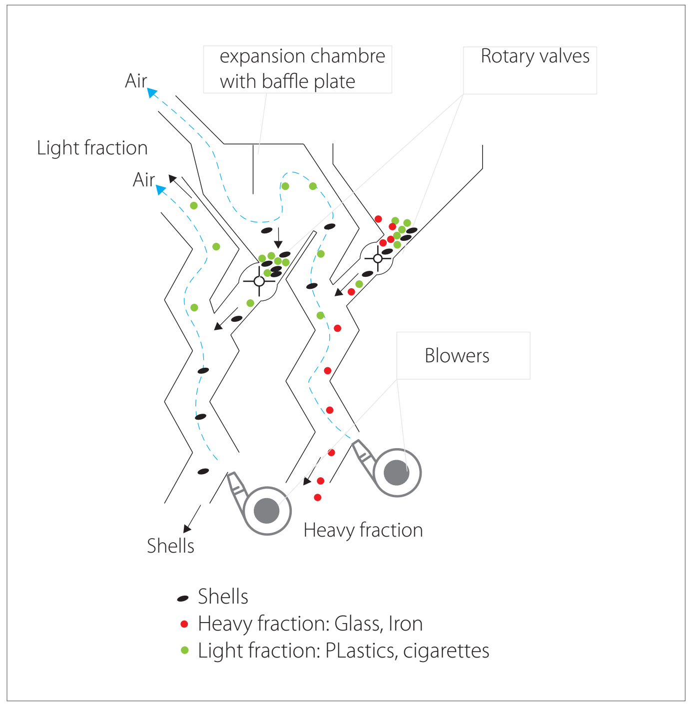
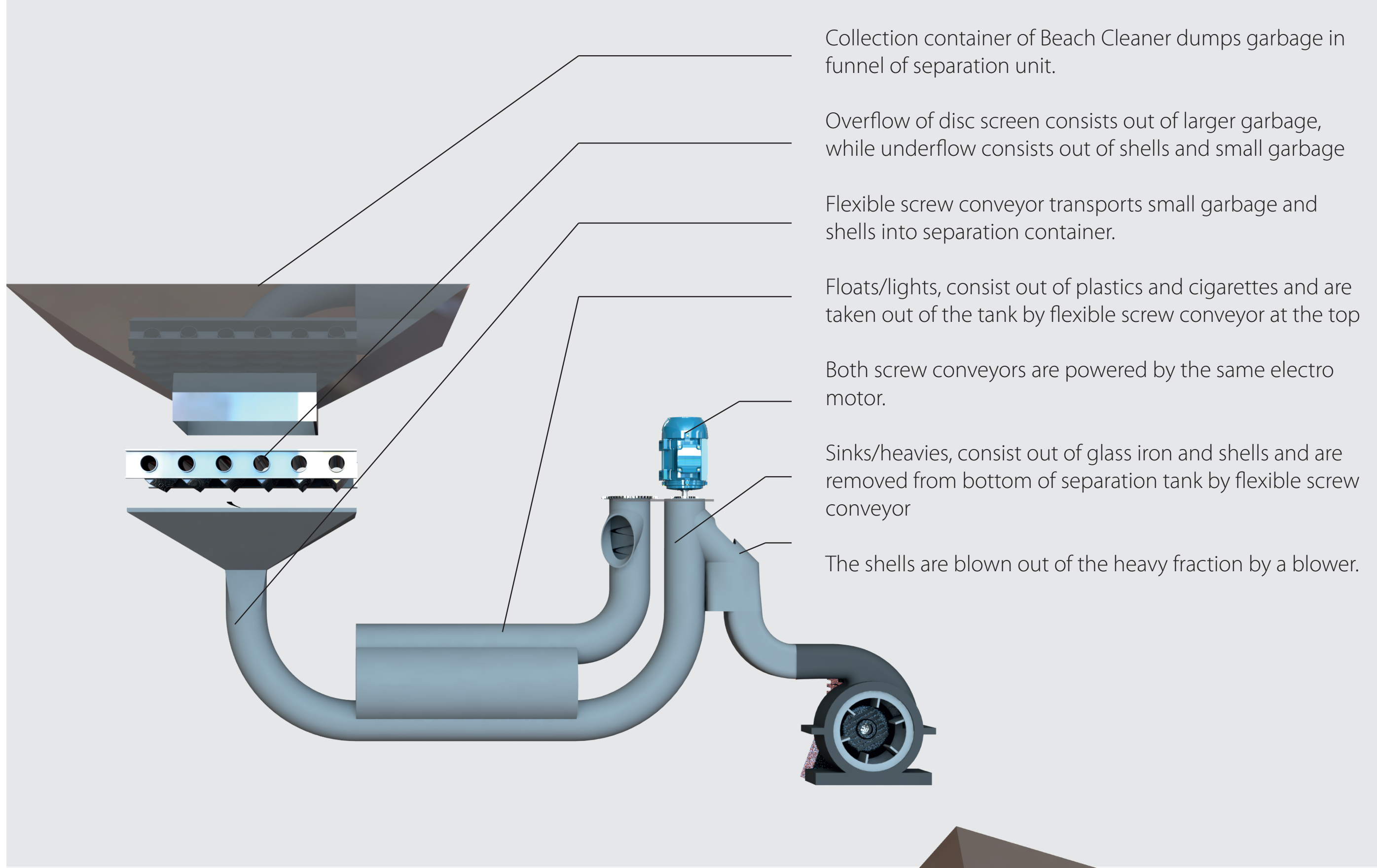
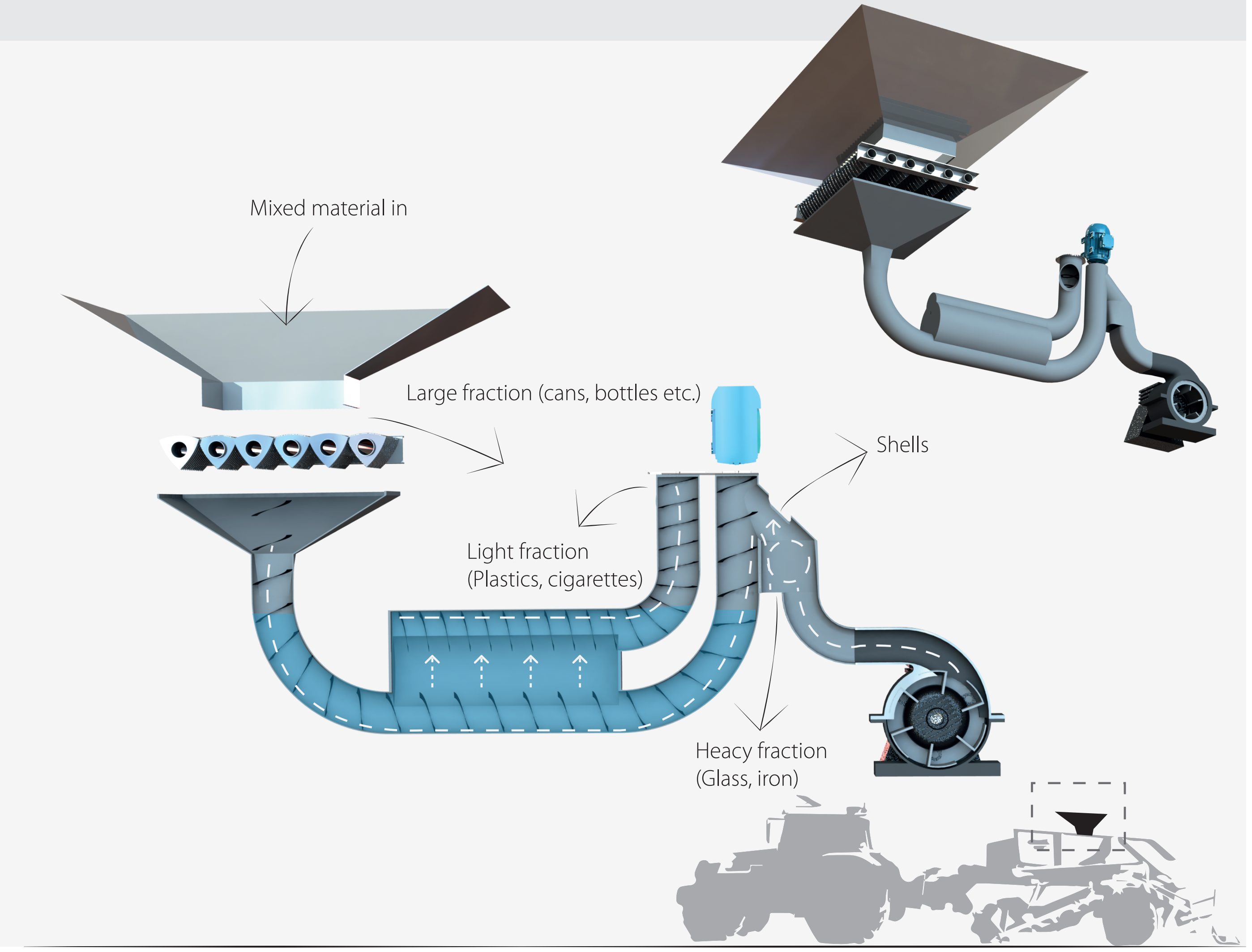


Figure 8.1.1, explanation of material flow through the double zigzag

8.2 SINK FLOAT CONCEPT





The first steps and the power supply to the system are the same as the in the Zigzag concept (first hopper, disc screen, second hopper). The small garbage and shells are transported into the sink float tank by a screw conveyor. Floats rise up to the top of the sink float tank and are taken out by a second screw conveyor. Both screw conveyors can be driven by the same electro motor because they are driven by the same drive chain.

Screw conveyor

The screw conveyors are important in this concept because they can transport material in and out of the sink-float tank while leaving the water in. The visualisation on the left gives a incorrect image of the conveyor routing since such sharp corners will cause excessive wear of both the conveyor and the housing. This problem is solved by the screw conveyor configuration that can be seen in figure 8.2.1).

Since the sink float process separates the lighter plastics from the mix, after this step only shells, glass and iron will remain. Since shells have thinner wall thickness and have a lower specific weight than both iron and glass a single cross flow separator will suffice to blow out the shells of the heavy sunken fraction.

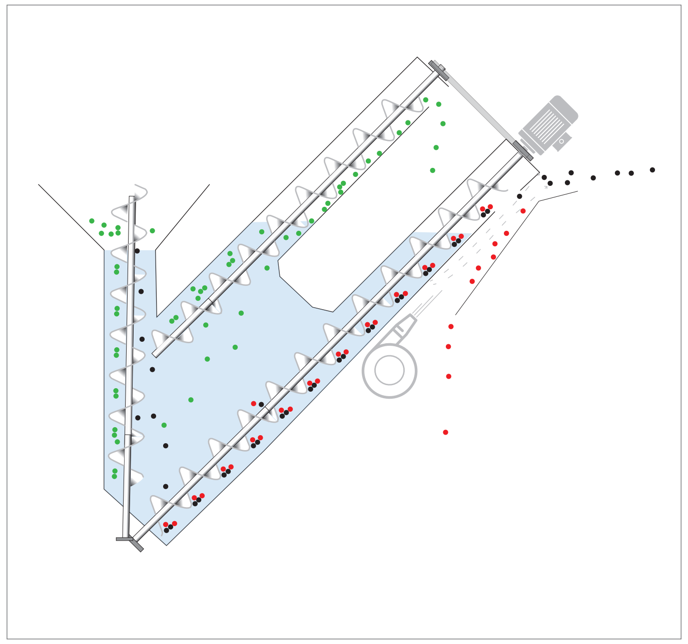


Figure 8.2.1, correct configuration of the sink float tank

8.3 CONCEPT CHOICE

Concept choice
In order to pick one of the two proposed concepts, they were considered according to the earlier stated requirements. The triangles that are shown on this page show how good the different concepts score on three requirements per triangle. The larger the dark grey area, the better the concept scores on that specific set of requirements. By doing so, the quality of the concepts is represented graphically and a choice is made accordingly.

As can be seen within the three comparisons, the Zigzag wind sifter is the better concept for the following reasons.

The technique will be less susceptible to the movement of the beach cleaner. The sink float tank will carry a lot of water and thus water will spill is the beach cleaner is moving.

The technique is also less expensive to develop and showed good separating efficiency during the tests performed at civil engineering. Integrating the design within the beach cleaner will be easier with the zigzag concept. Maintenance to the sink float concept will be harder since the water tank will be hard to clean.

If something gets stuck within the sink float concept during operation it will be hard to remove, since opening the tank will spill the water.

The power usage of the beach cleaner will also increase more when the sinkfloat concept would be implemented since the water reservoir will be very heavy.
All in all it will be much easier to implement separation by using air in stead of a sink float reservoir.

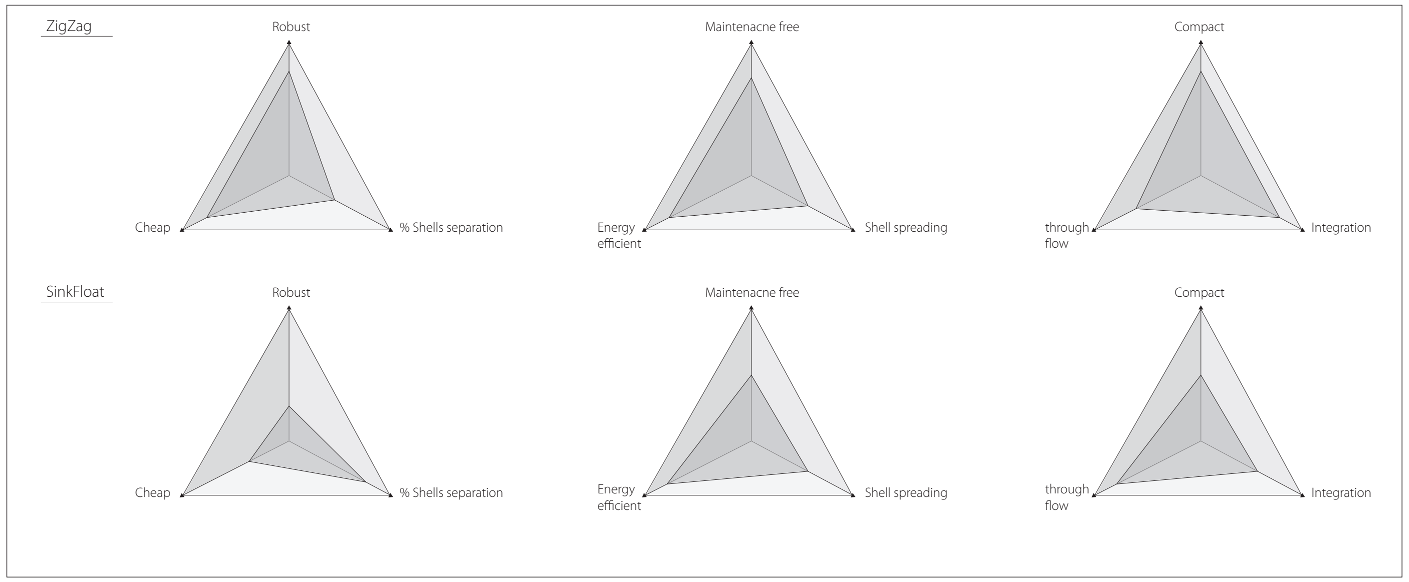
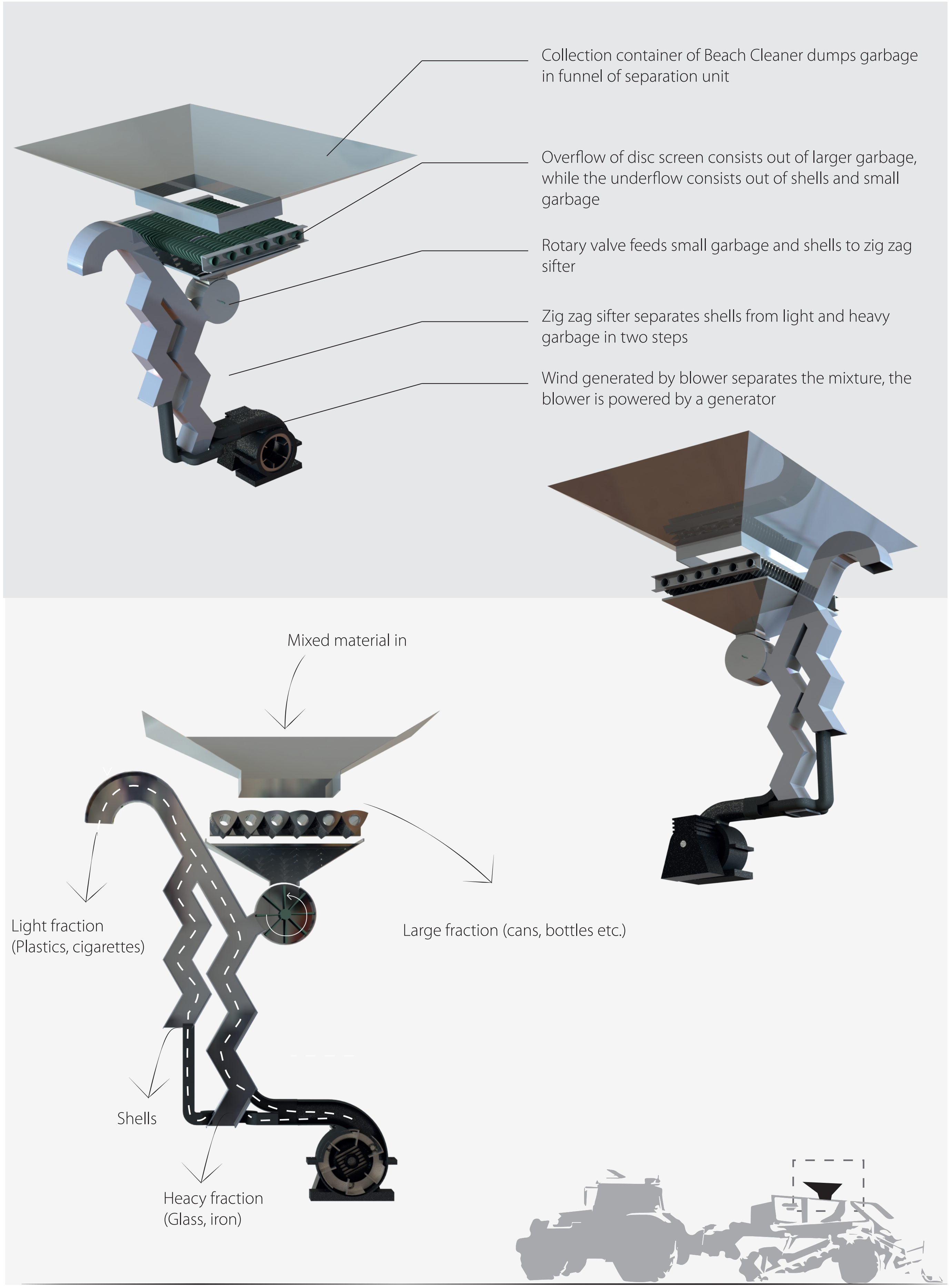


