# AMPHITRITE BY AQUAX

Product report - MA4-ID7 - June 2018 - Rasmus Nielson & Rasmus Ringsholt Nielsen

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*Ill. 1.2. Team members*

# TITLE PAGE

| | |
|---|---|
| Title | Aquax |
| Theme | Weed cutting in lakes |
| Team | MSc04-ID07 |
| Supervisor | Finn Schou |
| Co-supervisor | Jørgen Kepler |
| Number of pages | 24 |

# ABSTRACT

The purpose of this project was to develop a product for maintaining water weeds, in and around lakes on golf courses.
Amphitrite is the result of combining the different user needs into a robotic lake mower. The product is robotic and self driving, to free up as much time for the green-keeper to do other tasks.

# TABLE OF CONTENTS



# ILLUSTRATIONS

All the illustrations in the product report is the teams except Ill. 1.7. which is obtained from Hørsholm Golf clubs webpage: https://www.hoersholm-golf.dk/job/

# INTRODUCTION

The greenkeepers whom maintain the golf courses take great pride in doing their work in preparing a perfect golf course for the players. Most golf clubs have limitations in terms of time and resources, and therefore prioritize which tasks that have to be done. Underneath, it can be seen in what order the different areas of the golf course are prioritized. It can be seen that the lakes are the area that is paid the least amount of attention towards. This is a problem due to how much time it takes a greenkeeper to get a well maintained lake.

"*On the area around the lakes that are part of the play area, it is desirable to have grass of fairway standard all the way down to the water surface*"

Danish Golf Union

*Ill. 1.5. Lake on Aabybro golf course*

# CURRENT METHODS

The current way of maintaining lakes is either by doing it manually or hiring contractors with bigger machinery. On the right page some of the different solutions can be seen. The top picture shows how a greenkeeper is doing it manually with a scythe. Underneath it can be seen how it is done by an excavator and what kind of damage it leaves.

*Ill. 1.7. Manually weed cutting*

*Ill. 2.7. Excavator damage*

*Ill. 3.7. Excavator damage*

# AMPHITRITE

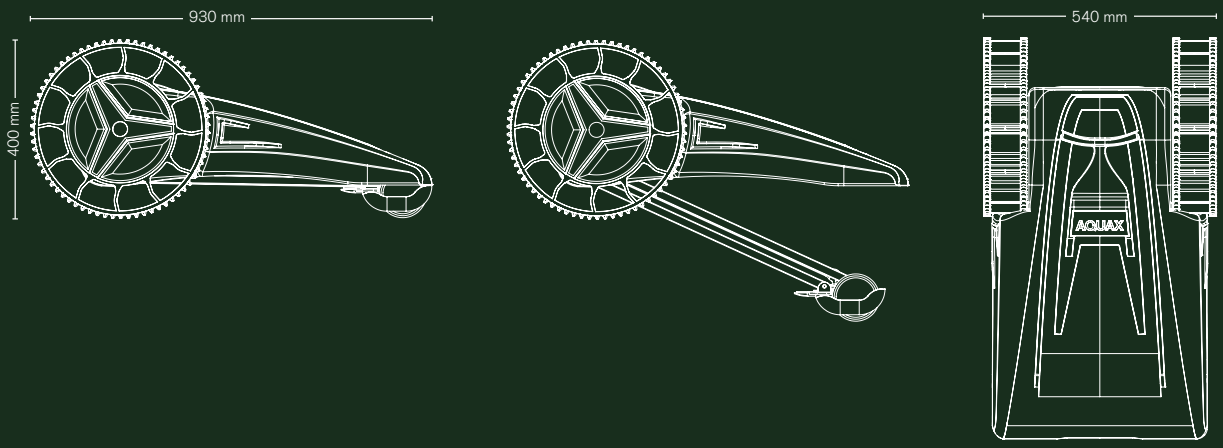
Is the solution for overgrown lakes. The robotic lake mower from Aquax is the ultimate product for the greenkeepers that strive for perfection. Amphitrite cuts all plants in and around the lake, leaving a picture perfect golf experience for the golf players.



*Ill. 1.8. Amphitrite*

# THE SOLUTION

Amphitrite solves the issue with unwanted plants in and around the lake.  The product is equipped with multiple sensors that ensure a fine cut and makes the product drive on its own, which is leaving time for the greenkeeper to do more important tasks on the course.
The big paddle wheels give Amphitrite its amphibious abilities making it agile on both sea and land.




*Ill. 1.10. Drawings of product*

*Ill. 1.11. Amphitrite*

*Ill. 1.13. Amphitrite*

# INTERACTION

The initial setup of Amphitrite is done on the computer, where the desired cutting area is appointed. After the initial setup the product just has to be activated close to the lake and it does the rest on its own.
Adjustments can be made on the 7 inch LCD display, located behind the protective cover.

*Ill. 1.15. Interaction with Amphitrite*

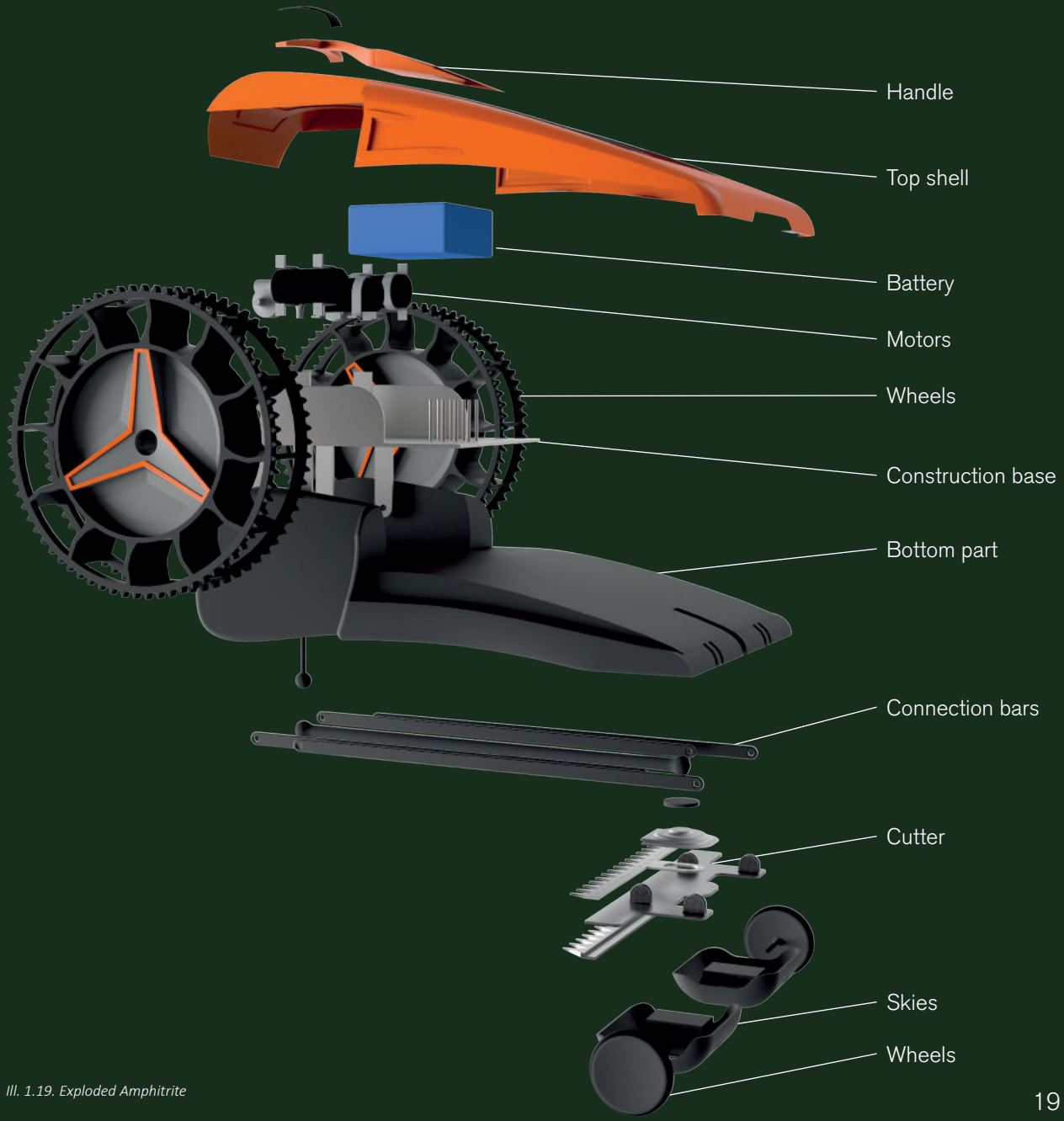
# THE CUTTER

The cutter is one of the most important part of the product as it is crucial it leaves a nice finish around the lake. The cutter is designed to follow the bottom in the water and on the ground. The cutter is equipped with replaceable industrial grade knives, that cuts down every obstruction.

*Ill. 1.17. Amphitrite*

# COMPONENTS AND SIZE

Amphitrite is the first of its kind, a robotic lake mower. One of the most noticeable things is its big paddle wheels. To spin the wheels powerful motors provide enough power to drive up 25° inclines. The battery on the product is a 12v 60Ah lithium battery that gives the product the ability to cut for 7 hours straight, in the roughest conditions.




*Ill. 1.19. Exploded Amphitrite*

# BENEFITS FOR THE GOLF CLUB

With Amphitrite the golf clubs do not only get a more aesthetically pleasing golf course, they will also be saving money.
On average it costs 18,000 DKK to have a contractor come and cut the weeds in just one lake. With a price of only 32,000 DKK for Amphitrite, the savings will be immense after just one year, depending on the amount of lakes, and the course will be better looking all year round.

*Ill. 1.21. Amphitrite*

# CONCLUSION

Amphitrite solves the issues of maintaining lakes, at a price that makes it a good investment for the golf clubs, while providing a more aesthetically pleasing golf course. Amphitrite is the first product of its kind, and there are many different areas where a robotic lake mower could be used: In the Netherlands to replace the weed cutting boats cutting the straight canals, in city parks, or in fishing ponds. The applications for a robotic amphibious mower seems almost endless.