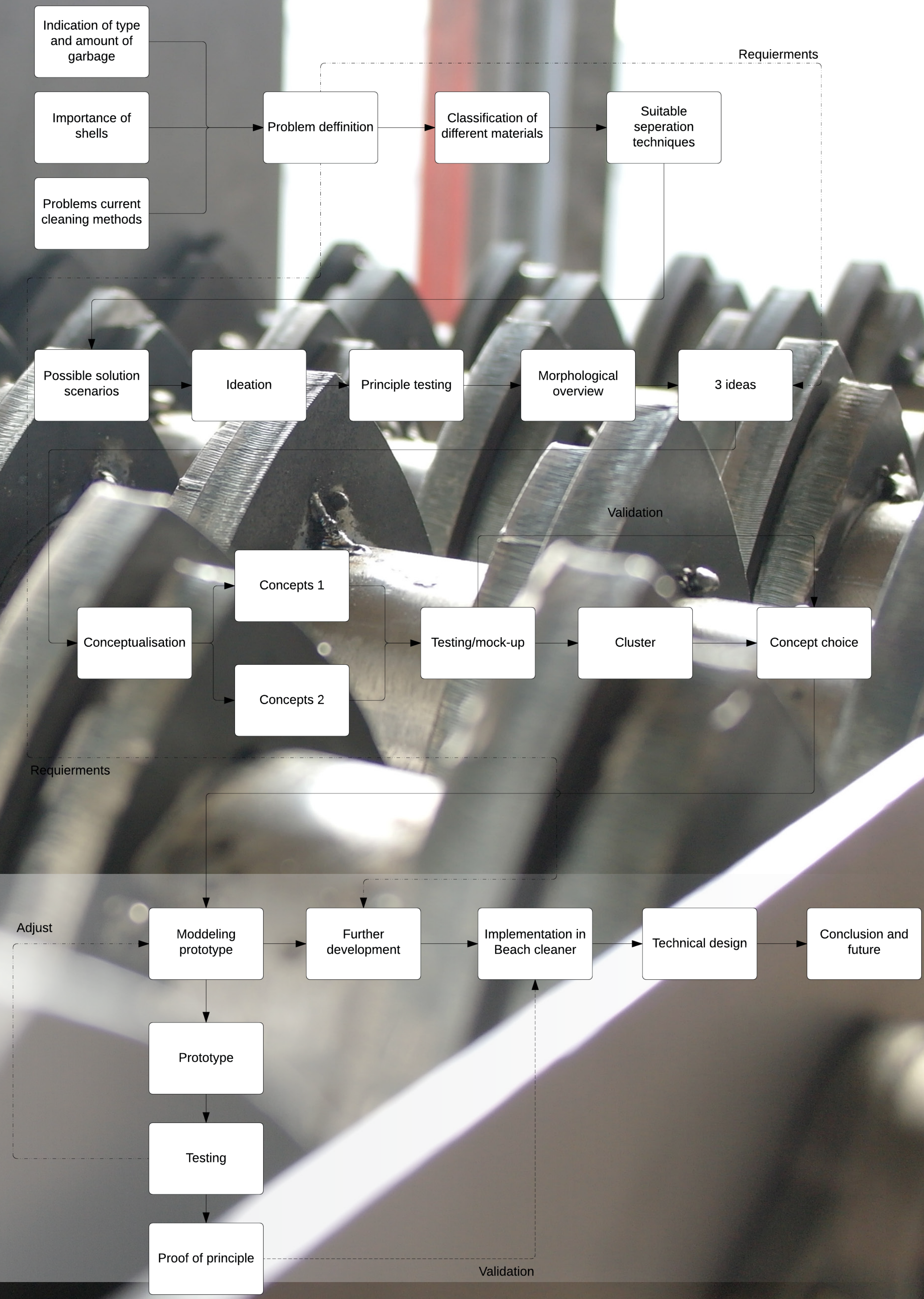
Figure 8.3.1, scoring the two concepts on three different sets of requirements.

8.4 CHOSEN CONCEPT



The embodiment phase will focus on two main aspects. First of all the generated concept in the concept phase was made into a prototype and put to the test. The gathered combination that should lead to a proper separation between the different garbage fractions and the shells has been placed in series and a representative mixture out of the beach cleaner was put in the prototype to see how it would separate the mixture.

After the prototype showed enough potential in executing the desired separation, application within the current cleaning process of the municipality was developed. By adding the design within the BeachTech-3000 and elaborating upon a new way of executing the clean up process, an integral solution was found for the problem statement developed in section 4.4.



9.EMBODIMENT

9. PROTOTYPE

9.1 PROTOTYPE OVERVIEW

In order to validate the working principle incorporated within the concept, a prototype was built and tested. Figure 9.1.1 shows an overview of the entire prototype with the different components listed. The concept consists of exactly the same parts incorporated within the final design which shall be discussed in the next section. This prototype is a proof of principle to see if the separation of garbage and shells is indeed possible. The journey of the different material flows through the prototype will be explained by the different parts that enable the separation. The four different material flows in which the prototype separates are:

- Large fraction
- Small-heavy fraction
- Small-light fraction
- Shells

(See figure 9.1.1)

Disc screen (nr1)
The mixed material is fed to the beginning of the disc-screen (1a). The shafts of the disc-screen are driven by an electro motor (1b) The larger fraction is transported over the rotating shafts to the end, where it falls down into a collection container (1c). The smaller fraction (shells, light and heavy fraction) fall through the openings between the shafts and are collected at the bottom of the disc screen housing (1d).

1st Rotary valve (nr2)
The smaller fractions are collected and fed to the first zigzag by a rotary valve that is situated at the bottom of the disc-screen (2). This valve consists of a rotating impeller that guaranties an air tight connection to the zigzag and a constant material feed of the material. The impeller is driven by an electro motor (2a).

1st Zigzag (nr3)
The first zigzag uses two blowers (2x 26,4M^3/min, 270km/h, 3a) to generate an air flow through the zigzag. The generated air flow travels upwards to the top of the zigzag sifter (3b), taking along the shells and lighter fraction with it. The heavy fraction falls down against the air-stream to the bottom of the zigzag where it is collected in a collection container (3c).

Air expansion chamber and air outlet (nr4)
The air generated by the two blowers, escapes through the screen (4a) while the shells together with the light fraction end up in the expansion chamber (4b). Where they fall down into the 2nd rotary valve.

2nd Rotary valve (nr 5)
The shells and light fraction are fed into the second zigzag by the second rotary valve, which operates in the same way as the first one, this rotary valve is driven by the same electro motor (2a)

2nd Zigzag (nr6)
The 2nd zigzag functions the same as zigzag 1 but uses one blower (13,2M^3/min, 270km/h, 6a) to separate the light fraction from the shells. Since the air-volume/minute is reduced, the shells now form the heavy fraction and these fall down to the bottom of the 2nd zigzag where they are collected in a collection container (6b). The light fraction comes out of the pipe at the top and is collected in the final container (6c).

figure 9.1.1, Material flows in the prototype

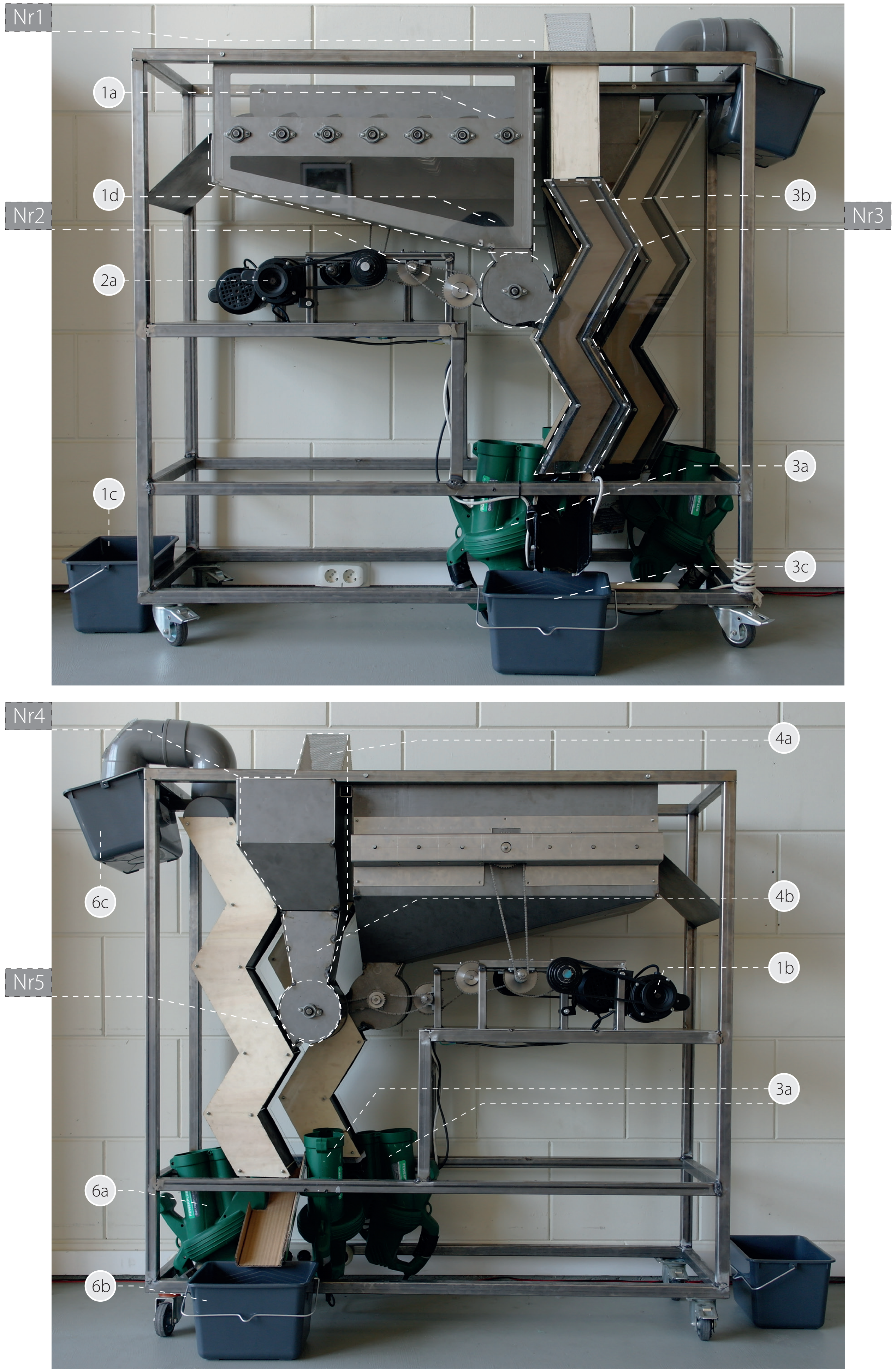


figure 9.1.2, the different parts of the prototype

9.2 MATERIAL FLOW PER COMPONENT

Disc-screen
The first component of the prototype is the disc-screen. This step is necessary to take out the larger fraction and thus prepare the material for the wind-sifting steps. The large fraction is separated from the small fractions. The large fraction is transported over the rotating shafts to the end. The shells together with everything that has the same size, falls through the openings that are made up between the interlocking discs and the shafts. The tilted bottom of the disc-screen makes sure the small fraction glides down to the rotary valve.

Rotary valves
The rotary valves make sure the small fraction that builds up at the bottom of the disc-screen is transported to the zigzag wind-sift channels. The impeller is made of steel and has rubber strips mounted along the edges in order to facilitate an air tight connection. This air tight connection is needed in order to prevent the air flow from disappearing through the valve and blowing the small fraction back into the disc-screen. This way, all air can be used for the separation process.

Zigzags
The uprising air flow is generated by respectively 2 and 1 blower in the 1st and 2nd zigzag. The zigzag wind-sifter consist of a multi-deck zigzag channel fed from the middle of the channel. Lights and fines are entrained in the upward flowing air and heavy large material falls down due to the gravitational forces that act on the particles. The heavy fraction in the 1st zigzag consists out of steel and glass, the light fraction out of shells and plastics. The heavy fraction of the second zigzag consists out of shells while the light fraction consists out of plastics and paper.

Air expansion chamber
The air coming out of the 1st zig zag disappears through a screen while the lights fall into the expansion chamber and down to the second rotary valve.

Blowers
A total of three blowers is used within the prototype. Each blower blows a maximum of 13,2M3/min, at 270km/h. Two blowers are situated at the bottom of the 1st zigzag, where an higher volumetric air flow rate is needed to blow up the heavy shells. The last blower is situated at the bottom of the second zigzag.

Electric drive
In order to drive the shafts of the disc-screen and the impellers of the rotary valves, two 350W/620RPM electric motors are used. To come out at the desired rpm of both the disc-screen and the rotary valves a series of retarding gear set ups have been implemented. The disc-screens RPM is 68 and the rpm of the rotary valves is 33. The shafts of the disc-screen are connected through a gear and chain connection.