*Ill. 1.22. Amphitrite from behind*


AQUAX

# AMPHITRITE BY AQUAX

Process report - MA4-ID7 - June 2018 - Rasmus Nielson & Rasmus Ringsholt Nielsen

# TITLE PAGE

| | |
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| Co-supervisor | Jørgen Kepler |
| Number of pages in the report | 97 |
| Total number of pages | 118 |

Rasmus Ringsholt Nielsen

Rasmus Nielson



*Ill. 1.3 Team members*

# ABSTRACT

The scope of this master is to design a solution for greenkeepers on golf course, to make maintenance of lakes less time consuming and at a lower price.

The currently solution for maintaining lakes on golf courses is that greenkeepers are using a mother scythe, in order to keep plants and weeds down. The task of using a motor scythe in water is a physical demanding task. A motor scythe is also a well known tool in the stream maintenance industry. Although the Danish Work Authority has started to give multiple stream workers from different municipalities injunctions to use this tool for cutting weeds while standing in water.
Even though the greenkeepers are cutting weed with the motor scythe, it is difficult for them to keep up with the regrowth of plants. Approximately once a year, the golf clubs have to hire contractors to remove plants and sediments from their lakes. This is done with excavators, which is expensive for the golf clubs. Besides the expenses, excavators on golf courses are not a good match, the big machines leave the green keepers with an enormous job of recreating the golf course.

This project started out concerning how a new tool for weed cutting in lakes could be designed, due to the fact that the unergonomic motor scythe is the only product used. A solution for the stream workers were presented. The response was that the solution was too complex, but they thought the solution would fit into the business of cutting weeds in lakes. The stream workers are already on the business, but only on a small scale, due to that the golf clubs do not always have the money to hire them.
A research of the market reviled a new and larger business opportunity, which the team took the advantages of.

Amphitrite is a amphibious robotic lake mower that can cut weeds in the lakes and the edges around it. This solution replace the traditional methods. Amphitrite is developed to run automatically without supervision, a GNSS module makes sure that Amphitrite always is on the desired path. The procedure for the greenkeeper is to move Amphitrite to the lake that needs to be cut, where the product will be activated and cutting the lake on its own.

# READING GUIDE

The project is divided into three reports.

1. A product report where the final solution is presented.

2. A process report, which describes all the steps the team have been through in order to get the final solution.

3. Technical drawings where the specifications and measurement of the product can been seen.

It is recommended to read the reports in the same order, as the report are listed above.

This is the process report, and consist of ten phases:

**Research, Ideation, Concept detailing, Research 2, Ideation 2, Concept development 2, Detailing, Business and Epilogue.**

As it can be seen there are some phases in green, these are from before the project was reframed. The focus in the start of the project was to find a new and more ergonomic solution for manual weed cutting in stream, as it described in the abstract. After a meeting with stakeholders it was chosen to change the context and problem area to how weed cutting can be done in golf lakes. The reframe is indicated in the process with a change in colour from green to orange.
The reason why it is chosen to keep the part from before the reframing, concerning weed cutting in stream, is because the team gathered much important knowledge throughout this period that evolved to demands for the finals solution.

To make it easier to understand the decisions that have been made, different types of summary boxes are used in the end of some sections:

| | |
|---|---|
| Information that is important to notice and remember |  |
| Information that need deeper investigating |  |
| User needs that are dragged directly into the House of quality where after they are transcribed to demands. |  |

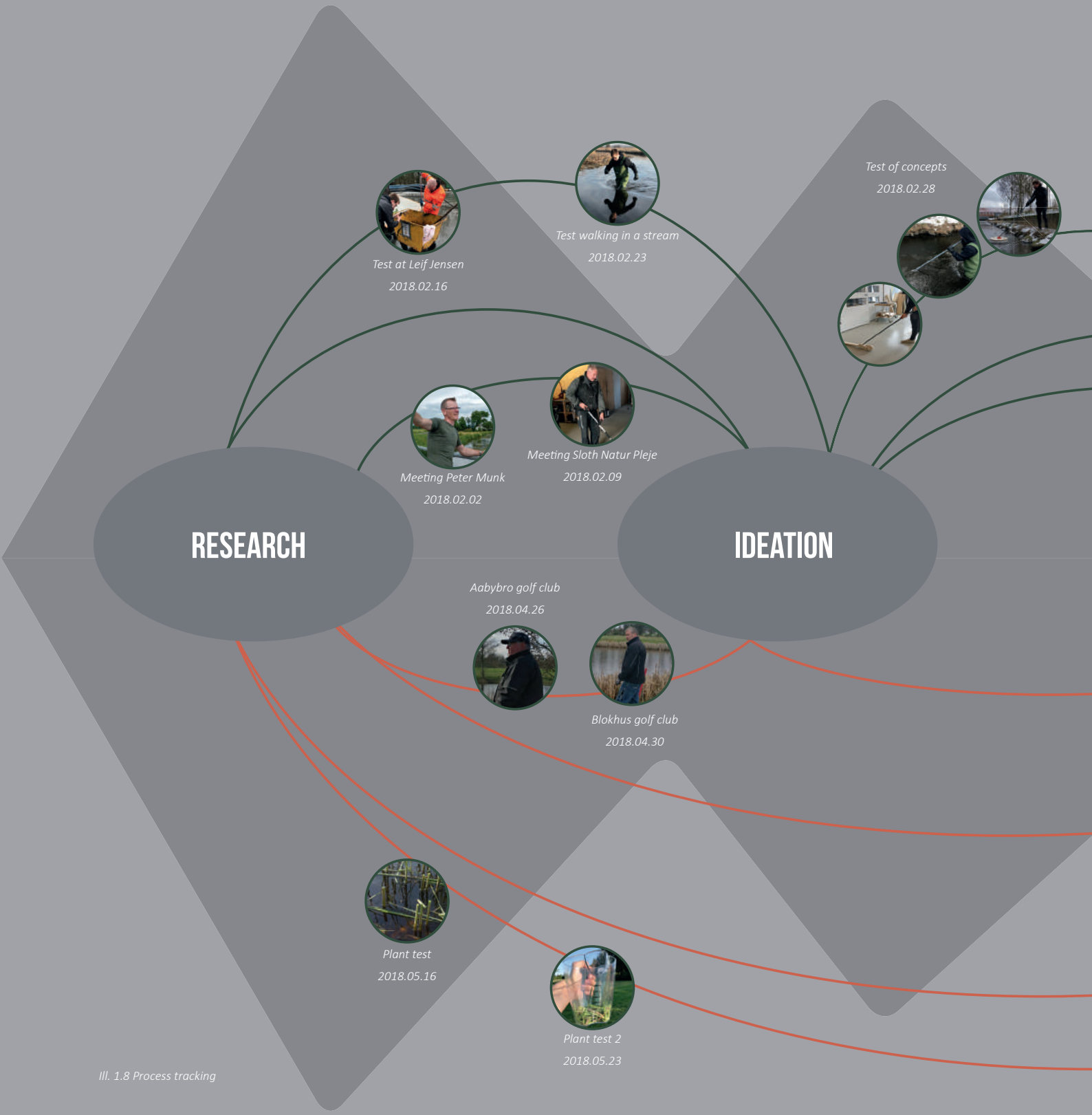
The Harvard method is used for references throughout all the reports “(author, year)”. All illustration and images are numbered like (Ill.X. [description of the illustration]).

# TABLE OF CONTEXT

# PROCESS TRACKING

On the model below all the interviews, models, and test that have been made can be seen in chronological order. The model illustrates how the team have been working iteratively between the different phases, jumping forward and backwards. The grey figure in the background illustrate how the solution space have diverged and converged.

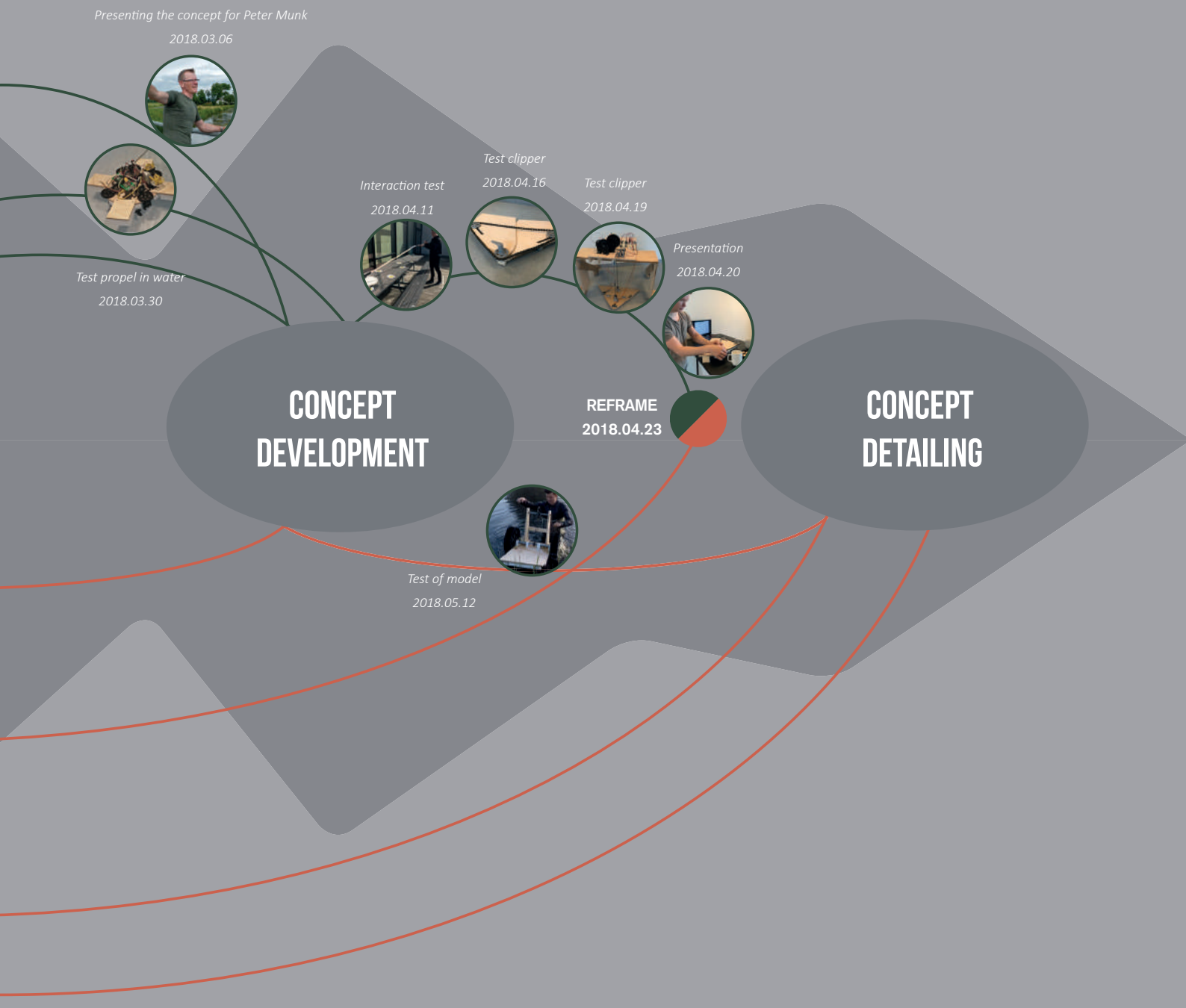
On the 23th April the scope of the project was reframed, as the colour shift from green to orange indicates. New research was therefore necessary in order to obtain new user needs for the new context.




*Ill. 1.8 Process tracking*

# APPROACH

Through the process the approach has been to incorporate stakeholders. From the stakeholders important user needs have been derived. The needs have been a guideline through the hole ideation. What is characteristic for this process is that each time an idea has seemed to fulfil a specific user need, the idea have been tested with a physical model. Even if the models managed to solve the problem or not, the psychical models have been an important tool, in order to gain further knowledge that could inspire to new ideas and opportunities.



# INTRODUCTION

In the abstract it is already reviled that this thesis ended up in a different area than it was intended when the project began, due to a discovery of a larger business potential.
In order to understand why the solution is designed as it is, it is necessary to go back to where the project began, concerning how it is possible to keep up with the increased amount of rain falling each year, which causes flooding.
The awareness of the importance of cleaning streams has been growing the past few years with more frequent floods destroying farmers crops and summerhouses. It is predicted that the weather will only become more extreme in the future. (Bjerregaard & Jarnvig, 2018) In Denmark at year 2081-2100 an increase of rain could be as much as 18% for the winter months. An increase of 18% may not sound like much, but on top of the regular rain fall the water table will raise resulting in flooding in low laying areas. (Ludwigsen, 2018)
The streams play a crucial role in leading the excess water out to the ocean. The streams ability to handle water is closely related to how well it is maintained, because an overgrown stream will quickly flood and create problems.
In Denmark there is approximately 70,000 km of streams, 28,000 km of these streams have regulations stating how they need to be maintained to ensure a good environment for the plants and fauna that live in and around the Danish streams. (Bach, et al., 2016)

Streams are divided into different categories regarding if it is the municipalities or private land owners that have to maintain the stream. 25% of the streams are under the maintenance of the municipalities, in the renaming 75% streams the private landowners have the responsibility to maintain them. The streams under the maintenance of private landowners is mostly small canals for draining fields or in areas with vacation homes. (Bach, et al., 2016)
The way each stream under the municipalities has to be maintained is defined in individual regulation. When flooding occurs conflicts often arise between the municipalities and people with damaged properties.

*Ill. 1.10 Flooding of field*

# FLOODING IN DENMARK

In 2017 the rainfall in Denmark was 849 ml/cm$^2$. In the last 150 years the rainfall has been raising with 100 mm, and it is expected that the increase will continue. (Jensen, 2018)

The increased waterfall cause flooding of fields, which can in some cases ruin the farmers crops. Most of the rainfall will evaporate when the rain hits the ground. A part of the rain will run to the stream and sewer and a smaller part will go directly to the ground water. Farmers drain their fields to avoid having their fields under water, the draining also help by lowering the water table. The drains leads the water out in streams, which increase the importance of having streams with a high flood water conveyance. (Jensen, 2018) To ensure high flood water conveyance the municipalities cut the vegetation in the streams. In Denmark the municipalities use 250 million DKK every year to maintain the streams. (melgaard, 2018)

The maintenance of the streams are subject to the watercourse law, Appendix A - Water course law, that among other things describe that streams can be used to lead water away, but it must be done in consideration to the environment.

Agriculture organisations and the liberal parties want to adjust the Danish streams so they accommodate the farmers needs and not the environment's. The agriculture organisations want an increased flood water conveyance in the stream, which they think an increased weed cutting effort will result in. Lars Peter Sørensen, an adviser from Lystrup, does not think that more aggressive weed will result in a higher flood water conveyance, and if it works it will only work in short term. He thinks that an increased weed cutting effort will cause a preferential treatment of fast growing spices as Sparganiaceae. When cutting the weeds of the stream the water level lowers, but with the better growth conditions for the Sparganiaceae family the water will be back to the original conditions after only few weeks, and then stream workers have to do the same procedure again. The removal of the water plants has environmental impact on the fauna. The amount of insects will be reduced, which reduce the amount of nourishment for fish and birds. Taken together the missing weed will result in decreased biodiversity. (Sørensen, 2018)

There are divided opinions about weed cutting, and its effect. By accommodating both parties interest in the future solution for weed cutting, the chances for a more successful product increase.

| | |
|---|---|
| Explore how a weed cutting product can accommodate farmers and the environment's need. | ?? |

# Research

*Ill. 1.12 Walking in stream*

# STRUCTURE OF STREAMS

To be able to design a product for maintaining streams and thereby limiting the chance of flooding it is important to gain insight in every aspect of the subject.
A stream is a rather complex ecosystem that does not need any human influence to maintain itself, but with requirements to flood water conveyance it is necessary. This is also why it can be difficult and requires experience to maintain a stream without disrupting the natural maintaining stream.

## Structure of a stream

Almost all the Danish streams have been altered by humans in the period from year 1850 - 1950, with the purpose of creating more land for agriculture. (Bach, et al., 2016) Even though they have been altered, most of the streams follow roughly the same path as they used to. This is a result of how streams form. In the lower areas, where the water table and the terrain are in the same hight, water will penetrate the ground and streams will form.
In Denmark the streams are generally small, shallow, and only with a small decline. This can also be seen in table 1.13.

| Variable | Mean | Min. | Max. |
|---|---|---|---|
| Stream width (m) | 6.9 | 0.6 | 30.0 |
| Stream depth (cm) | 54.4 | 7.5 | 167.0 |
| Water velocity (m/s) | 0.26 | 0.01 | 1.15 |

*Table 1.13 The Danish streams (Riis, Jensen, & Larsen, 2001)*

The information in this table is from 208 observations in 28 different stream systems from all over Denmark. It is noticeable how the mean depth is 54.4cm, even though the mean width is 6.9m.

I what size stream should the product be operational ?

## Plants in the stream

When talking about the plants in and around the stream they are divided into three different categories: Water plants, emergent plants, and riparian plants. The three different plant types are mostly different in the way they live.

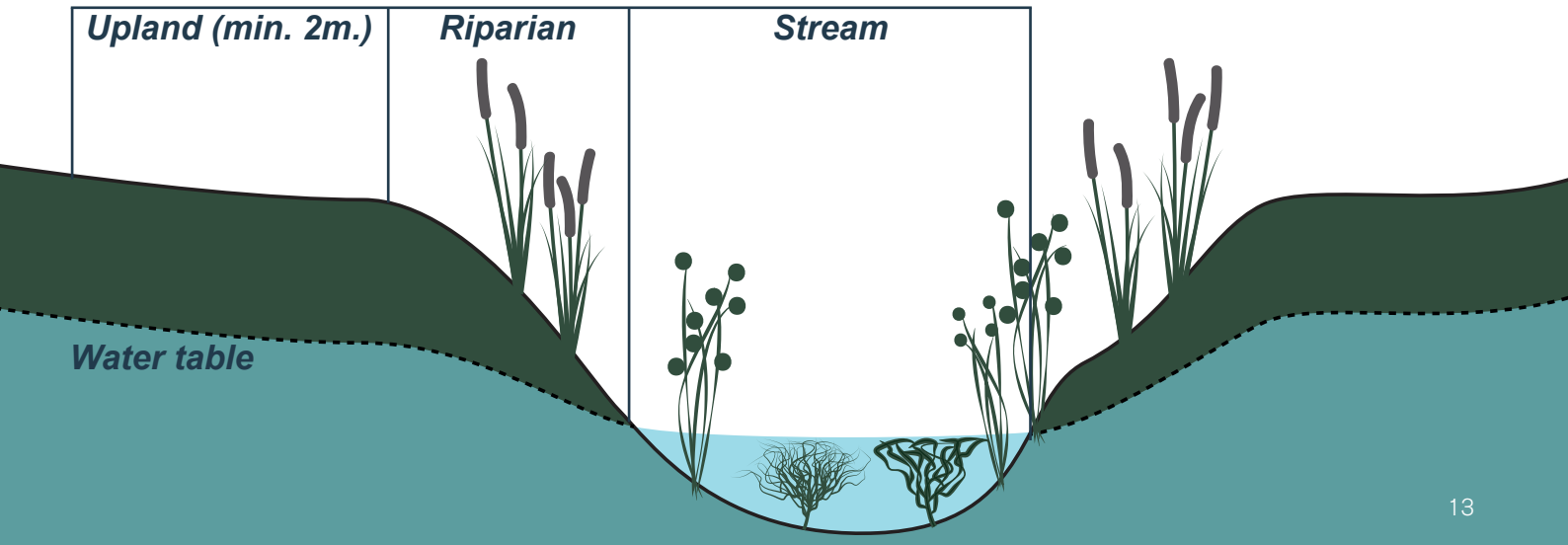
Water plants are the plants that are fully submerged under water and most of them can not survive being out in the open air.