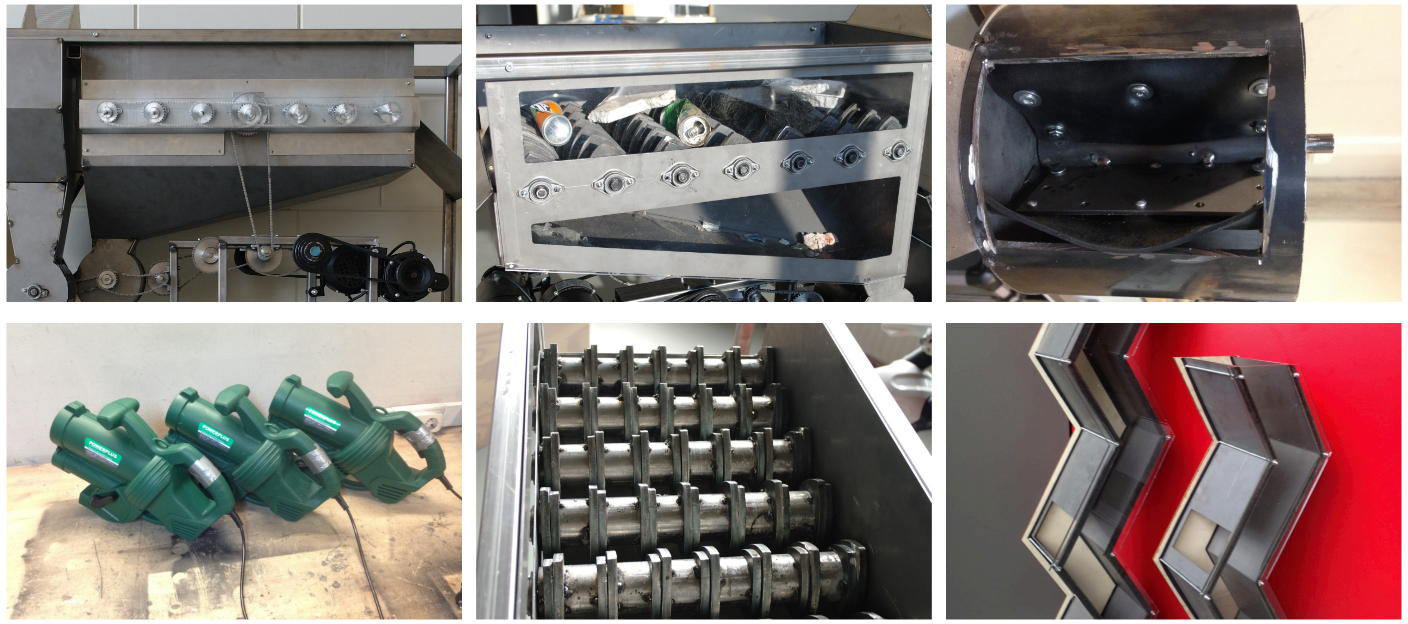


figure 9.2.1, F.L.T.R, electrical drive, discscreen, rotary valve, blowers, discscreen mesh, zigzag channels

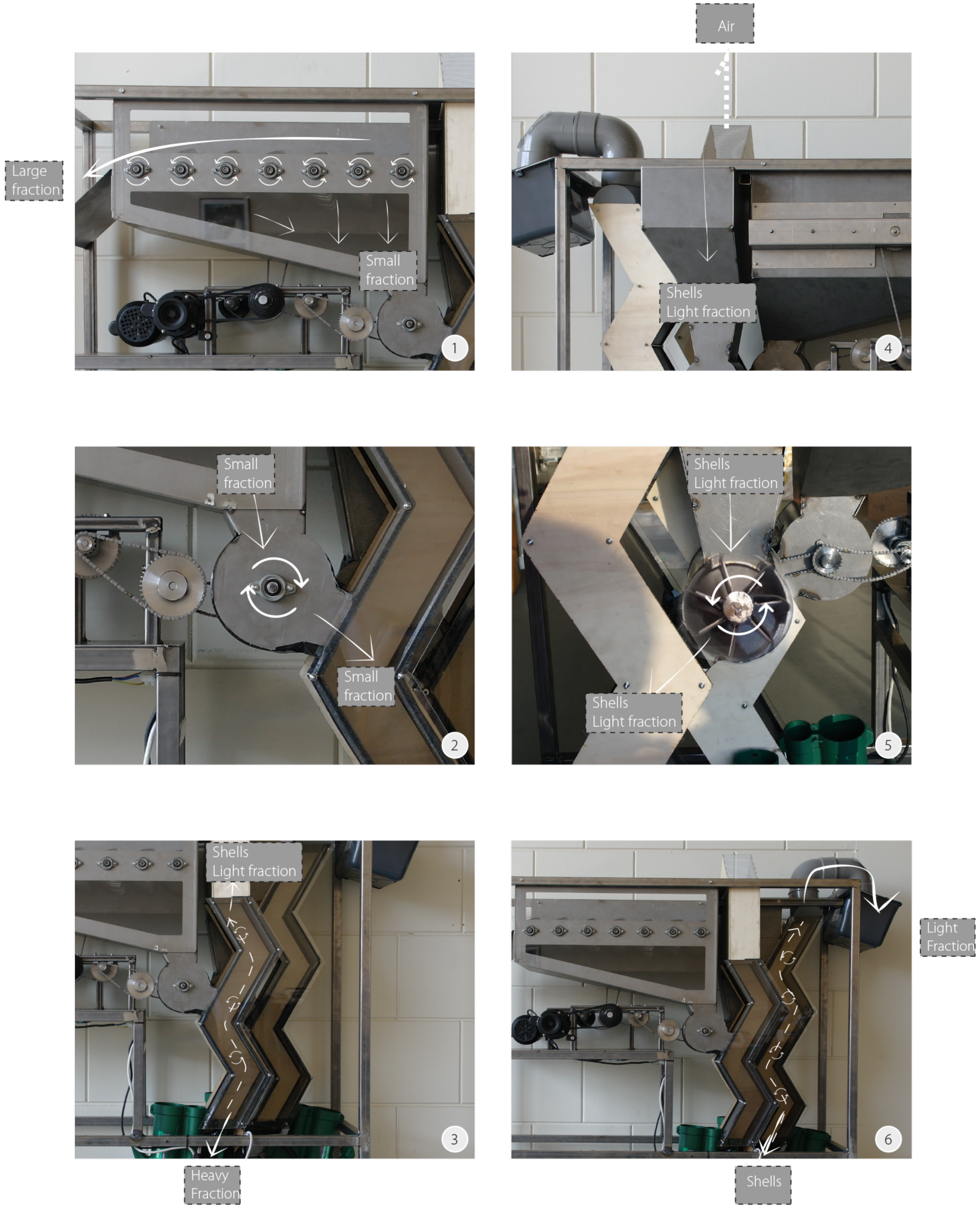


figure 9.2.2, material flow per component

9.2 TESTING THE PROTOTYPE

In order to test the prototype a sample was taken of the material collected by the beach cleaner and put into the prototype for separation. By doing so the working principle of the design can be tested and validated. The prototype is also used to generate insights into possible problems/issues with the chosen separation method and design and these are used for the further development of the concept.

Method
Two tests were executed, one in which each fraction was put separately into the machine to see how much of the fraction would end up in the designated container. And one test where a representative mixture of all four fractions was mixed and put into the machine. Figure 9.2.1 shows a picture taken from the sample that was collected by one of the beach cleaners. As can be seen all four fractions as described in the previous section are present within the material mix.

By analysing how much of each fraction went into the prototype and how much ended up in each collection container an estimation can be made about the separating efficiency of the prototype. As can be seen in figure 9.2.2 the mix consists of a large variety of materials. According to the analysis and the concept, the mixture should be subdivided into four main categories:

Large fraction:
Everything that is larger than the openings between the shafts of the disc-screen (bottles, cans, cardboard, nets, packaging material)
Small heavy fraction:
Particles with a high enough specific weight to fall in against the uprising air-stream of the 1st zigzag (Shards of glass, bottle caps, stones, screws)
Shells:
All shells that are present within the mixed material.
Small light fraction:
Particles with a low specific weight or small wall thickness/weight ratio (pieces of paper, cardboard plastics)

Results
The first results were promising since most of the particles of each material category ended up in the correct collection container. Some of the particles however ended up in the wrong container. Thin pieces of glass and bottle caps ended up in the shell container. A cork that should actually come out of the 'lights' output ended up in the shell container as well.


figure 9.2.1, sample taken from the beach cleaner.

Figure 9.2.2, four fractions into which the prototype separates


figure 9.2.3, the four outputs of the prototype

Other insights
Other insights that were generated during the tests were that the light fraction sticks to screen of the expansion chamber, however when the machine is turned of, they travel with the decreasing flow of air into the expansion chamber. Where they fall down into the now stationary rotary valve. When the machine is turned back on, they fall into the second zigzag and get ejected out of the light fraction outlet.

Some particles remain on the slope of the disc-screen. However when more material is fed into the machine the heavier fraction takes along the left over material.

All of the large fraction is effectively transported to the end of the disc-screen and ends up in the container.

The openings of the disc screen were to large, some particles that were to large for the rotary valve came through. Resulting in the system to jam.


Figure 9.2.4, bottle caps and thin pieces of glass in the shell container


Figure 9.2.5, particles left at the bottom of the disc screen


Figure 9.2.6, "lights" get stuck to the air exit screen.

9.3 FINAL DESIGN, THE SHELLSAVER

The shell saver is an add on that can be used as a supplement to the current beach tech 3000 (see the page on the right). It is placed within the large collection container of the beach cleaner and enables the machine to separate the shells that are collected along with the garbage during the cleaning process and return them to the beach.

Since more than half of the weight the beach cleaner collects consists out of shells, the machine can operate longer without intermediate trips to the dump truck and thus the cleaning process can be finished faster. The municipality has to pay per ton of material that is disposed at the dump site, since over half the weight currently consists out of shells, a lot of money can be saved by not collecting and disposing the shells.

Shells help prevent beach erosion.

Shells help prevent beach erosion since they hold and offer grip to the sand. The shell banks that are formed on the beach are important for the preservation of the beach and the dunes. Since beach cleaners remove a lot of shells, some areas of the beach are out of bounce and cannot be cleaned efficiently. With the shell saver mounted to the beach cleaner, the shells are not removed and thus the beach can be cleaned everywhere and as frequently as needed. Lastly shells contribute to a natural appearance and therefore should remain on the beach.

During operation the beach cleaner, rakes and ploughs sand, mixed garbage and shells onto a rotating screen. The sand is screened out while everything larger than the mesh-size of the screen is collected within the small collection container. When full, the operator of the beach cleaner lifts and empties the content into the hopper of the Shell Saver (figure 9.3.2, bottom). The small collection container is than lowered and the operator continues the cleaning process as usual. While the beach cleaner continues its usual operation the shell saver is automatically switched on and starts processing the material inside the hopper. A total of three separation steps separate the material into four fractions (see figure 9.3.2, top). All garbage types end up in the large collection container, while the shells fall back on the beach. The shells fall in front of the right wheel of the beach cleaner, so the shells get pushed in the sand by the wheel.

figure 9.3.1, the position of the ShellSaver within the beach cleaner

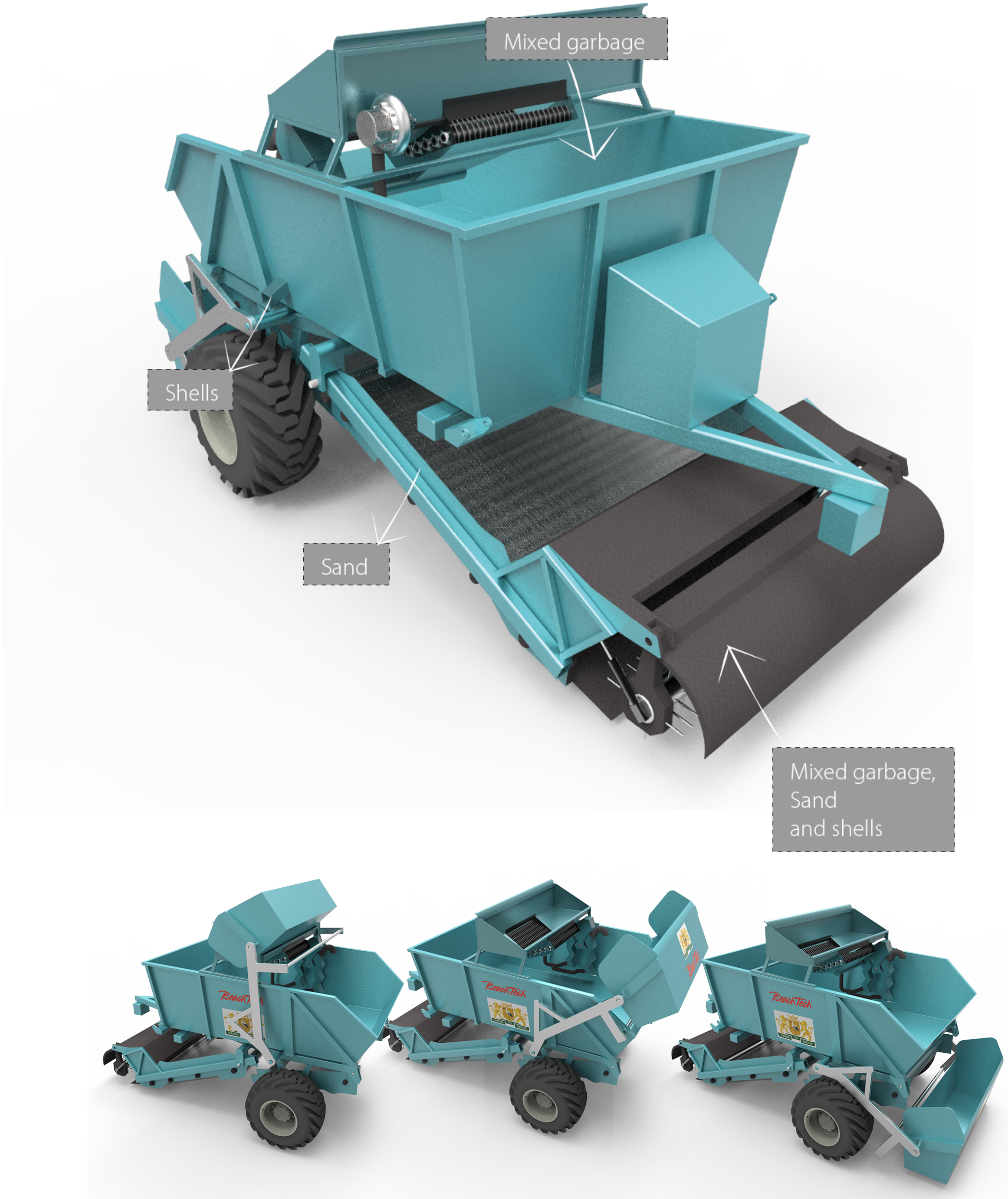


figure 9.3.2, top, material flow through the beach cleaner with the shell saver, bottom, filling the hopper of the shell saver with collected material

9.4 COMPONENTS

The exploded view seen on the page on the right shows all components integrated within the ShellSaver. According to the findings of the prototype test a few adjustments have been made to make it suitable for integration on the BeachTech-3000. For the main working principle of each component section 9.2 and 9.3 can be read. In this section all the extra components and alterations that have been made to the parts of the ShellSaver will be disused.

Disc-screen
The disc-screen is constructed in a V-shape in order to dispose the larger garbage on two sides of the machine. By doing so the collection container of the BeachTech-3000 will be filled equally on both sides, making maximum use of the load capacity of the container.

In order to prevent the small fraction (and the shells) from moving on top of the larger fraction to the discharge end of the disc-screen, two alterations have been made.

First of all both sides of the disc-screen are placed under an angle. This way, only the material that is in direct contact with the rotating discs of the disc-screen get transported to the end. The layers above, roll down back to the middle of the disc-screen until they are in direct contact with the rotating discs.

Secondly, at the ends of both sides of the discs screen, rubber flaps are placed. The flaps leave an opening for the mono layer that is in direct contact with the discs to get discharged from the ends. The material that travels on top of this layer gets swiped of and falls back to the middle of the disc-screen.

These alterations make it possible to perform effective screening within a relatively small disc-screen.

Second collection hopper
Underneath the disc-screen, a second hopper collects the small fraction that has fallen through the openings of the disc-screen. Within the prototype, especially the lighter fraction remained on the slope of the disc-screen. The angle of the second hopper is slightly increased. The movement and vibration of the BeachTech give extra agitation to the material making it more likely that it will slide down. Next to that, the prototype showed that the heavier fractions took along the remaining materials.

Screw conveyor
The 1st rotary valve that was used in the prototype was replaced by a screw conveyor. This was done in order to increase the area on which the small fraction is taken in and thus the hight of the second hopper could be decreased. The screw conveyor also makes it possible to transport the small fraction over a longer distance. This way the two zigzags can be placed at the side of the container (figure 9.3.2), decreasing the chance of garbage getting stuck behind the zigzags when the large collection container is emptied.

Zigzag channels
Both zigzag channels have more cascades incorporated. This is done in order to increase the separation efficiency of the wind sifting steps. Each cascade can be considered as an individual separation step, so more cascades means a better separation.

Air expansion chamber
In the prototype a screen was placed in the direct path of the air flow leaving the first zigzag, in order to take out the materials entrained within the air flow. This resulted in light, 2D material clogging the screen and the accumulation of light particles at this location. In order to prevent this from happening, a steel baffle was placed in the path of the airflow, the baffle redirects the airflow down and the air expansion within the chamber decreases the air speed enabling the entrained particles to settle. The air leaves the expansion chamber through a screen located behind the baffle, particles still entrained within the air flow will be stopped by this screen. Light material that has been accumulating here will fall down when the ShellSaver is turned off after all material within the hopper has been processed. This material will be processed during the next separation shift.

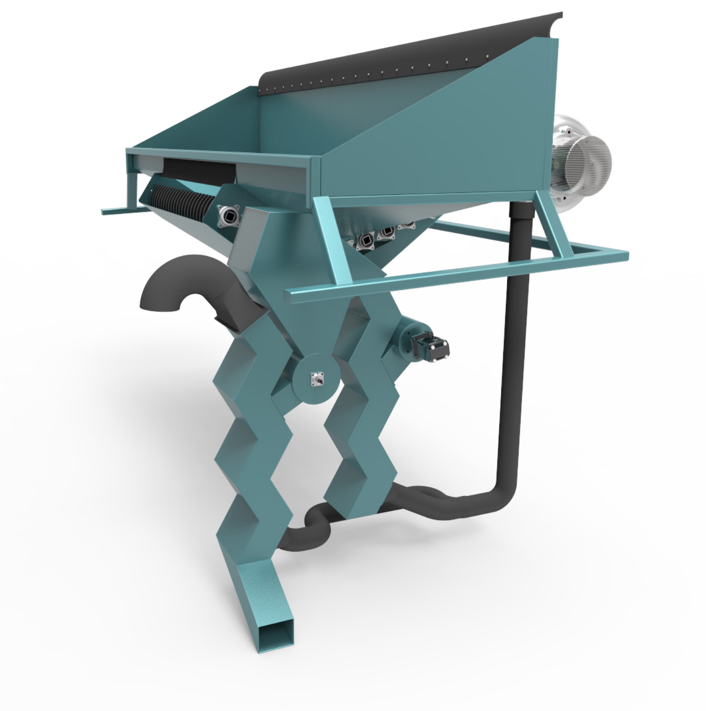
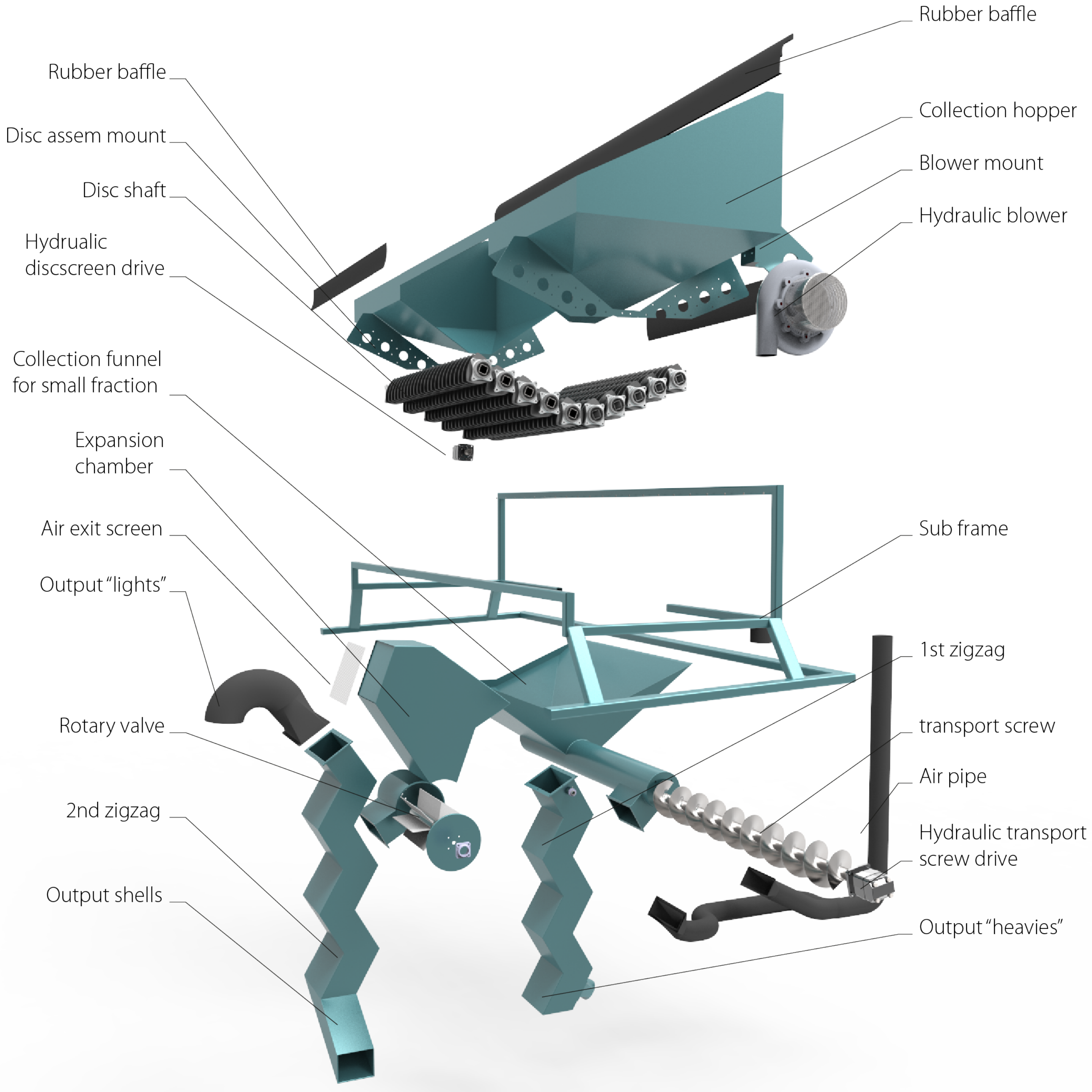
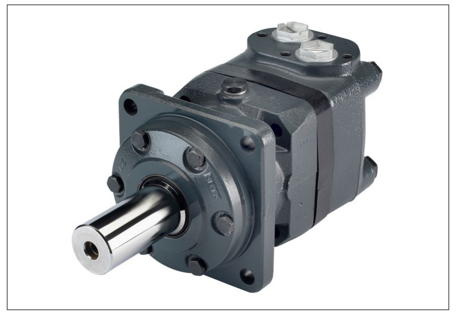


Figure 9.4.1, the assembled ShellSaver



PTO powered hydraulic pump

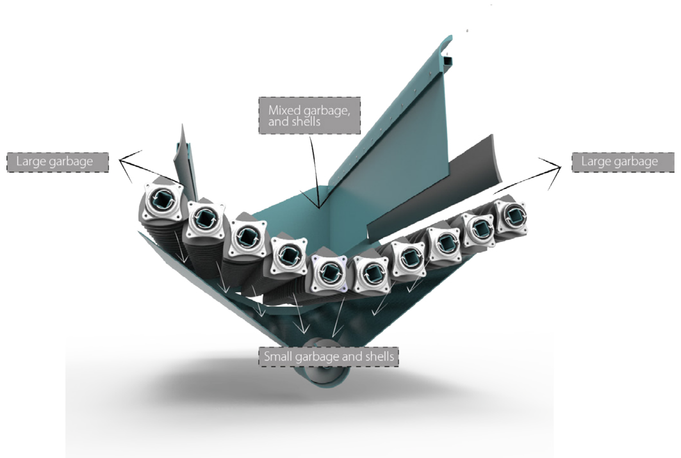


Hydraulic motor

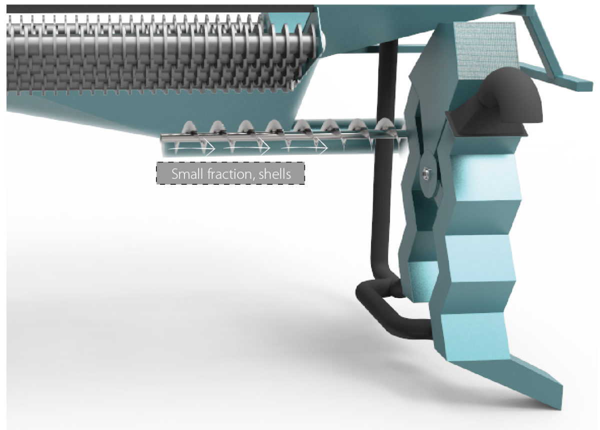
Hydraulic blower

9.5 MATERIAL FLOW PER COMPONENT

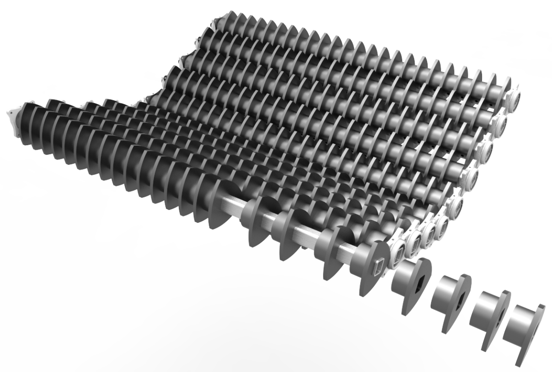
This page shows the different material flows of each of the ShellSaver components. Black arrows indicate material coming in and out of the component, white arrows indicate the movement of materials inside each component. Lastly the dotted lines show the movement of the airflow through the system. The blocks next to each arrow indicate what type of material goes in or out at that specific location of the component. Figure 9.5.4 shows the four different outputs of the ShellSaver.



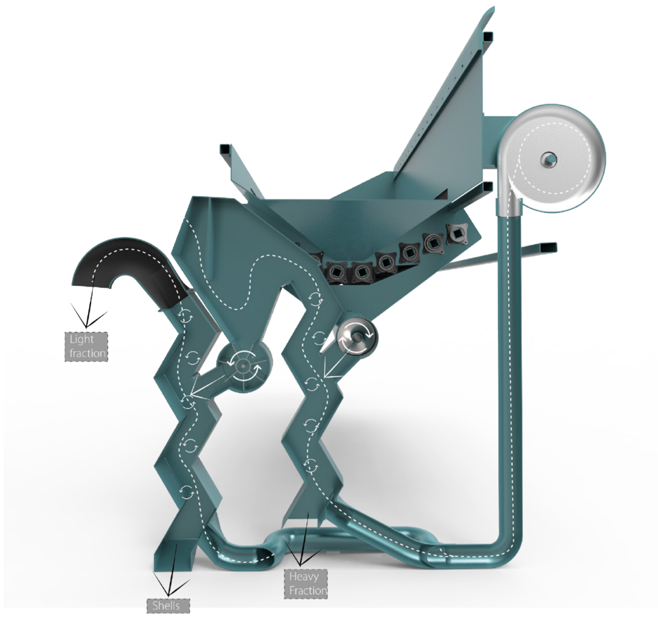
9.5.1, cross-section of the disc screen



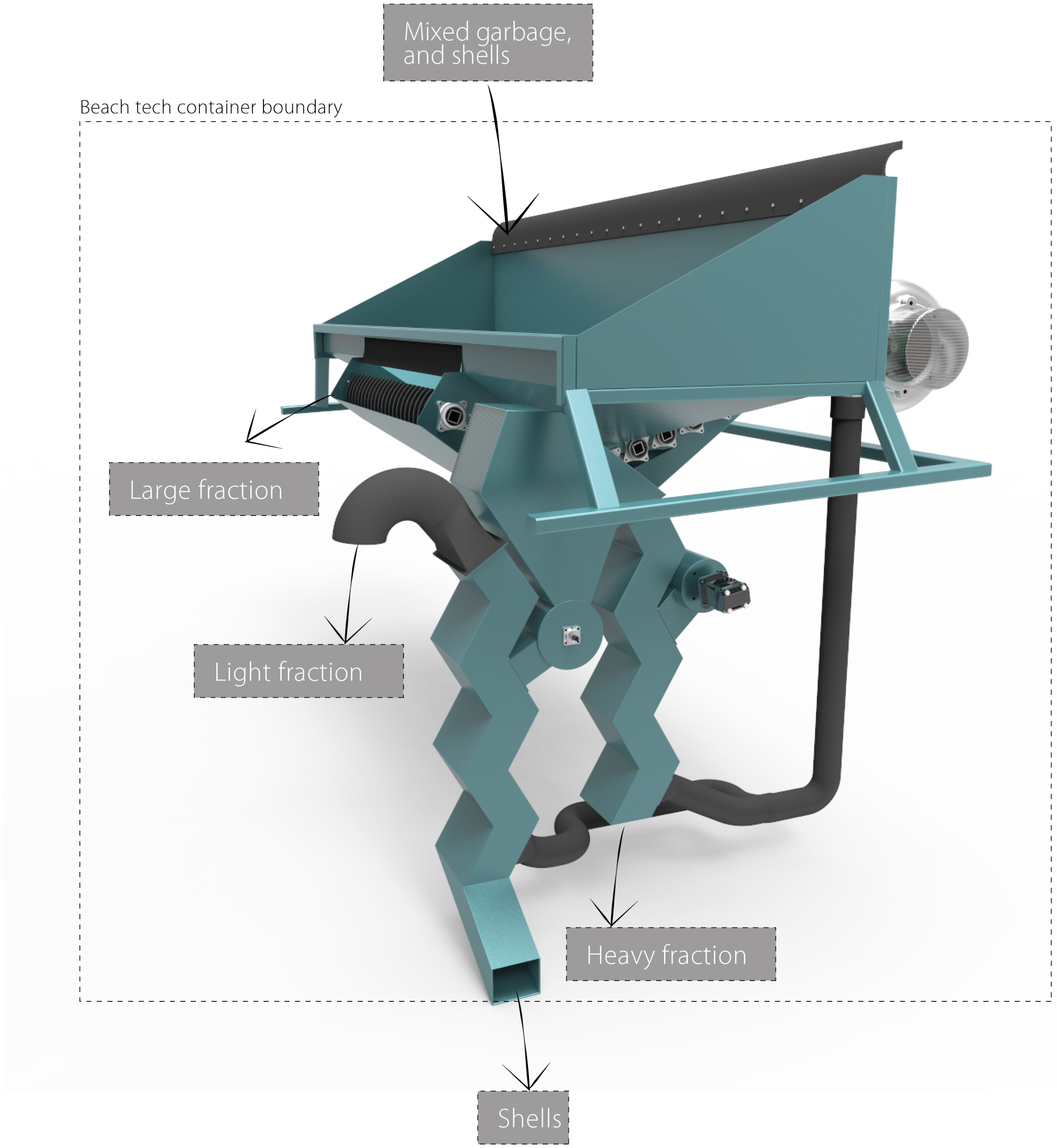
9.5.2, screw conveyor moves the small material to the 1st zigzag



9.5.4, one of the disc screen's shaft assemblies



9.5.3, the different small fractions get separated from the shells



9.5.4, overview of the ShellSaver and the different fractions in which it separates. The dotted line indicates the large collection container of the beach-cleaner

9.6. DRIVING THE SYSTEM

As discussed earlier, the add-on will be driven by the hydrostatic drive system of the BeachTech-3000. In order to be able to connect an extra of three hydraulic motors to the system a larger pump and extra piping is needed. Figure 9.6.1 shows the hydrostatic subsystem that is needed to power the ShellSaver. Pressurised oil flow is generated in the PTO powered hydraulic pump of the BeachTech-3000 (1). The oil flows through the regulator (4) to each of the three hydraulic motors (2,3 and 7). An oil filter (6) cleans the circulated oil and the radiator (5) cools the oil.

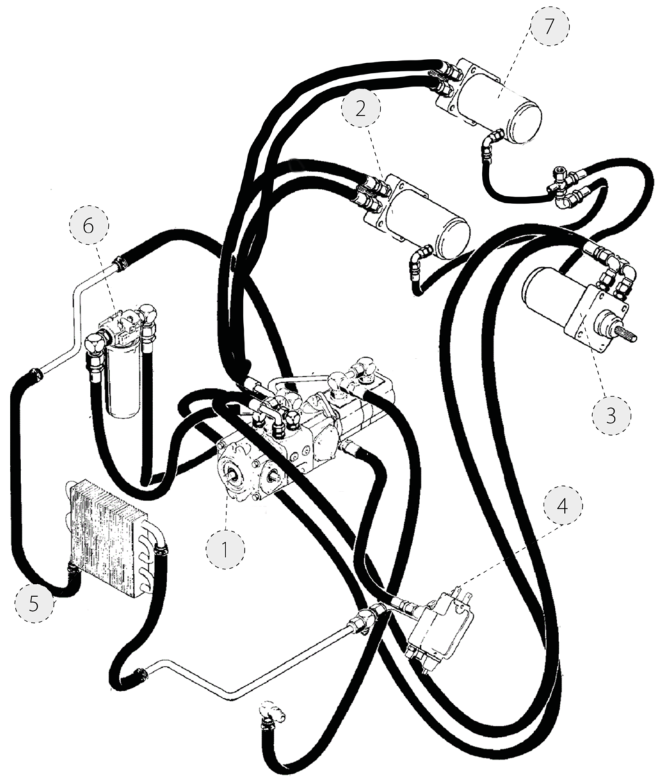


figure 9.6.1, hydrostatic drive of the ShellSaver

9.7, LOGISTICS

A total of six beach cleaners is used to clean the beach of the Hague. The beach is divided into subsequent sections and each beach cleaner is responsible for its own designated area. The way the beach is cleaned is by driving in increasingly smaller circles to the centre of the area (see figure 9.7.1). By doing so it is prevented that a certain area of the beach is cleaned twice.

Since the ShellSaver discards the shells on the right side of the BeachCleaner, a line of shells will be formed on the right side of the cleaned strip behind the beach cleaner (figure 9.7.1 and figure 9.7.2). If the beach cleaners keep following their normal cleaning procedure and route the shells will not be collected twice. If for some reason this might occur occasionally, the shells will be picked up and separated a second time which will not cause to much problems.

figure 9.7.2, shells and garbage in, shells out.