The emergent plants are the ones that are growing in the sides of the streams, they have their roots fully submerged in water or just above the water line, while their stem and foliage raise up in the air.

The riparian plants grown on the sides of the stream where the soil is more dry. Some of the riparian plants can sustain periodical flooding. The riparian plant category is the one with the most diversity in species. (Moeslund, 2007)

The distribution of the three plant categories depends heavily on the size and shape of the stream.
In the smallest streams <1m the emergent plants and riparian plants dominate, almost no water plants can be found in these streams, due to the lack of the crucial sunlight reaching the bottom. If the smaller streams are in level with the surrounding terrain the emergent plants dominate, but if the stream is cut deep into the terrain the riparian plants will dominate. When the smaller streams have a width at <2m enough sunlight will reach the water to allow water plants to grow, but under natural conditions they will not be dominant.
In the bigger streams with a bottom width of 2-10m water plants almost always grow. As with the smaller streams the distribution of emergent plants and riparian plants depends on how low the stream is in relation to the surrounding terrain. If the water is cloudy or the depth exceeds 160 cm water plants will be rare because of the lack of sunlight reaching the bottom.
(Moeslund, 2007)

Cut on both edges and bottom ?




*Ill. 1.13 Structure of stream and plant habitat*

## Hydraulic resistance

The hydraulic resistance is an expression used to explain the effect water weeds have on the flood water conveyance. If the hydraulic resistance is increasing the flood water conveyance will decrease. (Moeslund, 2007)

The composition of water weed species and amount have influence on the hydraulic resistance. The different species effect on the hydraulic resistance is related to how the plants grow and how much they slow down the water. Some water plants are soft and are moving along the current, other water plants are growing in small bushes and therefore generate more hydraulic resistance. (Bach, et al., 2016)
With the knowledge of the influence of water weeds on the hydraulic resistance there is still other factors that influence the flood water conveyance. This is why that in some streams there are great variance in the relation between the flood water conveyance, the hydraulic resistance, and the amount of water weeds. (Bach, et al., 2016) (Moeslund, 2007)

A mathematical representation of how the water weeds affects the flood water conveyance can be seen in, Appendix B - Hydraulic resistance in streams. The result of the calculations show how much effect water weeds have on the flood water conveyance and how the effects are much greater on the smaller streams.

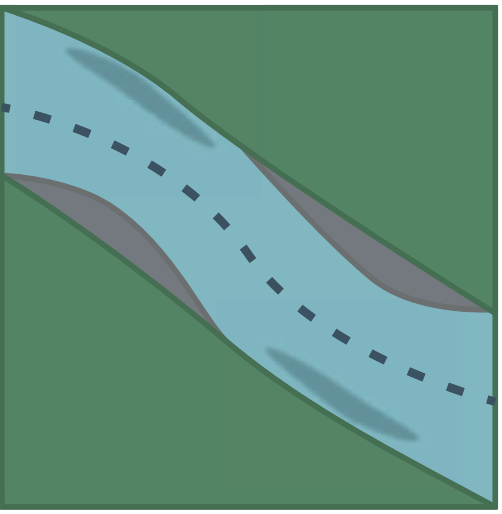
## Meandering in streams

The current in the streams is constantly flowing and the thalweg can change direction and power, depending on the season and amount of water in the stream. The thalweg is the part of the stream where the water velocity is the highest. The meandering is the curves a thalweg flows in.

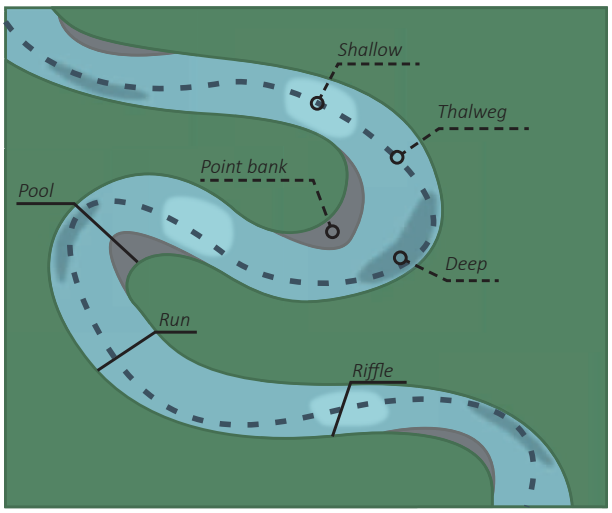
Meandering appears in all streams including straight canals. Nature will over hundreds of years depending on the conditions transform a straight canal into a naturally curved stream. The flow of the thalweg in a canal can be seen on Ill 1.14.
The shape of a more natural stream can be seen on Ill 2.14. The thalweg will still be changing the shape of this stream, because of the erosion appearing in the corners where pools occur, and where the water velocity is high near the edges. This erosion results in migration of the stream. The materials from the erosion settles further down stream on point banks where the water velocity is the lowest. (Moeslund, 2007)

Between the corners of the meanderings where the pools are occurring there is a section with run and riffle. The run is a part of the stream where the water flows evenly and the maximum velocity is in the centre, which can be seen on Ill. 3.14. The riffle is a part of the river where the water is shallow, which resulting in high water velocity. In the riffle there will often be a rocky bottom. Stones will sometime pierce the surface of the water in these sections of a stream. The rocky bottom appears, because the high water velocity in the shallow water is able to wash away the settling sediment. (Bach, et al., 2016) (Moeslund, 2007)

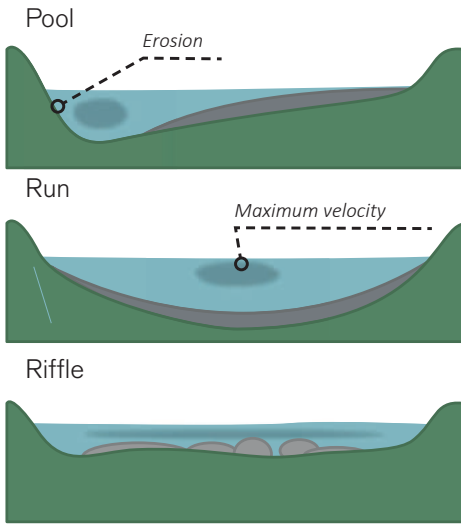
| | |
|---|---|
| Where in these sections of the stream does the plants grow | ? |
| How much does the stream differ in bottom depth and width | ? |



*Ill. 1.14. Flow of water in channel*




*Ill. 2.14. Flow of water in a natural stream*




*Ill. 3.14. Water velocity in stream*

# TOOLS FOR WEED CUTTING

Weed cutting can be performed in many different ways, Appendix C - Methods for weed cutting . Depending on the stream and the stream workers´ preferences different tools can be used. In this section tools for weed cutting will be explored and advantages and disadvantages will be explained in light of knowledge gained through literature.

## Scythe

In decades stream workers have used a scythe for weed cutting. A scythe is a phenomenal tool that stream workers easily can manoeuvre.

The stream worker walks in the stream with the scythe, to cut the weed. During the process the stream worker can choose which plants he wants to remove and which ones he wants to keep. It requires experience to do selective weed cutting.

A second stream worker is removing all the cut off by throwing it up on the riparian with a pitchfork. The cutting is preformed upstream, so the cut off float down to the person with the pitchfork. The process of cutting the weeds with a scythe and removing it with a scythe is time consuming and hard labour. (Sloth, Moeslund, & Marcus, 2008)

*Ill. 1.15 Scythe*

## Motor scythe

A motor scythe is a substitute to the traditional scythe. The motor scythe reminds of a combination of a weed wacker and a hedge trimmer. The motor scythe and scythe are both refereed to as manual tool in the weed cutting industry.

A motor scythe is not made for cutting in the bottom, because the blade is sensitive to sand and gravel. The blade does not just become blunt, there is a risk that the gravel will jam the blade and damage the motor. When using a motor scythe the weed is therefore, cut at a hight where specific plants have good conditions for quick regrowth.

In some streams it is necessary to cut the weed on the riparian above the water, in this case a motor scythe is a great tool.

The motor scythe have the disadvantages that it shatters the weed when cutting it, which make it difficult for the stream worker to remove the cut off with a pitchfork. Another disadvantage, when the weed is shattered, is that some plants like water thyme has the ability to regrowth from a small cutting. (Sloth, Moeslund, & Marcus, 2008)

*Ill. 2.15 Motor scythe*

## Dredging bucket

The dredging bucket is the most common tool used for weed cutting. A dredging bucket is attached to an excavator. The dredging bucket cut the weed and at the same time it removes the weed from the stream. The dredging bucket is wide to ensure efficiency, but it make it hard to cut the weed selectively, which aggravate environmental weed cutting. Even for an experienced machine operator it can be a difficult task to distinguish between the different spices, due to a long distance from the driver cap to the stream, especially in streams that are cut deep into the terrain. (Sloth, Moeslund, & Marcus, 2008)

*Ill. 3.15 Dredging bucket*

## Weed cutting moped

A weed cutting moped is a tool for weed cutting in smaller and medium sized streams. The weed cutting moped reminds of motor scythe that is floating. The weed cutting moped floats on two pontoons, which can be seen on Ill. 5.15. How low the knifes go down in the water can be adjusted by the stream worker man-

*Ill. 4.15 Weed cutting moped*

ually. The weed cutting moped is uncommon and not described fully in any paper.
(Sloth, Moeslund, & Marcus, 2008)

## Weed cutting boat

A weed cutting boat is used in medium sized and big streams, because of the required water level. The boat is equipped with a cutter that reminds of the cutter that can be seen on the weed cutting moped on Ill. 5.13.
Some boats also have a cutter attached to the side, so the boat are able to cut the emergent plants at the same time. A weed cutting boat is good at making the normal thalweg cutting, but the more environmental combined thalweg cutting is not possible due to the wide cutter and the boats manoeuvrability. (Sloth, Moeslund, & Marcus, 2008)

*Ill. 1.16 Weed cutting boat*

## Sum up

The different tools for weed cutting have their advantages and disadvantages.
In a report from the Danish ministry of environment it states:

***"When you look at the spectrum of tools for weed cutting, it could be desirable with new tools or redesigns for the existing solutions"***
*(Sloth, Moeslund, & Marcus, 2008)*

It clearly indicates that there is a market for a new tool that can perform selective weed cutting and possibly replace the need for manual weed cutting in the smallest stream.
The manual tools are psychically demanding and in most cases the motion is monotonous. When developing the future solutions it is crucial that the product limits or removes the physical strain for the user.
A redesign of the dredging bucket that is able to do selective cutting and is suitable for smaller streams can be a possible solution to replace the need for manual work in some of the smaller stream.