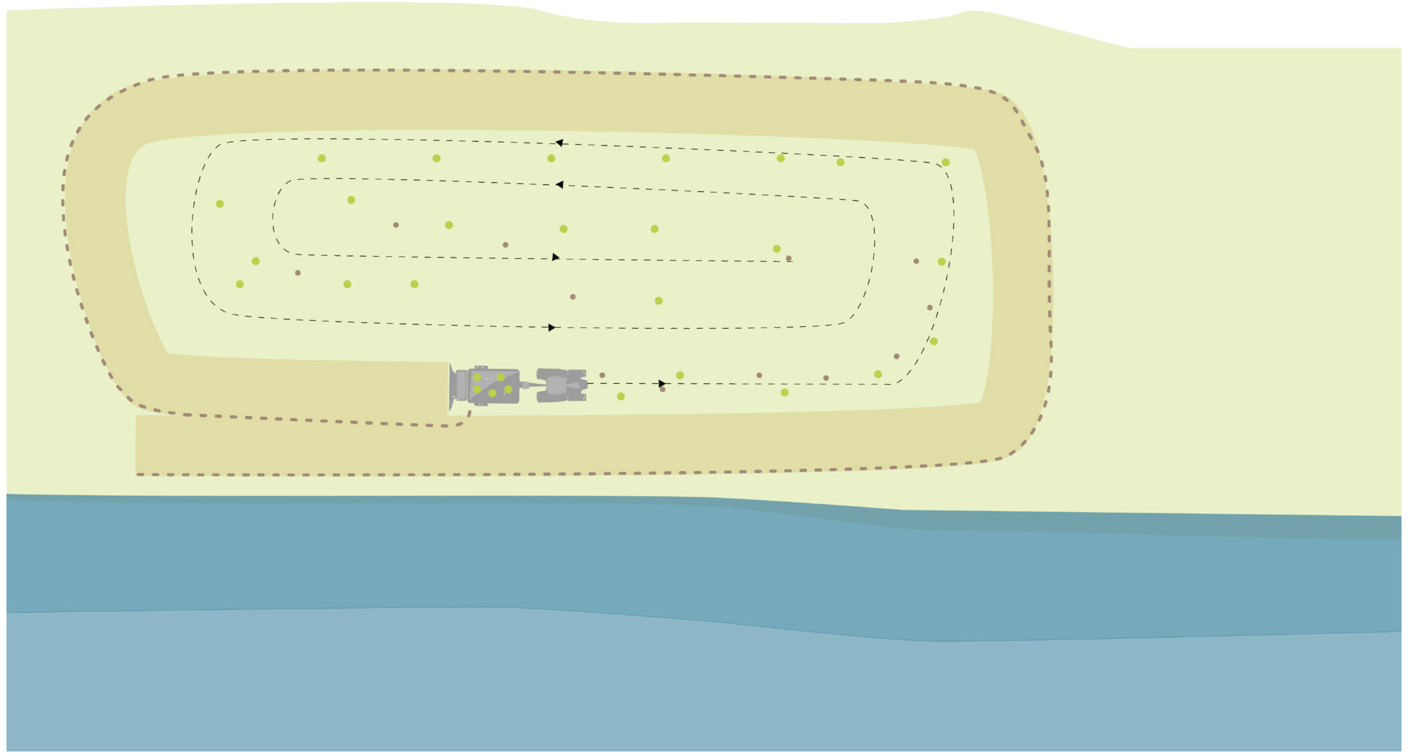
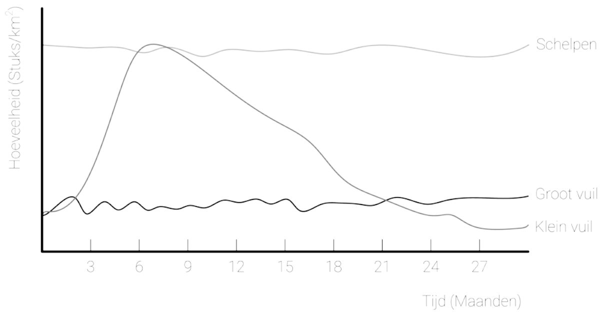


figure 9.7.1, route of the beach cleaner and the resulting line of shells that are returned after the cleaning process

Small garbage removal

The problem of the small garbage removal that was stated in the problem definition, will be dealt with by assigning one beach cleaner to the small garbage removal task. The beach cleaner can remove significantly more small garbage if it is equipped with a smaller mesh sized screen and the screening mode is used in stead of the raking mode as was explained in section 4.4. Since the beach cleaner cannot operate as fast when using the screening mode the other five beach cleaners will keep removing the larger garbage the same way as they did.

A log should be kept in which is depicted which part of the beach has been thoroughly cleaned and which areas still need to be thoroughly cleaned this requiers some extra logistics and planning. The small-garbage beach cleaner will clean a different part of the beach each shift. So in that specific area the amount of small garbage will removed (figure 9.7.3 and 9.7.4). Since there are six beach cleaners in total, each specific zone of the beach will be thoroughly cleaned once every week and thus the total amount of small garbage will decrease slowly (resulting in graph 9.7.1). All six beach cleaners will be equipped with a ShellSaver in order to leave the shells on the beach.



Graph 9.7.1, the different materials and their amount over time.

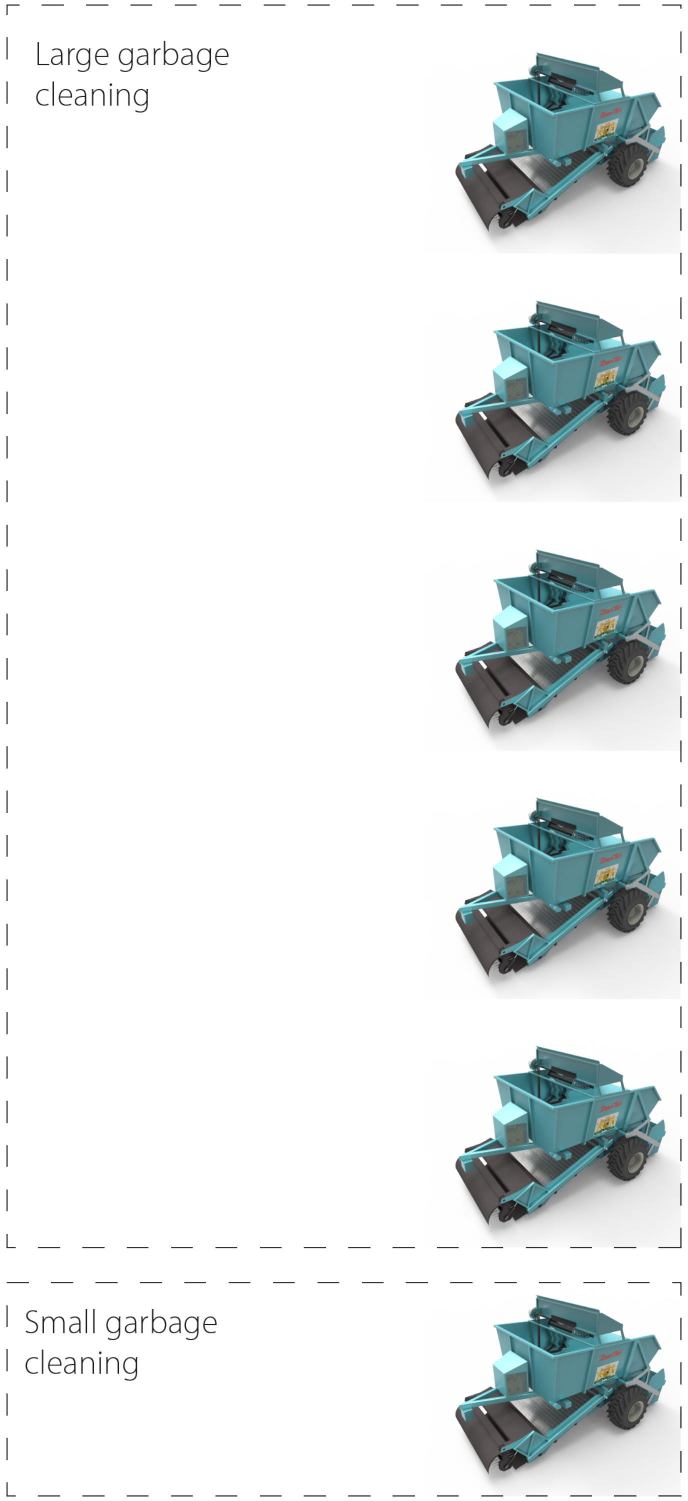


Figure 9.7.3, division in small and large garbage cleaning of the beach cleaners

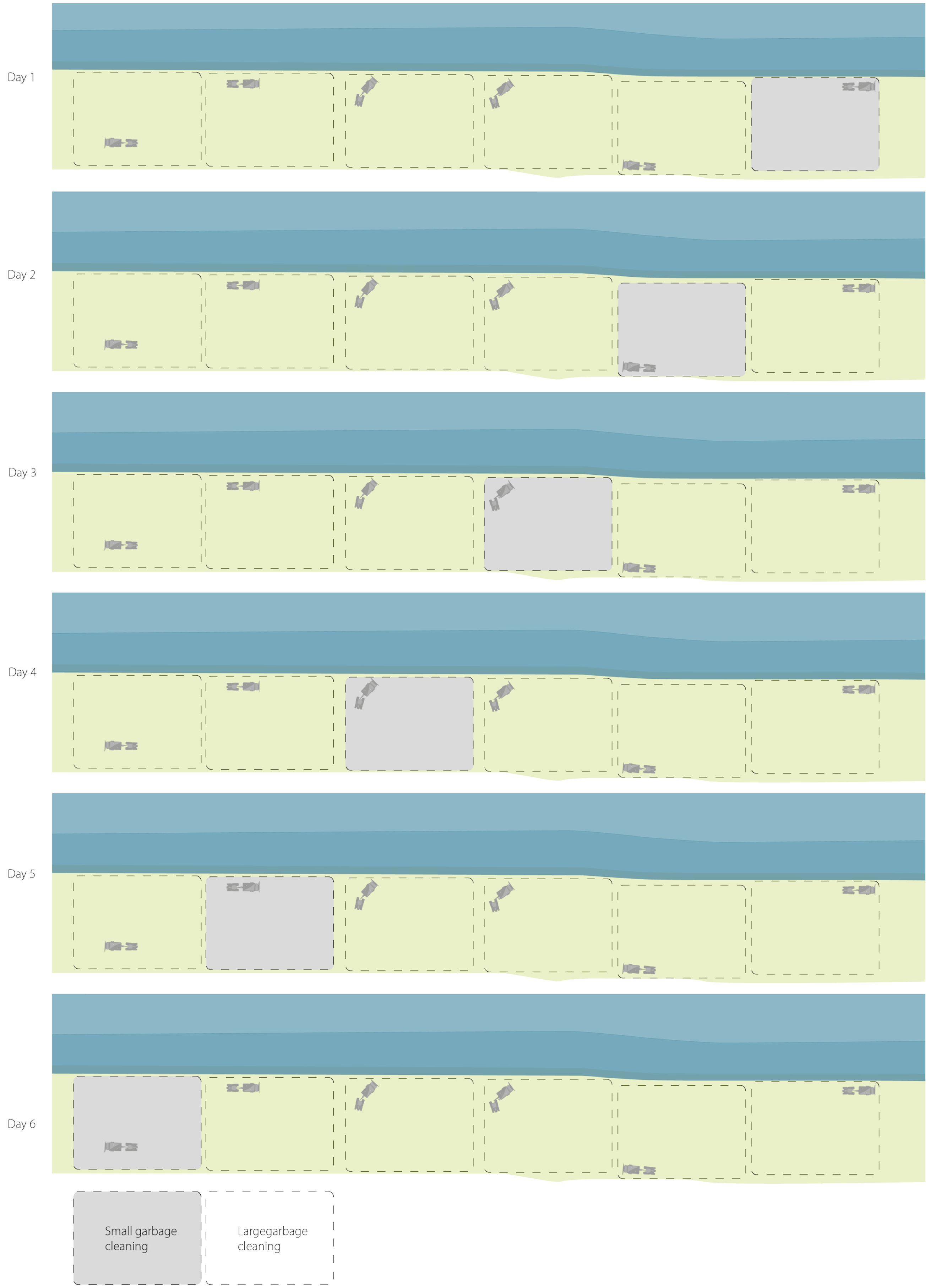


Figure 9.7..4, different cleaning zones of the beach.

EVALUATION

Conclusion

This thesis showed the process and development of an add on for the beach cleaners currently used by the municipality of the Hague. At the end of the analysis phase, the problem definition showed the problems with the current beach cleaner and the benefits of leaving shells on the beach. A selection of appropriate separation techniques was made to separate shells from a large variety of garbage. In the synthesis and concept phase these techniques were combined and elaborated upon to see if they were usable for the given context. The concept that was finally developed is the ShellSaver. This machine will create added value to the beach cleaner and its cleaning process because it enables the beach cleaner to make a distinction between garbage and shells. Not only do shells belong to a natural beach, they also help in preventing beach erosion.

An extra advantage of using the ShellSaver is that a lot of disposal costs can be saved when no more shells are dumped at the dump site (estimated 20.000€ annually). The prototype that was developed showed great potential in creating the desired separation and in this way validated a part of the concept. The final concept of the ShellSaver showed how the chosen techniques could be implemented within the BeachTech-3000 and how operation of the device would work.

Recommendations

This thesis showed the general exploration of possibilities to separate shells from a large range of different kinds of garbage. Although the prototype showed great potential of the chosen techniques, more research needs to be done in order to see what types of garbage form a problem within the separation process. Large-scale tests should be done on collected beach litter to see if the concept is capable of generating a sufficiently pure shell fraction. At this point the prototype is not robust enough to handle large amounts of waste and only validated the working principle.

Next to that it should be investigated if the PTO driven hydrostatic pump can generate enough oil flow to power the extra 3 hydraulic motors needed within the ShellSaver. If not, a possibility would be to incorporate a separate hydrostatic system to power the actuators of the ShellSaver.

The ShellSaver concept is incorporated within the BeachTech-3000 because disposing the shells near their original location was a requirement and by adding the Shell saver to the beach cleaner the cleaning process does not have to be altered. This results in a total of 6 ShellSavers needed in case of the the Hague situation. Out of a commercial point of view this is a good thing since more ShellSavers can be sold. If further research indicates however that it is very difficult/expensive to implement the ShellSaver within the beach cleaner, an alternative would be to implement the shell saver within a separate device. This would mean less restrictions to the design and possibly a better separation.

If application within the beach cleaner does show enough potential, the best idea would be to patent the given combination of techniques within the described context. With the developed and patented idea, BeachTech should be approached and the idea must be presented. Not only does BeachTech has a lot of knowledge within this beach cleaning sector, they are also market leader. With the current trends of natural beaches together with the other described advantages, the developed concept shows great potential and thus value for the BeachTech company.

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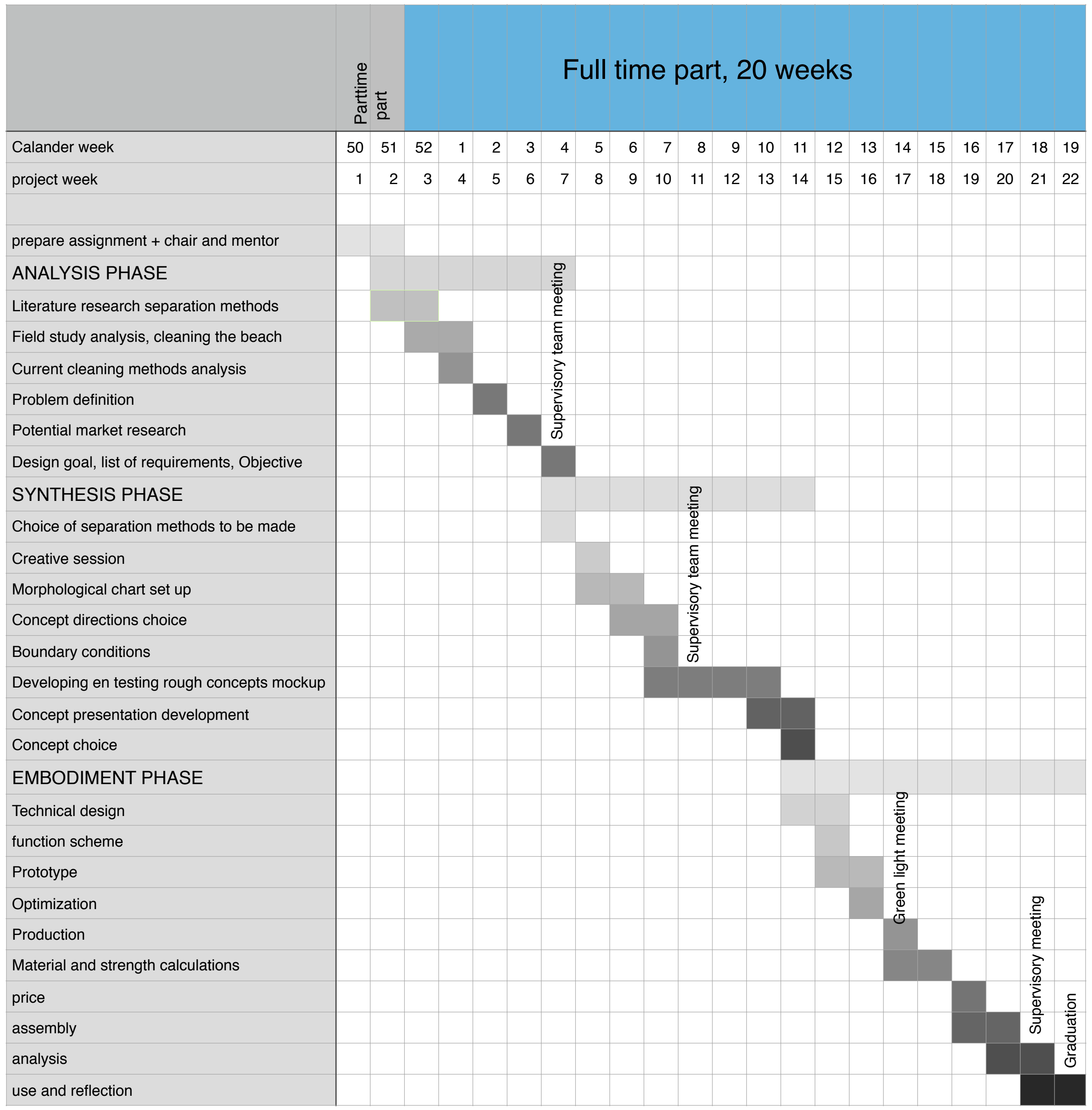
APPENDIX 1A. PLANNING OVERALL

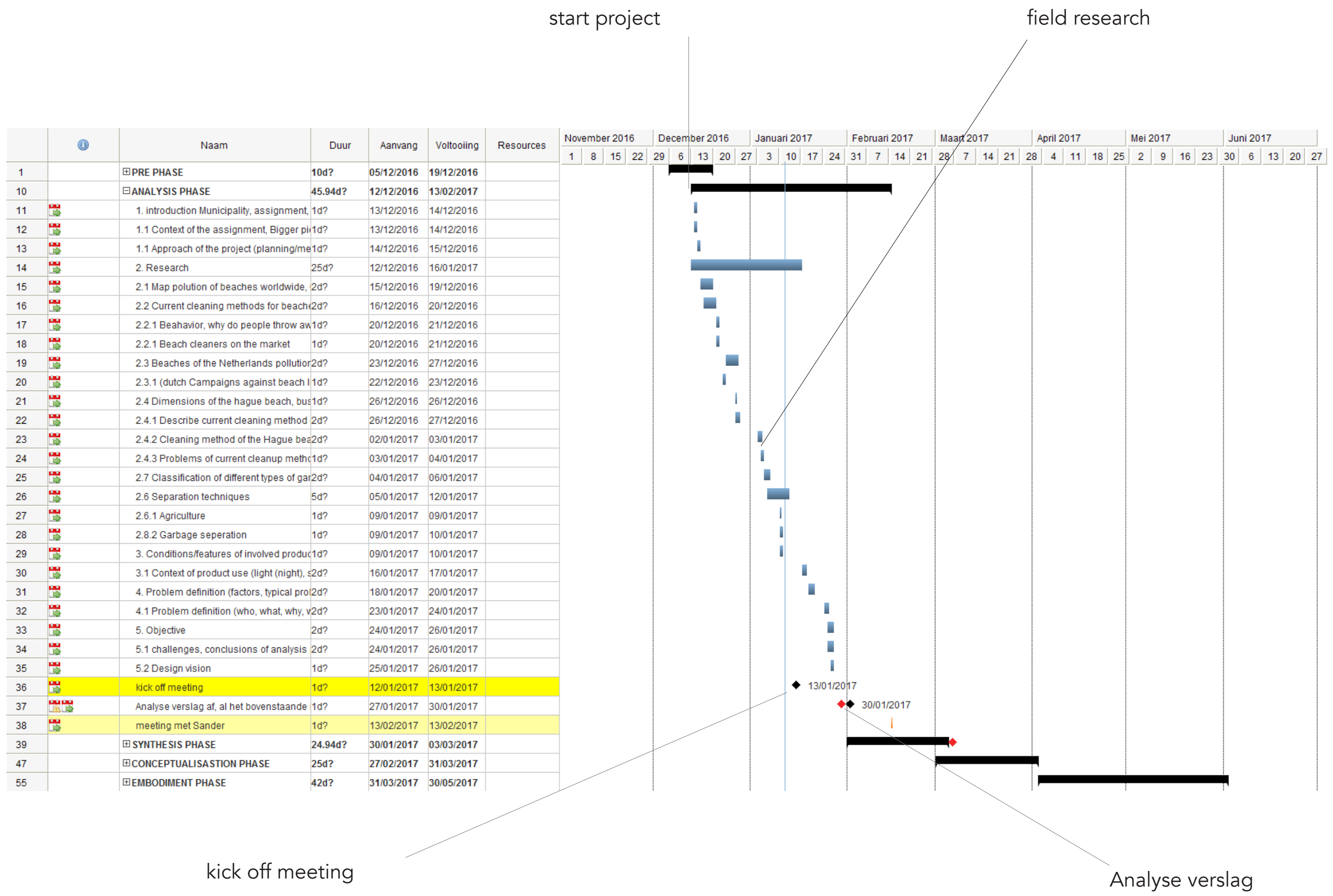
Graduation project planning Tijmen Oudshoorn



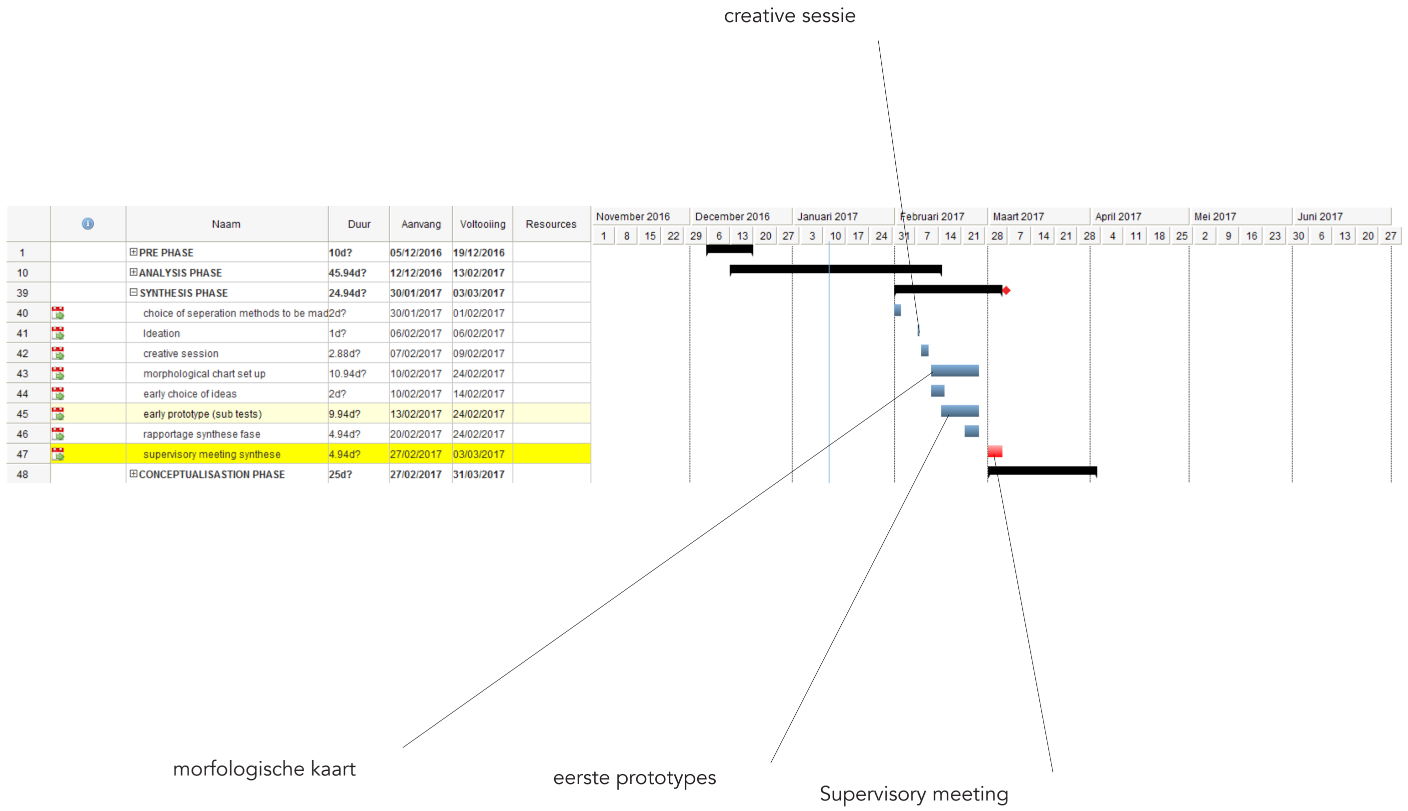
APPENDIX 1B. PHASES OF THE PROJECT

Fase	Resultaten
Analyse	Analyse verslag: Vervuiling wereldwijd en in Nederland De stranden van Den Haag (dimensies etc.) Huidige schoonmaak technieken Classificatie van het afval Andere geschikte scheiding methoden (landbouw en afvalverwerking) Probleem definitie PVE
Synthese	Morfologische kaart Idee combinaties/techniek selectie Sub principe oplossing testen Verslaglegging
Concept	Concept prototypes (sub oplossingen) Concept presentatie (Techniek, kosten, voor-, na-delen) Concept keuze
Embodiment	Werkend, gevalideerd prototype Technisch pakket Aanbevelingen

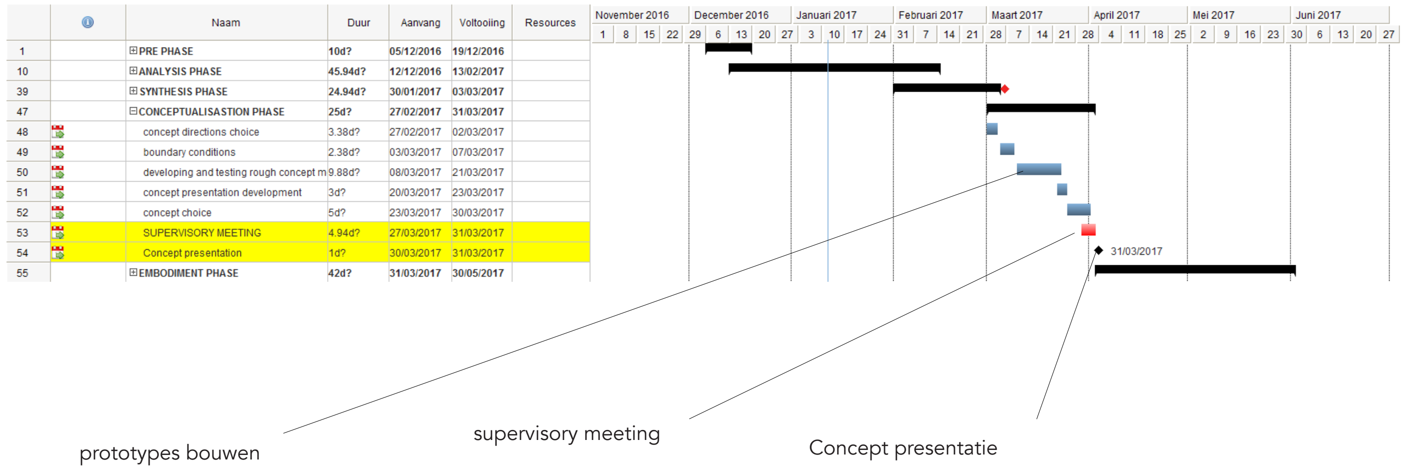
APPENDIX 1C. PLANNING PER PHASE
PLANNING AND MILESTONES



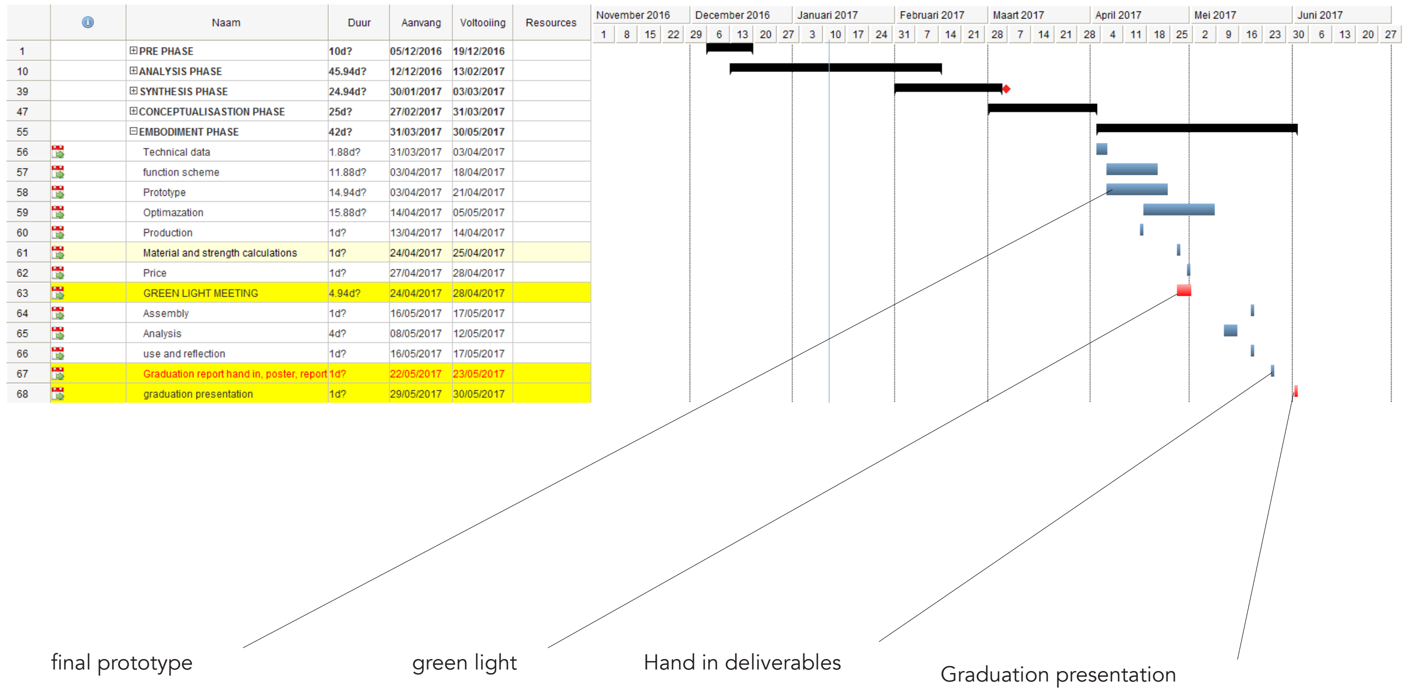
		Naam	Duur	Aanvang	Voltooiing	Resources
1		⊞PRE PHASE	10d?	05/12/2016	19/12/2016	
10		⊟ANALYSIS PHASE	45.94d?	12/12/2016	13/02/2017	
11		1. introduction Municipality, assignment,	1d?	13/12/2016	14/12/2016	
12		1.1 Context of the assignment, Bigger pi	1d?	13/12/2016	14/12/2016	
13		1.1 Approach of the project (planning/me	1d?	14/12/2016	15/12/2016	
14		2. Research	25d?	12/12/2016	16/01/2017	
15		2.1 Map polution of beaches worldwide,	2d?	15/12/2016	19/12/2016	
16		2.2 Current cleaning methods for beache	2d?	16/12/2016	20/12/2016	
17		2.2.1 Beahavior, why do people throw aw	1d?	20/12/2016	21/12/2016	
18		2.2.1 Beach cleaners on the market	1d?	20/12/2016	21/12/2016	
19		2.3 Beaches of the Netherlands pollutior	2d?	23/12/2016	27/12/2016	
20		2.3.1 (dutch Campaigns against beach l	1d?	22/12/2016	23/12/2016	
21		2.4 Dimensions of the hague beach, bus	1d?	26/12/2016	26/12/2016	
22		2.4.1 Describe current cleaning method	2d?	26/12/2016	27/12/2016	
23		2.4.2 Cleaning method of the Hague bea	2d?	02/01/2017	03/01/2017	
24		2.4.3 Problems of current cleanup methc	1d?	03/01/2017	04/01/2017	
25		2.7 Classification of different types of gar	2d?	04/01/2017	06/01/2017	
26		2.6 Separation techniques	5d?	05/01/2017	12/01/2017	
27		2.6.1 Agriculture	1d?	09/01/2017	09/01/2017	
28		2.8.2 Garbage seperation	1d?	09/01/2017	10/01/2017	
29		3. Conditions/features of involved produc	1d?	09/01/2017	10/01/2017	
30		3.1 Context of product use (light (night), s	2d?	16/01/2017	17/01/2017	
31		4. Problem definition (factors, typical pro	2d?	18/01/2017	20/01/2017	
32		4.1 Problem definition (who, what, why, v	2d?	23/01/2017	24/01/2017	
33		5. Objective	2d?	24/01/2017	26/01/2017	
34		5.1 challenges, conclusions of analysis	2d?	24/01/2017	26/01/2017	
35		5.2 Design vision	1d?	25/01/2017	26/01/2017	
36		kick off meeting	1d?	12/01/2017	13/01/2017	
37		Analyse verslag af, al het bovenstaande	1d?	27/01/2017	30/01/2017	
38		meeting met Sander	1d?	13/02/2017	13/02/2017	
39		⊞SYNTHESIS PHASE	24.94d?	30/01/2017	03/03/2017	
47		⊞CONCEPTUALISASTION PHASE	25d?	27/02/2017	31/03/2017	
55		⊞EMBODIMENT PHASE	42d?	31/03/2017	30/05/2017	