When preforming the Aalborg method it is necessary that the tool used for weed cutting is able to cut very close to the bottom. The current tools on the market are expensive to maintain when preforming the Aalborg method or not able to perform it. Because of the high maintenance cost on the equipment new ways of cutting weeds needs to be explored to possible find solutions that will lower the cost.

| | |
|---|---|
| The product must be able to cut selective |  |
| Explore other methods of cutting water plants to limit the maintenance cost | ?? |
| Why is the weed cutting moped not a more common tool for weed cutting | ?? |

## SUMMARY OF DESK RESEARCH

The research revealed two problem areas within weed cutting:

1. Work environment problems in the smaller streams when using manual tools
2. Selective weed cutting of plants when using the dredging bucket.

Both of these problems are related to tools used for cutting weeds in smaller streams. Therefore there is a possibility that by solving one of the problems the product will also be solving the other.
To verify the different problem areas contact to experts and stream workers will need to be established.

# MEETING PETER MUNK

A meeting with Peter Munk from the environment- and energy department of the Aalborg municipality was established in order to discuss the two initial problem areas:

1. Work enviroment problems in smaller streams when using manual tools.
2. Cutting selective with the dredging bucket

Peter is an environmental technician. His job is to ensure the maintenance of streams in and around Aalborg. The environment- and energy department in Aalborg uses contractors to do the maintenance of streams. Peter and his colleagues mainly coordinate the contractors and inspects their work. With the experience Peter has, he knows exactly which contractors to use at the different streams and what directions they need to have to do their job to Peter's satisfaction. A part of Peter's job is to form the regulation that states exactly how each stream is supposed to be maintained, and which tools to use.

## The Aalborg method and selective weed cutting

Peter Munk has been a big part of developing the Aalborg method, Appendix C - Methods for weed cutting. Peter and a dedicated contractor, Lars from Sloths Entreprenør & Naturpleje, have been developing the method for years and they have been perfecting it from year to year. Peter talks about how it has changed streams from being dominated by reed sparganium to clearing a path with the thalweg cutting to make space for rocks and water plants, which are crucial for fish. The way they made it possible was by altering the equipment on the weed cutting boat to cut down in the roots of the Reed Sparganium. This idea has been in Lars´ head for several of years, and together with Peter they started testing the effect of cutting aggressively in the bottom. The weed cutting boat was a good tool in the beginning, but after the natural rocky bottom was revealed and water plants started growing the weed cutting boat is too rough a tool. With the wide cutter and difficult manoeuvrability it makes it almost impossible to make selective cutting.

Peter has the responsibility of maintaining many different streams and managing a budget of the maintenance cost, he has to decide which streams he wants to pay extra attention to. Peter has changed many streams in Aalborg from being maintained manually to being maintained by the dredging bucket. It is surprising that peter is a proponent for the use of the dredging bucket, but he states the importance of responsible and experienced machine operators. Peter knows what limitations the dredging bucket has, but in most of the smaller streams in Aalborg the dredging bucket is able to create a good water environment for plants and fauna.

## Manuel weed cutting

When Peter talked about manual weed cutting he refereed to a case from Rebild municipality. In Rebild they have their own stream workers, but they have gotten an injunction from The Danish Work Environment Authority of doing manual weed cutting more than a few days in a row. This injunction is only affecting the stream workers from Rebild municipality, but it is not unlikely that it will spread to every other stream worker in Denmark.

*Ill. 1.17 Peter Munk*

Peter only hires contractors for manual stream cleaning when it can not be done with a machine, or in special streams like Binderup-å where extra care is used to make the stream attractive for fishermen.

***"Everything that can be done with a machine should be done with a machine"***

*Peter Munk*

The streams that are not accessible with an excavator are often forest streams, but the amount of weeds is also limited in these streams, because of the shadow from the tress. Peter also states that it is not only the operation of the motor scythe that is exhausting, but also just walking in the stream is a problem.
Other municipalities use the manually weed cutting in streams where they want to increase the environmental conditions, but these streams often have a deep layer of mud making it even more exhausting for the stream worker. Peter states that if a new tool for manual weed cutting was designed, it will be important that the product is easy to transport from the car to the stream, without using an excavator.

## Sum up

Peter expressed that there are problems with the work conditions for the manual weed cutting. If the stream is suitable for use of machines Peter would prefer that to spare his contractors even though the manual weed cutting creates a better result.
It was surprising that Peter had such an positive attitude towards bigger machinery, which the team initially thought were the root of the environmental problem in the Danish streams. Peter was sure that a person with a scythe could do as much damage to the environment as a big machine, and said that it all depended on the operator of the scythe or the machine.
To get a better understanding of the tools and to meet people that work in the stream Peter introduced the team to his main contractor Sloths Entreprenør & Naturpleje.

| | |
|---|---|
| Find information about the injunction issued by the The Danish Work Environment Authority | ? |
| The product needs to be able to cut close to the bottom | |
| Solution for the exhausting task of moving in streams, especially upstream or in muddy streams | |
| Easy transportation from car to stream | |

# SLOTHS ENTREPRENØR & NATURPLEJE

After the meeting with Peter Munk his main contractor Sloths Entreprenør & Naturpleje was contacted, and a meeting was arranged.

Sloths is based in the northern part of Jutland and has clients from most of the surrounding municipalities. They have around 15 employees and have the responsibility of maintaining approximately 1,800km stream. They use the stream cutting boat and the dredging bucket most, but they use the motor scythe for special assignments. They maintain roughly 800km with the weed cutting boat, 800km with the dredging bucket, and 2-300km with the manual motor scythe. The two owners, Lars and Ole, do not take the public procurement on the manual tasks, they only take them if it is necessary to land a bigger contract. Sloths have gotten an injunction from the Danish Work Environment Authority against using manual tools, without rotating between tools and personnel. Lars and Ole shares Peters view regarding, everything that could be done with a machine should be done with a machine.

## The Aalborg method

Lars has been preforming the "Aalborg method" for many years, but the quality of the method was first appreciated by Peter from Aalborg municipality. Together they have developed the method further and tried to convince the rest of the Danish municipalities that the method is better for the streams.

There is a division in Denmark where some people and environmental originations think that cutting near the bottom destroys the bottom of a stream. Then there is Lars and Peter that have seen how this seemingly rough method actually can remove the mud in the bottom and create a bottom filled with rocks and gravel, which is crucial for fish and diversity in plant life.

The Aalborg method works by tilting the cutter down and cutting the plants near their roots slowing their regrowth. This method is very rough on the equipment and Sloths often break teeth on the cutter. He explained that before they started cutting close to the bottom they broke around 100 teeth per year now they break around 2,000 on the dredging bucket and weed cutting boat.

## The dredging bucket

Sloths Entreprenør & Naturpleje are cleaning around 800km stream each year with the dredging bucket. It is their preferred tool for the smaller to mid size streams. Lars states that the dredging bucket is challenged in the smallest streams where the width of the thalweg cutting is under 50 cm, which is smaller than the width of the dredging bucket. When using the widest 4 meter dredging bucket in a stream with a steep decline they also have the problem that in one end they are digging in the bottom, which is against the regulations and in the other end the plants might be cut too high. This problem is easily solved by using a more narrow dredging bucket but it will then be less efficient.

*Ill. 1.18 Lars Sloth showing of the motor scythe*

## Weed cutting boat

One of the biggest problems with the boats is keeping their weight down. This is why Sloths have 16 different boats for specific situations. They have boats, which they do not use anymore that could cut sides while cutting the bottom, but it has a weight around 3 ton while their normal boats weigh around 1 ton. The weight makes the boats lay deep in the water making it easier to get stuck in narrow water at the riffles or at point banks.

## Manual weed cutting

Sloth was a family business where they have always been working with the scythe, but after Lars became leader they have been shifting their focus on using big machinery to reduce the amount of hard labour. They still have some streams they maintain with the motor scythe, but it is becoming less. Sloths have also gotten the injunction from The Danish Work Environment Authority, so they can only work with the same tool for a limited time. Lars thinks that this injunction almost does more damage than good, due to his experience with a season of manual stream cutting, only the first two weeks are hard and then it becomes a good workout for the body.

Another part of the problem is the competition and reduction of the pay, in year 1980 they got 8 DKK/m and now they get around 4 DKK/m. Lars states that the change in pay makes it hard to make a living while taking care of the body.

*Ill. 2.18 The teeth on the weed cutting boat cutter*

## General though on the problems

Lars did not really highlight the problem with selective cutting, while using the boat nor the dredging bucket like Peter Muck did, but Lars had more focus on efficiency and keeping the cost down.

The problems that Lars and Ole could see were mainly related to the manual weed cutting in the smallest streams where the dredging bucket is too big. They talked about how they had not tried the weed cutting moped. Though, they could see clear limitations like, it being too big and clumsy for the smaller streams the weed cutting moped it targeted for. The problem with the weed cutting moped is that it is in few streams it fits, because streams often change in width and depth. Nevertheless they could see the potential in designing a product that the stream worker does not need to carry or swing around.

Lars explained that other countries also cut the weed in their streams, but it is primarily the dredging bucket that is used.

## Sum up

Sloths Entreprenør & Naturpleje does not take jobs in streams that must be done with manual tools, because The Danish Work Environment Authority do not accept the methods they have used to maintain the streams manually. Sloths has a big expense on the maintenance of their equipment, especially the replacement of the damaged knifes as a result of the Aalborg method. The injunction they have received will have to be examined to get demands to what to avoid in the future product.

| | |
|---|---|
| The dredging bucket need to be able to cut narrow streams with a desired thalweg cutting of >50 cm | ✓ |
| Find cheaper cutting methods | ✓ |
| Manual tool must be more efficient than existing solutions | ✓ |
| Explore market potential in other countries | ? |

# INJUNCTION ON MANUAL WORK

The injunction that Sloths Entreprenør & Naturpleje received from The Danish Work Environment Authority was examined, to find out what it stated as the problems with the current way of manual weed cutting. The injuntion can be seen in Appendix D - Injunction.

***"The company is demanded to ensure that work on pruning and maintenance of streams is planned and organized, so that it can be carried out in all stages with focus on safety and health..."***

*The Danish Work Environment Authority*

The injunction is based on observations by two supervisors from the The Danish Work Environment Authority of Sloths Entreprenør & Naturpleje preforming weed cutting. They observed how two stream workers were working, one person with the motor scythe cutting weeds and another person with a pitchfork throwing cut off up on the riparian. The stream workers had their arms extended and raised, and sometimes their arms raised above the head. They also bend in their backs, especially when they cut in the bottom of the stream. The muscles used for the two different tasks are also the same, shoulder and back muscles. The changing bottom conditions requires the motor scythe operator to focus to not fall over.

The motor on the motor scythe weights 10.3 kilo and the shaft approximately 3 kilo, the two streams workers switch positions every hour. The worker with the pitchfork is removing 5-10 kilo of weeds with each shovelful and it has to be thrown up in a hight of 10-200 cm, depending on the riparian.

On a 8 hour work day the stream workers are pruning and removing of water weeds for around 5.5 hours, while the rest of the time goes with transportation, breaks, and refuelling.

| | |
|---|---|
| The product should not apply any direct weight to the stream worker | ✓ |
| The product should not rely on the stream worker to work with their arms extended from their body or with the back bend | ✓ |
| The product should be able to run 5.5 hours a day | ✓ |

*Ill. 1.19 Two stream workers*

# NIELS OLE KRINGELHOLT

To uncover if stream workers from different municipalities have the same problems, Niels Ole Kringelholt from Hjørring municipality was contacted. Niels Ole is the leader of the department for stream workers in Hjørring and has years of experience himself with work in the stream.

## Weed cutting moped

Niels Ole told that in Hjørring the stream workers have used the weed cutting moped before, but do not use it anymore. They do not use the weed cutting moped, because it was only suitable for a few streams. Furthermore, Ole explained that the moped had technical issues. The knifes for example had the problem that they could not get close enough to the bottom. The weed cutting moped was very heavy so it was difficult for the stream worker to get the weed cutting moped up and down of the stream. The weed cutting moped was in certain situations able to cut the weed fast, but that was tiresome for the person behind that had to remove all the weed from the stream. Ole strongly recommended if our idea is to create a product in the lines of the weed cutting moped, it must be able to remove the cut off from the stream.

## Manual tools vs. machinery

In Hjørring municipality the stream workers still use manual tool like a motor scythe for around 50% of the streams. The other half is executed by boats and dredging bucket. When there is a need for a dredging bucket, Hjørring municipality outsourced the task to subcontractors, because Hjørring municipality do not have their own excavators with dredging buckets. Niels Ole explain that it is not possible for them in many streams to gain access with an excavator, due to the trees next to the stream.

Another issue for the stream worker is if they use a dredging bucket in untouched twisted stream, the wide bucket will straighten out the stream, which is bad for the streams' ecosystem.

Niels Ole also explain that it is more expensive for them to use a dredging bucket instead of manual tools, which is different from what Lars explained. In Hjørring municipality they pay 5 DKK/m for contractors with dredging buckets, and only 3.5 DKK/m for their own employees doing manual work. However, a pair of stream workers with manual tools must be able to cut 1,200m weed a day before the estimation of 3.5 DKK/m is valid. All streams where the bottom is muddy, and the water level reaches over the navel, they have chosen to use the dredging bucket in, because the stream worker can not move fast enough and gets exhausted.

Niels Ole supports Peter Munk's statement that an educated and experienced machine operator can preform environmental weed cutting with a dredging bucket, but Ole does not think that the demanding manual labour will harm the stream workers he argues that it is healthy. In Hjørring the work routine is that they are two workers in the stream, but they maximal use the motor scythe 2.5 hours a day because of the vibrations, which means they maximal work in the stream 5 hours per day. The motor scythe can run 45 minutes on one tank of fuel before it has to be refuelled. Every time they refuel the motor scythe they switch position.

## Sum up

It was surprising that in Hjørring municipalities they used manual tools equal to how much they used machinery to maintain the streams. Ole expressed how important it is not only to have a tool that can cut the weed fast, the tool also needs to be able to remove the weed from the stream.

Another important aspect is that it need to be considered how the product deals with changing depth in the stream and the changing bottom.

| | |
|---|---|
| The weed cutting moped is too big and clumsy | !! |
| The product needs to be light and agile to access the smaller streams. | |
| The tool must be able to cut a depths at 100-900 mm | |



*Ill. 1.20 Background illustration*

# MARKET POTENTIAL

It is clear that a new weed cutting tool has potential in Denmark. To discover the full market potential a research of the weed cutting industries in other countries has been made. The countries that were looked into was Netherlands, Germany, England, and USA.

Weed cutting in stream is a task that is preformed in all the countries. The most common tool that is used is the dredging bucket.

Environmental weed cutting is a concept there is mentioned many times in the literature, and while talking to stakeholders. Not a single time while researching for weed cutting in other countries was it questioned if the dredging bucket was to the detriment of the environment. In multiple articles from USA was in recommended just to use poison to kill plants in streams (Everest, 2004)]. In spite of no finding about the dredging bucket negative side effects, several fishing club web-pages from England were found, showing pictures of people removing weed manual from streams. (Riverworks, 2004)

In the Netherlands the dredging bucket is also very popular. A law were found about that in several region in the Netherlands the house-owners are bounded to do weed cutting if they live near to a stream. It is assumed that not everyone want to have a dredging bucket in their back garden. (agv, u.d.)

| | |
|---|---|
| Further market research need to be conducted | ? |

*Ill. 1.21 Background illustration*

# Ideation

# INITIAL PROBLEM AREAS

Two problems were uncovered in the desk research. The two problems were discussed with different stakeholders in order verify the problems. The problems were verified to be the most common problems.

The two main issues for the two exciting solutions are:

- Size of dredging bucket
- Manual weed cutting and removal of weed

## Size of dredging bucket

The size of the dredging is comprised of two sub problems. The problem Peter and the Danish ministry of environment explained with making selective weed cutting with the bigger machinery, and the problem Lars and Niels Ole explained with the size of the dredging bucket making it too big to make thalweg cutting in the smallest streams.

## Manual weed cutting and removal of weed

Cutting the weed is demanding work. The motor scythe is heavy to carry around at the same time the vibrations makes the work tiresome.

The way of removing the weed now is a stream worker using a pitchfork to remove it. Niels Ole and Lars explained how just moving in the stream is physically exhausting, and the monotonous movement in the upper body of removing the cut off weed is one of the reasons why the Danish Work Environment Authority made the injunction against Sloths Entreprenør & Naturpleje and Rebild municipality.

A list of user needs were compiled for each problem, which will be the guidelines for the future ideation.

| User needs |
|---|
| **Scythe and motor scythe** |
| The product must be able to cut selective |
| The product needs to be able to cut close to the bottom |
| Solution for the exhausting task of moving in streams, especially upstream or in muddy streams |
| Easy transportation from car to stream The product should not apply any direct weight to the stream worker |
| Find cheaper cutting methods |
| Manual tool must be more efficient than existing solutions |
| The product should not apply any direct weight to the stream worker |
| The product should not rely on the stream worker to work with their arms extended from their body or with the back bend |
| The product should be able to run 5.5 hours a day |
| The product needs to be light and agile to access the smaller streams. |
| The tool must be able to cut a depths at 100-900 mm |
| **Dredging bucket** |
| The product must be able to cut selective |
| The product needs to be able to cut close to the bottom |
| The dredging bucket need to be able to cut narrow streams with a desired thalweg cutting of >50 cm |
| Find cheaper cutting methods |
| The product needs to be light and agile to access the smaller streams. |

*Ill. 1.23 Background illustration*

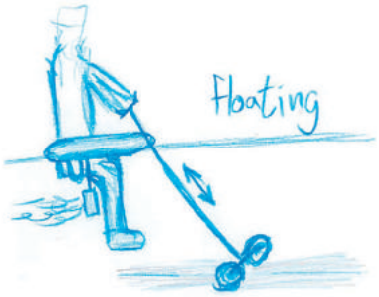
# INITIAL IDEATION

The purpose of the initial ideation round was to come out with different immediate ideas and thoughts that have been forming during the interviews and research phase. The sketches were on this point not build on demands, but were used as tool to reflect upon inputs and problems that stakeholders had expressed.
In this section selected sketches will be showcased and the thoughts behind each sketch will be explained.