		Naam	Duur	Aanvang	Voltooiing	Resources
1		⊞PRE PHASE	10d?	05/12/2016	19/12/2016	
10		⊞ANALYSIS PHASE	45.94d?	12/12/2016	13/02/2017	
39		⊟SYNTHESIS PHASE	24.94d?	30/01/2017	03/03/2017	
40		choice of seperation methods to be mad	2d?	30/01/2017	01/02/2017	
41		Ideation	1d?	06/02/2017	06/02/2017	
42		creative session	2.88d?	07/02/2017	09/02/2017	
43		morphological chart set up	10.94d?	10/02/2017	24/02/2017	
44		early choice of ideas	2d?	10/02/2017	14/02/2017	
45		early prototype (sub tests)	9.94d?	13/02/2017	24/02/2017	
46		rapportage synthese fase	4.94d?	20/02/2017	24/02/2017	
47		supervisory meeting synthese	4.94d?	27/02/2017	03/03/2017	
48		⊞CONCEPTUALISASTION PHASE	25d?	27/02/2017	31/03/2017	

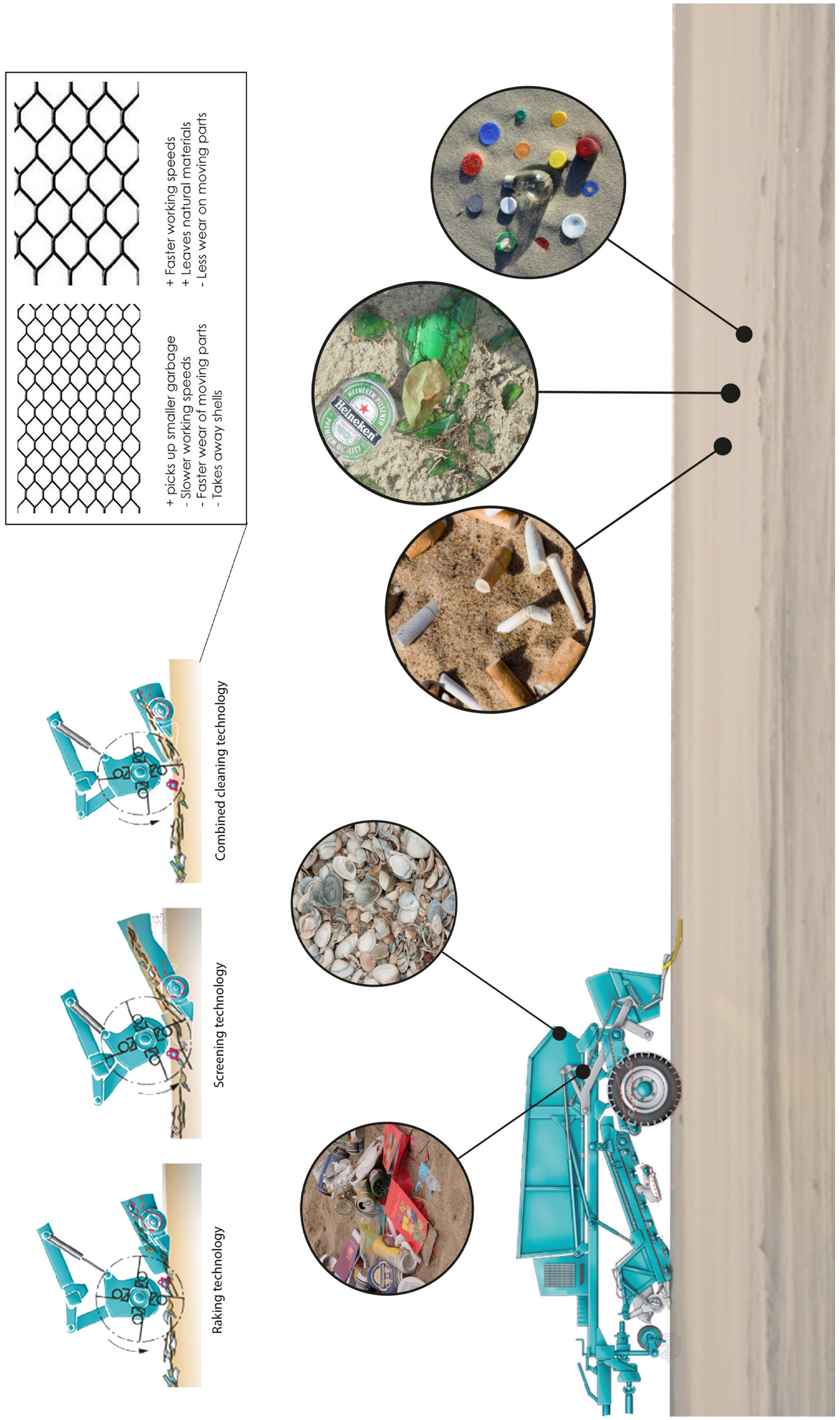


		Naam	Duur	Aanvang	Voltooiing	Resources
1		⊞PRE PHASE	10d?	05/12/2016	19/12/2016	
10		⊞ANALYSIS PHASE	45.94d?	12/12/2016	13/02/2017	
39		⊞SYNTHESIS PHASE	24.94d?	30/01/2017	03/03/2017	
47		⊟CONCEPTUALISASTION PHASE	25d?	27/02/2017	31/03/2017	
48		concept directions choice	3.38d?	27/02/2017	02/03/2017	
49		boundary conditions	2.38d?	03/03/2017	07/03/2017	
50		developing and testing rough concept m	9.88d?	08/03/2017	21/03/2017	
51		concept presentation development	3d?	20/03/2017	23/03/2017	
52		concept choice	5d?	23/03/2017	30/03/2017	
53		SUPERVISORY MEETING	4.94d?	27/03/2017	31/03/2017	
54		Concept presentation	1d?	30/03/2017	31/03/2017	
55		⊞EMBODIMENT PHASE	42d?	31/03/2017	30/05/2017	



		Naam	Duur	Aanvang	Voltooiing	Resources
1		⊞PRE PHASE	10d?	05/12/2016	19/12/2016	
10		⊞ANALYSIS PHASE	45.94d?	12/12/2016	13/02/2017	
39		⊞SYNTHESIS PHASE	24.94d?	30/01/2017	03/03/2017	
47		⊞CONCEPTUALISASTION PHASE	25d?	27/02/2017	31/03/2017	
55		⊟EMBODIMENT PHASE	42d?	31/03/2017	30/05/2017	
56		Technical data	1.88d?	31/03/2017	03/04/2017	
57		function scheme	11.88d?	03/04/2017	18/04/2017	
58		Prototype	14.94d?	03/04/2017	21/04/2017	
59		Optimazation	15.88d?	14/04/2017	05/05/2017	
60		Production	1d?	13/04/2017	14/04/2017	
61		Material and strength calculations	1d?	24/04/2017	25/04/2017	
62		Price	1d?	27/04/2017	28/04/2017	
63		GREEN LIGHT MEETING	4.94d?	24/04/2017	28/04/2017	
64		Assembly	1d?	16/05/2017	17/05/2017	
65		Analysis	4d?	08/05/2017	12/05/2017	
66		use and reflection	1d?	16/05/2017	17/05/2017	
67		Graduation report hand in, poster, report	1d?	22/05/2017	23/05/2017	
68		graduation presentation	1d?	29/05/2017	30/05/2017	

APPENDIX 2A PROBLEM DEFINITION AND LIST OF REQUIREMENTS



PROBLEM DEFINITION IN PICTURES

APPENDIX LIST OF REQUIERMENTS

Tabel 1

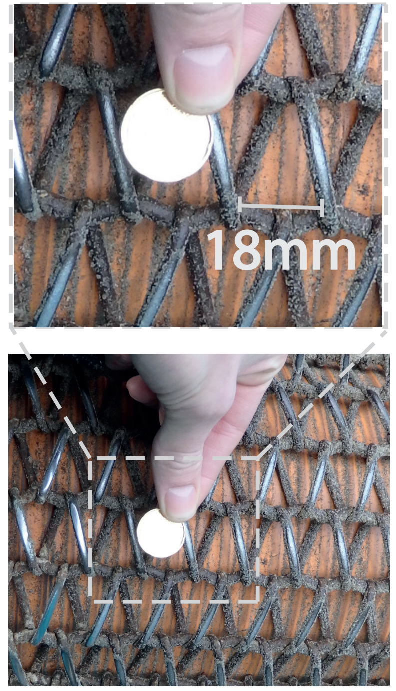
code	Requirement	Argumentation	Origin
A1	The design should leave as much shells on the beach as possible	Shells are natural materials present on the beach, out of aesthetically and ecological motives, they should remain on the beach, next to that shells prevent sand drift and therefor aide in preservation of the beach.	assignment description and ecological research
A1.1	The shells should return near their original location on the beach.	The natural position of shell is on the high water mark where they are left by the tides. Returning them here helps in the natural look of the beach. The shells should remain there where they are left by natural water and wind movement	Exploratory study
A2	the design should clean as much small garbage smaller than 2cm at more than 12.500m2/hour	The design should pick up as much small garbage (cigarette buts, bottle caps and shards of glass, garbage smaller than 2cm) as possible but at least significantly more than the BeachTech-3000 currently does when screening is used (working with 2,5 meters at 5km/h, 12.500 m2/h)	assignment description and research
A3	the design should clean small and large garbage at a speed of >12.500m2/hour	This is the speed at which the current BeachTech-3000 cleans when screening is used, so this is the benchmark to which the design will be compared. or the design is used a couple of times a year in order to decrease the amount of garbage <2cm	benchmarking research on current Beach cleaner
A5	The process should leave the shells as intact as possible.	Broken shells could hurt beach visitors and the larger the shells the better they prevent erosion of the beach. So it is important that the process does minimal damage to the shells.	Assignment description and research
A6	The device should use as less power as possible	Since higher power consumption means higher costs this has to be prevented	research
A7	The device should be as cheap as possible	If the device will be cheap it will be more easily be implemented	analysis
A8	The device should be as simple as possible	The less complicated the working principle of the device, the cheaper and more easily implemented within the beachcleaner	analysis
A9	The device should have low energy usage	Since the device will be added to the beach cleaner and most probably will be powered by the hydrostatic drive system, the device should nog take to much power of the hydrostatic pump.	analysis
A10	The device should be robust	Since the environment is very abrasive (sand, water, heavy garbage) the device should be robust and withstand as long as possible	analysis
A11	The set up time should be as short as possibel	If the preparing and mounting of the device will take to long the work flow of the cleaning process is decreased	analysis
A12	The device should have as low an impact in the ecosystem if the beach as possibel	Since the device must aid in restoring the ecosystem of the beach, the device itself should have low impact on the ecosystem	analysis a
A13	Spreading of shells	the device should spread the shells in order to have most effect on preventing beach erosion	analysis
A14	the device must be feasible	it should be feasible to research, analyse and develop the concept within the time span of the gradation project	analysis
A15	Low maintenance needed	If the device needs a lot repairing and maintenance, it will not be feasible to implement within the beach cleaner	analysis

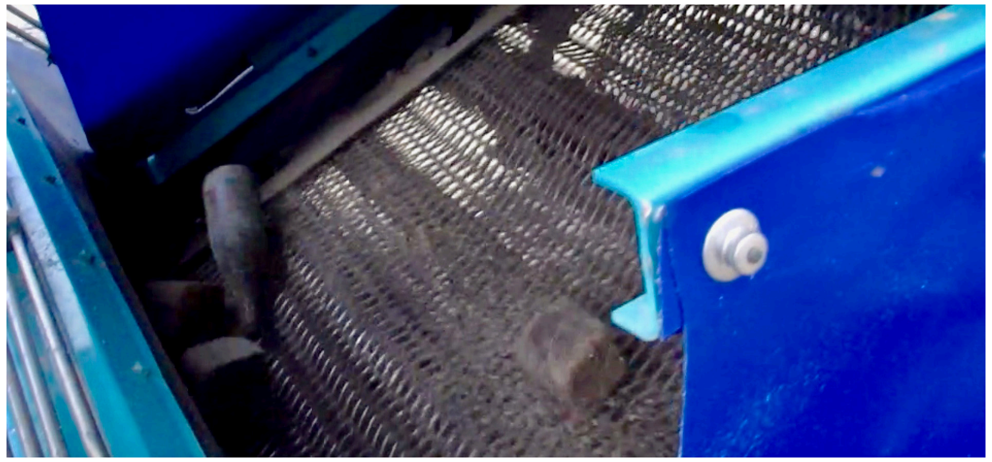
Tabel 1

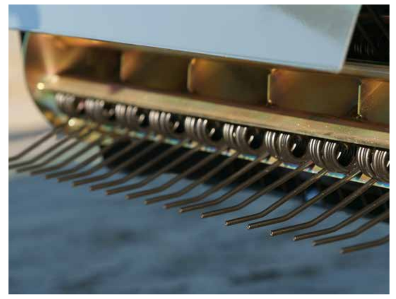
code	Requirement	Argumentation	Origin			
B1	if the design will be an addition to the current BeachTech-3000, it should either fit in the small collection container (2,5 x 1,00 m) or the larger collection container on top of the BeachTech-3000 (2,7 x 2,5 m)	These are the most logical locations when a separation unit will be mounted on the BeachTech-3000	BeachTech brochure			
B2	if the design will be an addition to the current BeachTech-3000, it should not hinder the emptying of the smaller 0,7m3 container into the larger container on top of the BeachtTech-3000	if the design will be an addition to the current BeachTech-3000, it should not obstruct the dumping of waste of the small container into the larger collection container. And cause damage to the BeachTech-3000	BeachTech brochure			
B3*	if the design will be an addition to the current BeachTech-3000, it is a which should use the PTO of the tractor to supply its energy. or use the hydraulics of the BeachTech-3000	if the hydraulics of the tractor can be used this would make the implementation a lot easier				

Code	Requirement	Source		
c1	The device should be operated from the tractor that is pulling the device or should work autonomously.			
c2	In case of jamming or other problems with the device it should notify the tractor driver, or clear the blockage by itself			