## Manual weed cutting

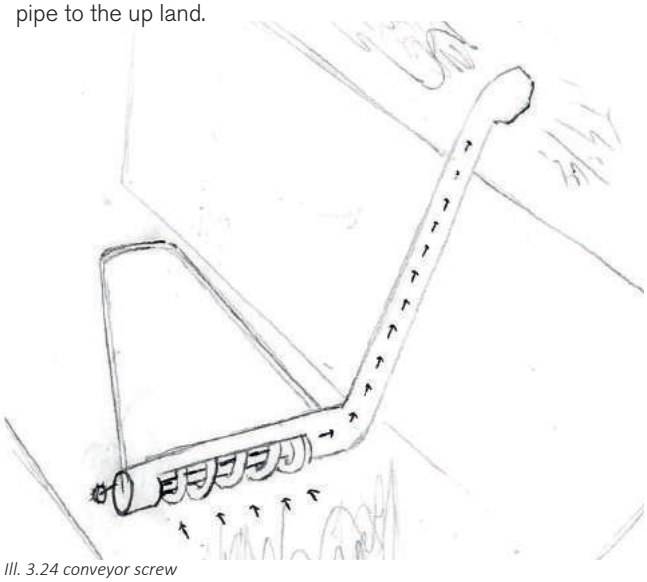
During the interview with Lars and Ole it was clear that working with a scythe and pitchfork in the stream is physically demanding work. To relieve the stream worker from the exhausting work of moving around in the stream one idea was a product that would be able to pull the stream worker forward, as for example a lawnmower does. On Ill. 1.24 an idea is that the machine have motorised wheel that can drive on the bottom, and rotate to work as propellers when the water level is higher as can be seen on Ill. 2.24


*Ill. 1.24 Driving machine*



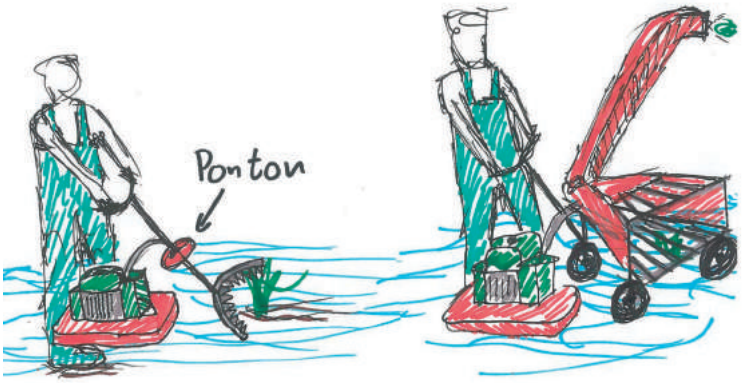

*Ill. 2.24 floating machine*

Another important observation was that the product should be able to remove the weeds and not just cut it. To minimise the weight of the product it was considered if the product could in the same movement cut and remove the weed. In that way only one motor output is necessary and would result in a much lighter product. This idea can be seen on Ill. 3.24 The thoughts behind it was to use a sharp conveyor screw to shatter the plants and in the same movement transport the cut off up through a pipe to the up land.



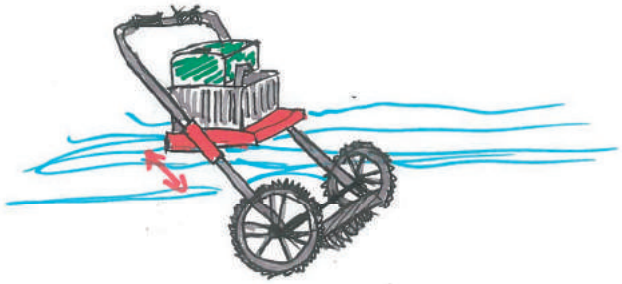
*Ill. 3.24 conveyor screw*

Lars told that they have tried to make tools that had rotary part. The problems with those tool was that the plants fibre entangle in the axle.




*Ill. 4.24 Multi porpose tool*

A second idea was to make a motor that would be able to power different tools, which can be seen on Ill. 4.24. The idea is that a motor is floating on a pontoon. Different tools can thereby be attached to the motor so the stream worker only has to carry the tool around.



*Ill. 5.24 Multi porpose tool*

In this idea the water was again used to carry the weight Ill. 5.24. This idea is also solving another problem stated by Ole and Lars, in terms of the water level can change in the stream rapidly. The motor is floating on the water and is fasten to the rails. If the water level decreases the motor will slide down along to the rails, and get closer to the wheels axes, which will make the product easier to manoeuvre.

## Size of dredging bucket

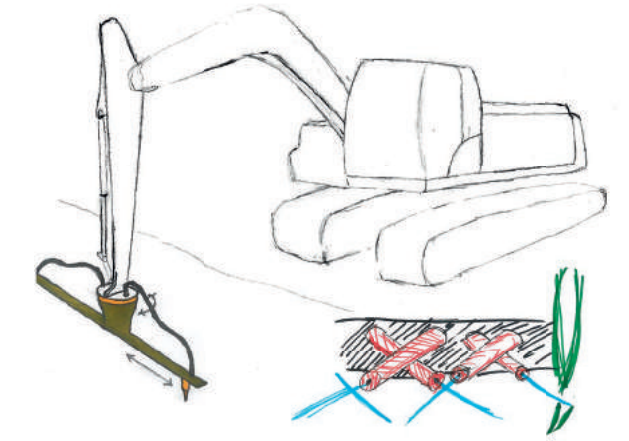
In the interviews with Lars and Peter they both spoke well of the dredging bucket, and how experienced driver was capable of cutting environmental, which contradict to what are written in the literature.
The reason why the dredging bucket currently can not be used is smaller streams is due to the size of the bucket. There is a problem with the width and the depth of the bucket. The problem with the width of the bucket is that in twisted stream the wide bucket straighten out the stream, which is bad for the streams' ecosystem. The depth of the bucket is a problem, because in some streams the bucket is to deep to even get down in the stream. Lars explained that in some streams they need a bucket there is only around 30 cm deep, so they would be able to do thalweg cutting.

*Ill. 1.25 Vertical dredging bucket*

An idea was to make a vertical dreading bucket that could be used along the stream while driving the excavator, opposite compared to the original solution, which is cutting weed across the stream. The advantages of this bucket, which can be seen on Ill. 1.25, is that it would be able to do thalweg cutting, and not straighten out streams. The idea might also be faster, which is very important in this industry, which Lars highlighted.

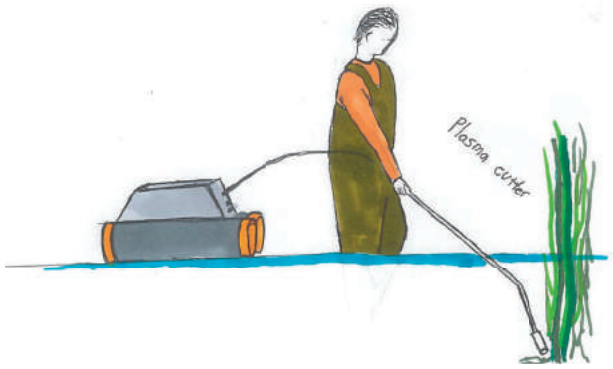
## A new cutting technique

At the visit at Sloths Naturpleje Lars explained that the knifes in the end of the dredging bucket and the boat are not made for cutting in the bottom, the same problem was with the motor scythe. New cutting techniques have been considered in order to lower the maintenance cost of the equipment.



*Ill. 2.25 excavator with water jet*

The first idea is to use a water jet to cut weed. A water cutter use this technique in order to cut sturdy materials. The water is sometimes blended with sand in order to get a sharp jet. When cutting pipes in the ocean a water cutter is used.
An idea was to connect a water jet to an excavator, which can be seen on Ill. 2.25. The water jet would then be able to use the energy from the excavator to run the pump that is needed. An assumption is that the high pressure from the water also would remove the mud from the bottom, which will result in ideal living conditions for sensitive plants.
As mentioned earlier the dredging bucket had the problem that it can not cut selective. In this idea it is possible to turn on and off for the individual nozzles so some plants can be spared.




*Ill. 3.25 Plasma cutter*

Another idea for a different cutting tool was to use a plasma cutter to give the plants in the stream a fast blast of heat. This technique is used in normal weed removal where a weed burner is used. (Garden, u.d.) The technique is not to burn the plants, but to give the plants a blast of intense heat to burst the cell walls. After a few days the weed will wither away. This technique could maybe be used on the unwanted species as for example reed spagnum. The problem with those plants is that the regrowth faster than all other plants, because they have their energy is in its roots.

## Sum up

In this section the solution space has been explored. This exploration in the solution space has been useful in making it clear how some of the sub issues are difficult to combine like having a manual tool that can cut and remove weeds while being light and manoeuvrable.
The problems and the concepts need to work through in order to determine which direction to go.
The two techniques for weed cutting need to be tested in order to find out if it is possible to do under water.

| | |
|---|---|
| Is it possible to cut plants with a water jet | ?? |
| Is it possible to burn plants under water | ?? |


*Ill. 1.26. Test at Lief Jensen*

# LEIF M. JENSEN

To test the possibility of using water to cut water plants a meeting was set up with the company Leif M. Jensen, which specialises in a wast variability of tasks of industrial cleaning. They had an high pressure cleaner which is capable of producing a pressure of 3,500 bar.

Because of the season no water plants are naturally available, so Peter Munk was contacted to propose the best possible substitute. Peter Munk suggested a leek to repentance the toughest water plants and a ivy to repentance the toughest emergent and riparian plants.

The purpose of the test was first of all to detainment if it is even possible to cut with high pressure water under water, or if the resistance in water would slow down The Jet of water to much. Secondly it was important to find at what distance it was possible to cut and at what pressure.

## Test Setup

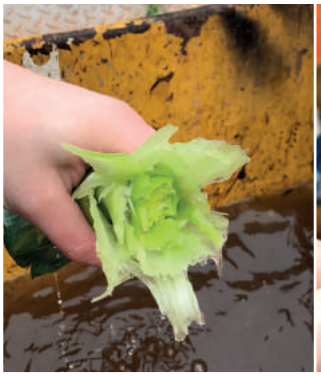
For the test a round 0.6 mm nozzle was used. To measure the distance to the leek and ivy a ruler was added to the nozzle. A metal container was filled with water and the leek and ivy was placed on the bottom. The ruler on the nozzle showed the distance from the top of the leek to the water table, and was then raised 100 or 150 mm.

*Ill. 2.26. Measurement*

## Results

The test showed the possibility of using a high pressure water jet to cut water and emergent plants, the full results can be seen in Appendix E - Cutting with water pressure.