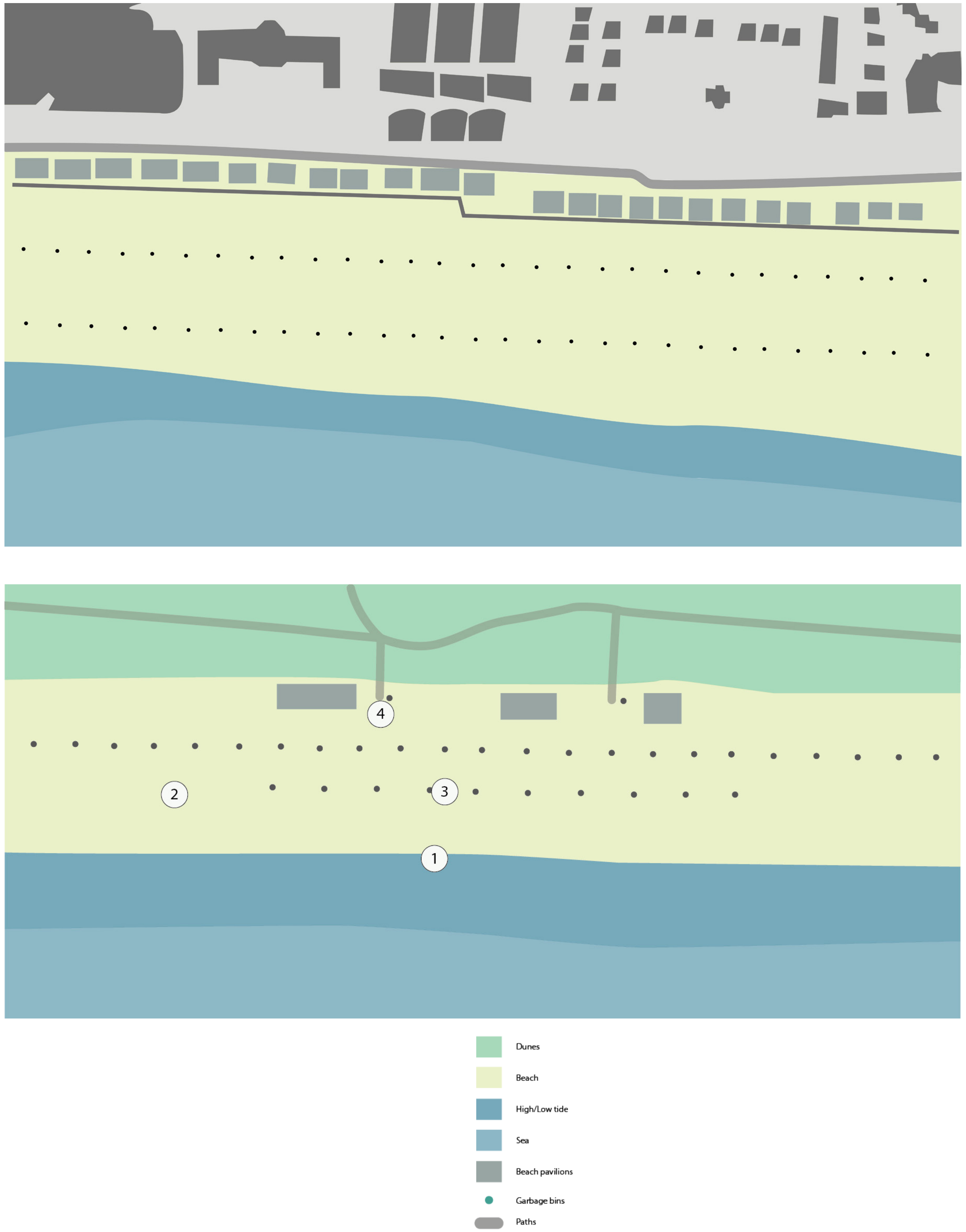
APPENDIX 2B PROBLEMS BEACHTECH-3000



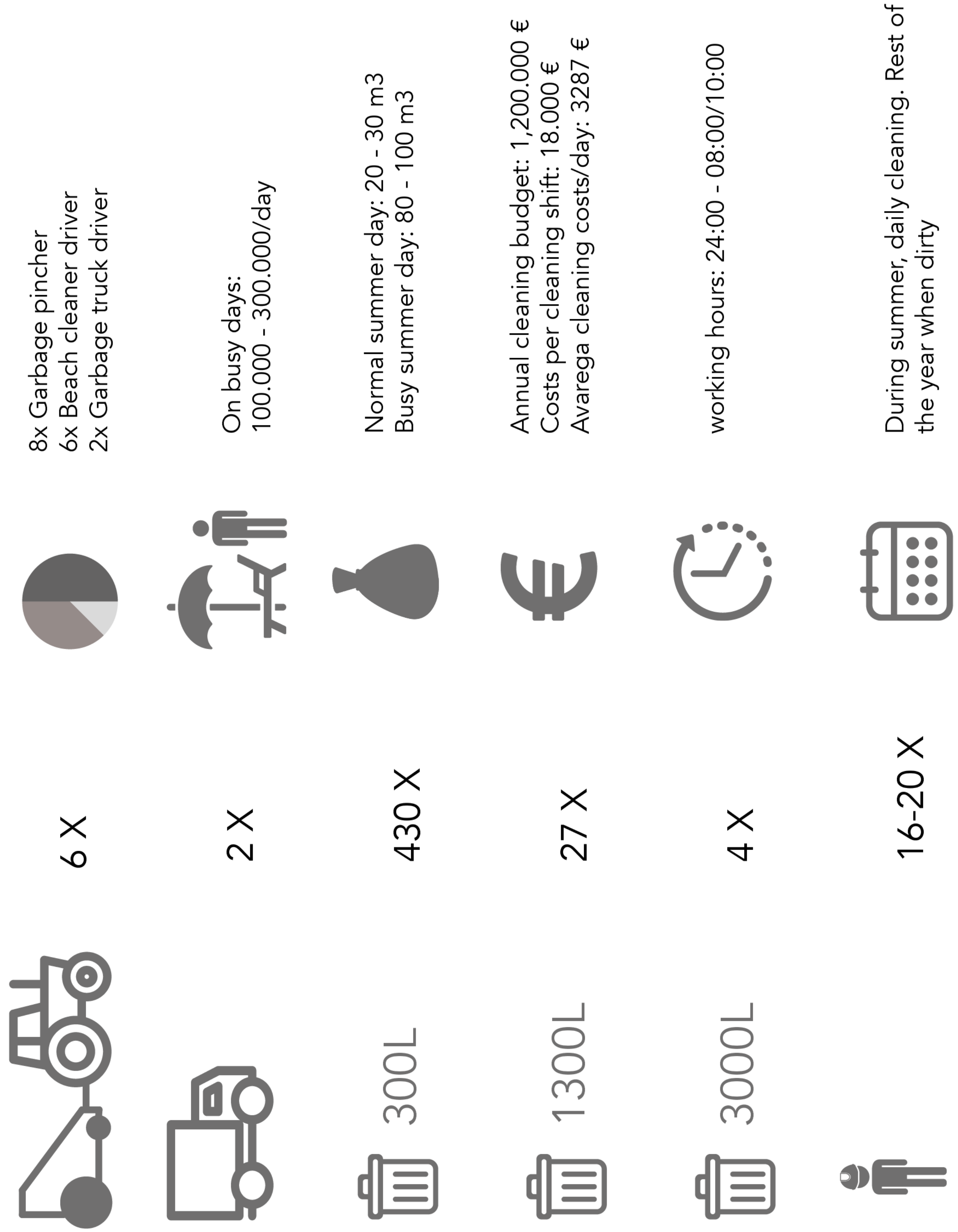




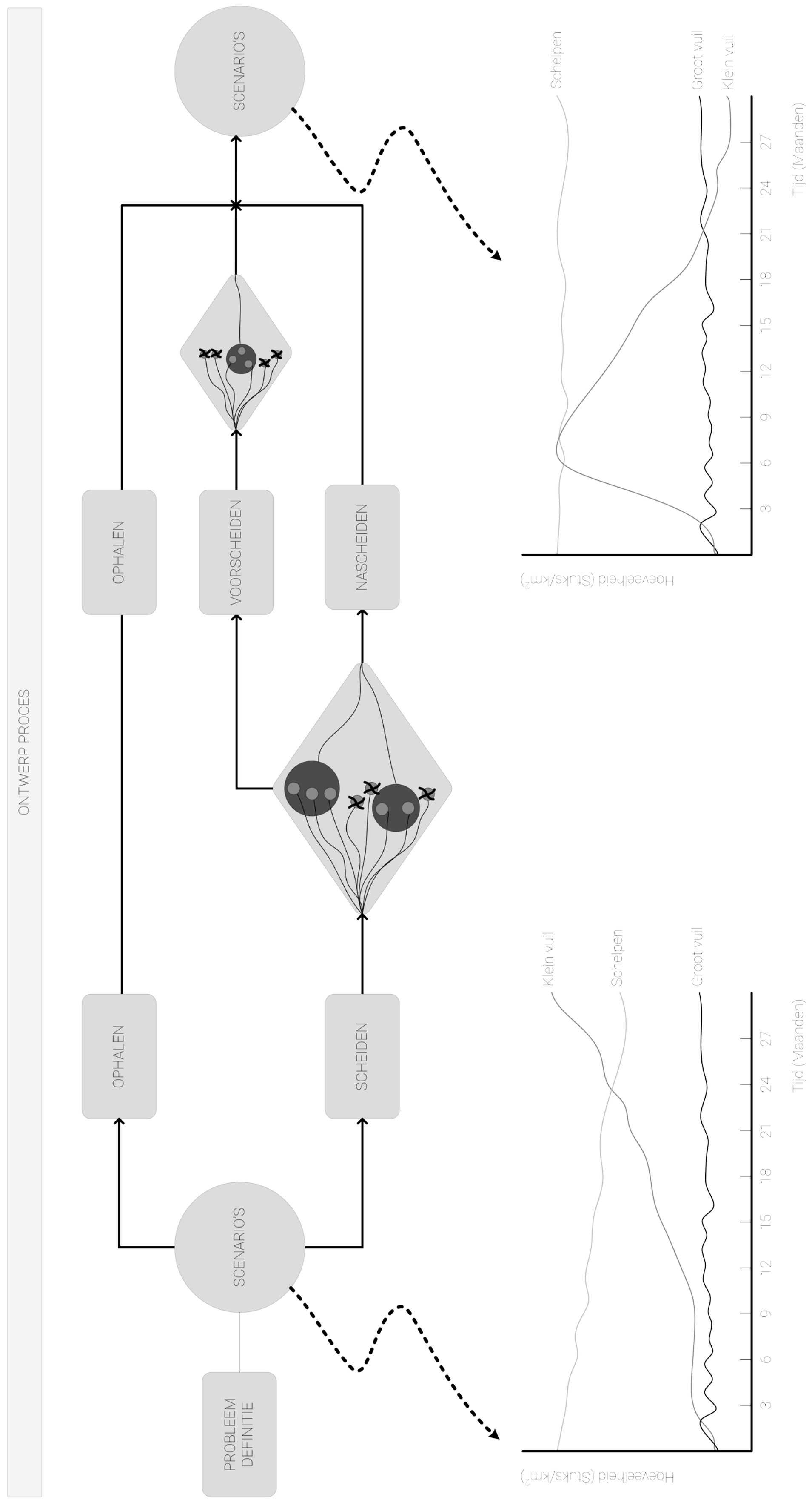
APPENDIX 2C MAPS OF THE HAGUE BEACH



APPENDIX 2D OVERVIEW CLEANING



APPENDIX 2E, ACCUMULATION OF MATERIAL AND PROCESS



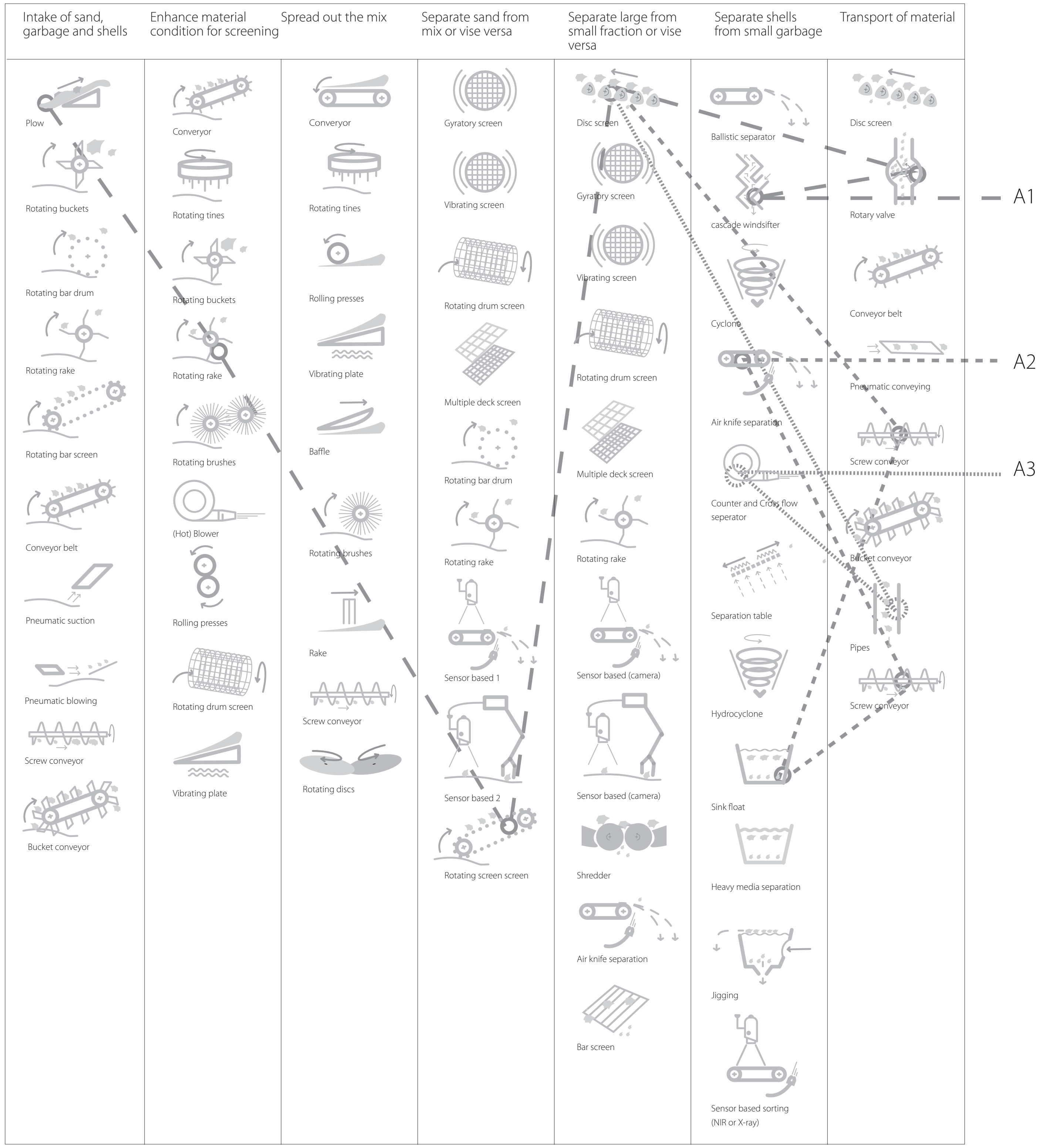
APPENDIX 2F, APPROPRIATE SEPARATION TECHNIQUES

Wind ziften
-Soortelijk gewicht-
-Grootte-
-Vorm-

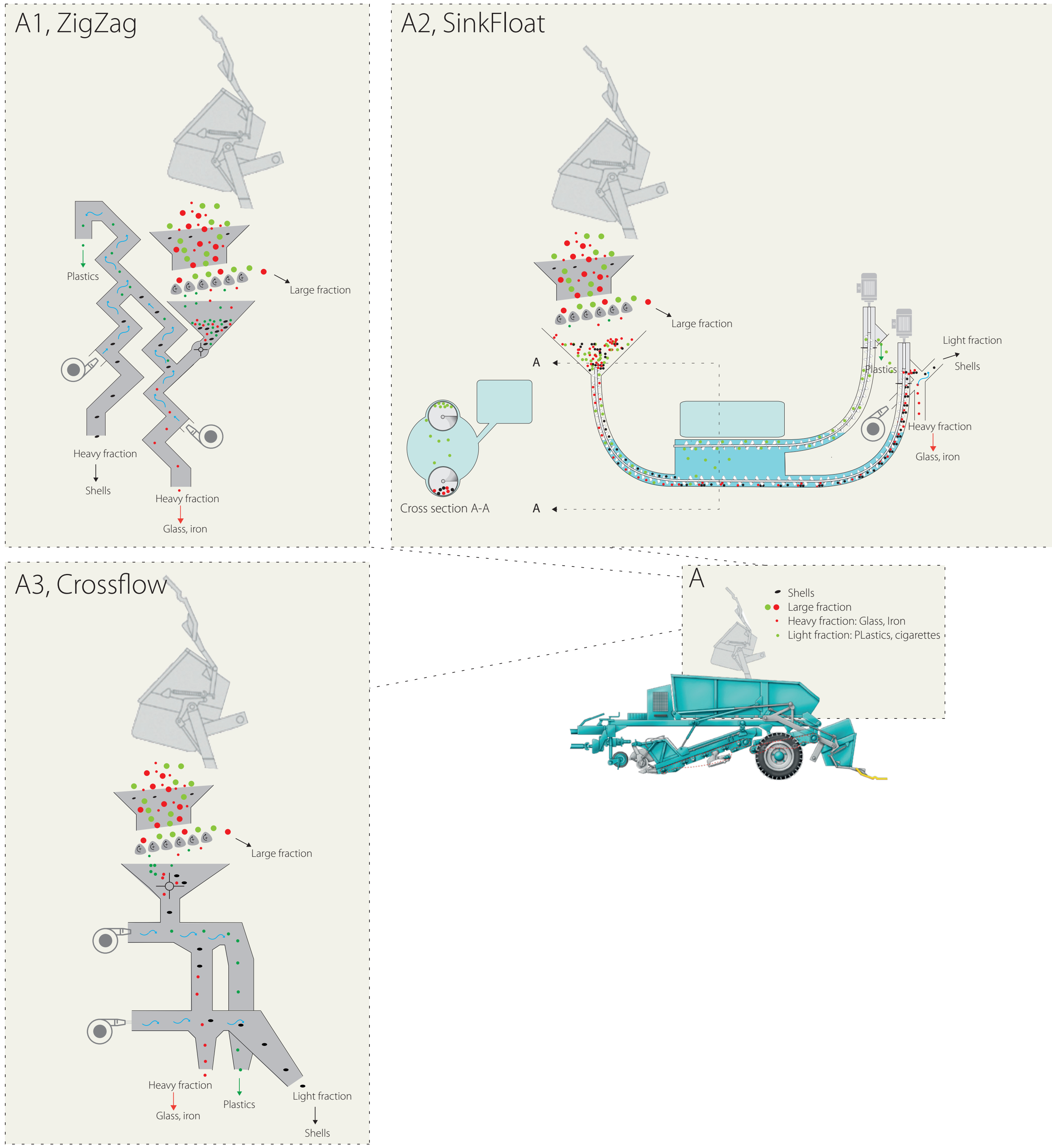
Bezinken
-Soortelijk gewicht-

Optisch scheiden
-Molecuul structuur-
-Dichtheid-

APPENDIX 2G, MORPHOLOGICAL OVERVIEW



APPENDIX 3A, IDEA SCHEMATICS



APPENDIX 3B, CONCEPTS