The first test was at 200 bar and with 0-50mm of distance, which resulted in a clean cut of the leak. The second test was at a distance of 100-120mm and that could not cut the leek. The pressure was raised to 400 bar and at the close distance the leek was cut clean. At the distance of 100-120 mm the leek was also cut but a bit more roughly, which can be seen on Ill. 3.26. The distance was raised to 150-170 mm, at this distance the leek was not cut through but was almost blasted through.



*Ill. 3.26. 100-120 mm from the leak*

*Ill. 4.26. 40-60 mm from the ivy*

It was tested if the high pressure water jet could cut ivy. At the close distance of 40-60 mm the ivy was cut as can be seen on Ill. 4.26. At 100-120 mm the skin was broken and the fibres was starting to unravel.

The test was successful because it showed the possibility of using a high pressure water jet to cut water and emergent plant substitutes. This test showed the potential of using water to cut. More research is needed to determine the viability of this cutting method.

| | |
|---|---|
| Find out what kind of pumps that are available that can deliver the required pressure | ?? |

# GAS BURNER

When researching alternative weed removal methods the idea of searing plants was explored, as it is used in normal weed removal. A test will show if it is possible to use this method of weed removal on water plants. There is the problem with the season of this project because the plants are not active and growing.

## Validation of the method

Heating the plants leafs will damage the cell structure and ultimately kill the plant. The leafs should not be charred so no immediate results will be visible, but after a few hours the leafs will be withering. (Garden, u.d.)

The information of the use of this method in relation to removal of water weeds is limited. One scientific article from India briefly covers the use of searing water weeds. They suggest to sear the plant with a hot flame to get the plant to wither. Then they suggest to after 10-12 days to burn the plants completely away. (Jayan & Sathyanathan, 2012)

## Test

The tests were preformed in streams near Øster Å 23th February, Ill. 1.27. All three plant categories: Riparian, emergent, and water plants were tested, even though it was hard to determine if the plants were alive, hibernating or already dead.

A kitchen gas burner was used to preform the test and the plants were exposed to the heat for 5-20 seconds.

## Result of the test

The result of the test is inconclusive as it was not possible to observe any change in the exposed plants. This is most likely because of the season or mistakes in the test. The temperature on the test day was close to freezing, so the amount of heat actually hitting the plant was difficult to determine.

| | |
|---|---|
| This method of removing weeds has not been successful in our test | ! |

*Ill. 1.27. Burning plant*

*Ill. 2.27. Burning plant 2*

# WALKING IN STREAM

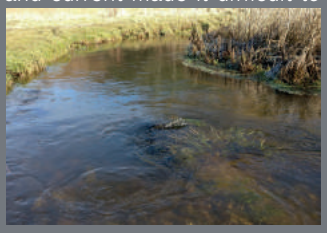
It has been stated by all the interviewed assets in this report how demanding it is to walk in the stream. As a part of finding the solution for the manual weed cutting it was important to try the conditions the stream workers are working in. Four different streams that all are maintained manually were visited to get an idea of the different conditions the streams workers work with.

## The different conditions

The first stream was the Øster Å Ill. 3.28. This stream had a width of around 3.5m and a depth of around 75 cm. It was relatively easy to walk in this stream, because it only had a small layer of mud even though the water reached the middle of the thigh. In the corners, where the pools were occurring, the bottom was hard, but the water level was the highest here. In the opposite side of the pool at the point banks it was difficult to walk because of the thick layer of mud. The current in the Øster Å was not strong, so it made only a little difference in the hardness regarding if the movement was up- or downstream.

*Ill. 1.28. Walking in smaller stream*

A smaller stream connecting to the Øster Å system was also explored and it was a different experience, Ill. 1.28. The conditions in the stream was changing much more rapidly. The difference between pool and point bank was also more clear in this smaller stream where one foot was standing in deep water with a hard bottom and the other foot was stuck in a deep layer of mud. This stream was more exhausting to walk in, due to a generally softer bottom, and the rapid change in conditions even though the water level was much lower. Another factor in this stream was a stronger current. In some sections the combination of mud and current made it difficult to walk, without using the arms for balancing. When moving downstream the experience was different, the air in the boots of the waders made the feet almost flow downstream.



*Ill. 2.28. Tostrup-Restrup Å*

Tostrup-Restrup Å was a different experience to walk in Ill. 2.28. The bottom of this stream was mostly hard with small or big rocks. It was easy to walk in this stream, because of the rocks, but the bottom was uneven with much variance in the depth across the stream. Big rocks was also piercing the surface.

## Sum up

It is crucial that the product makes it less demanding for the stream worker to move around, as it was difficult even without the added weight of the motor scythe.

| | |
|---|---|
| The product needs to help the stream worker move in the stream. |  |
| The product should be able to handle rapid changes in terrain |  |



*Ill. 3.28. Walking in stream*

# CHOICE OF PROBLEM AREA

In the previous ideation round the solution space were explored in relation to solving the issues: Size of the dredging bucket, and manual weed cutting and removal of weed. When sketching on these solutions some of the solutions needed more research to validate their practicality. Different tests were performed: If it was possible to cut with water underwater, if it is possible to kill water plants with heat, and how difficult it is to walk in a stream? When preforming the test of walking in the streams, it became clear for the team the difficulties the stream workers are daily exposed to. It made the result in the injunction, issued by The Danish Work Environment Authority, more understandable to why the current tools are no longer allowed to be used continuously in the demanding environment of a stream.

The direction for the project will be to develop a product that can replace the motor scythe and reduce the wear on the stream workers. The reason for this direction is that there needs to be developed a solution because of the injunction on the current tool. The problems related to the dredging bucket were more leaning towards a redesign of the current design. The problem of finding a replacement to the motor scythe is interesting because the need has been expressed by all the involved stakeholders in the previous interviews.

None of the current sketches are solving more than a few of the initial problems stated on page 21. The action of selecting a specific problem area will allow the team to unfold more of the sub issues to develop more polished concepts.

# IDEATION

In the previous ideation round the purpose was to put all the initial ideas down on paper, which resulted in more questions than answers. In this ideation round the course was more structured. Each round had a specific user need, which had to be fulfilled in the idea. The needs that were drawn upon were:

1. Solution for the exhausting task of moving in stream
2. The product must be able to cut selective
3. Removing the cut off mechanically

On Ill. 1.30. all the sketches that were drawn can be seen. The sketches were pinned up, and categorised into the needs. Even though that the purpose was to solve one need some of the ideas fulfil more than one. While sketching on the individual needs it was back of one's mind that the product should be able to cut and remove the weed, which maybe resulted in that the team had a narrowed mindset. In general the need that coursed most frustration was how to remove the cut off manually from the stream, which is why that 2/3 of the sketches that were pinned up was ideas that were concerning this need.


*Ill. 1.30. Wall of sketches from group room*

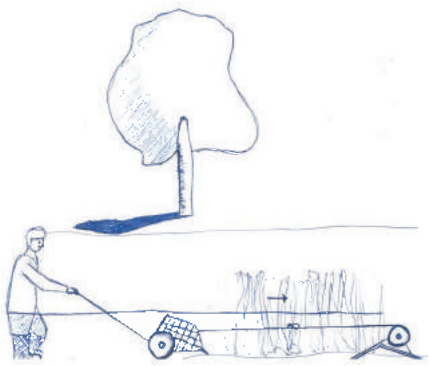
## Moving in the stream

Based on the test "walking in the stream" and interviews a need for the product is to find a solution that make it easier for the stream worker to move around in the stream.

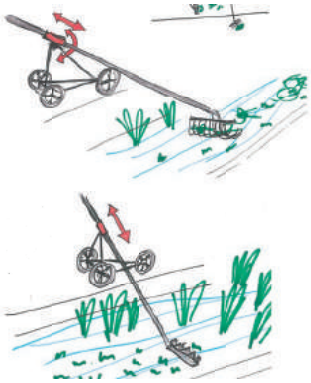
The first idea Ill. 2.30. is to have winch around 25m in front of the stream worker. The stream worker move the cutter from side to side, and control the tempo of the winch. The cons about this ideas is that the stream worker need to move the winch every 25m. Furthermore, the small original streams makes many twists and bends through the terrain, which make it difficult to use a winch.

The second idea Ill. 3.30. is that the stream worker is walking next to the stream with a trolley. From the trolley the stream worker can control a stick where a cutter or a rake is attached to. Peter Munk, from Aalborg municipality, comment that it would be difficult to drive vehicle next to the stream because of riparian plants and trees.

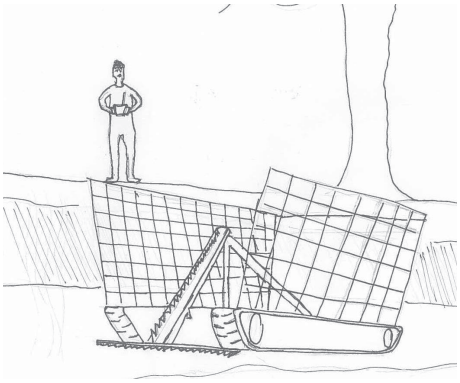
The third idea Ill. 4.30. is a robot that can be controlled from the upland. The robot is able to cut and collect the cut off. The problem with this idea is also common for the first idea, which is that the product is supposed to move on bottom. The problem is that it was observed that the terrain of the stream vary much and the bottom was hardly ever flat. It would maybe be possible if the product was thin, in order to avoid big stone for example, while moving around in the stream.



*Ill. 2.30. Pulled through plants*



*Ill. 3.30. Pulled through plants*



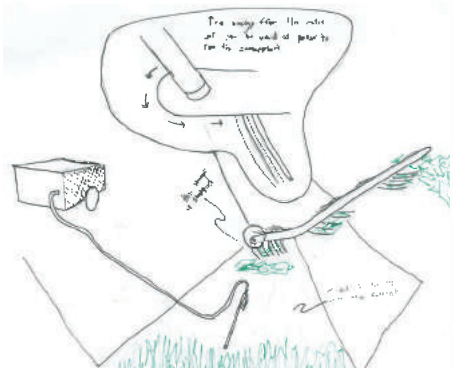
*Ill. 4.30. Pulled through plants*

## Cutting selective

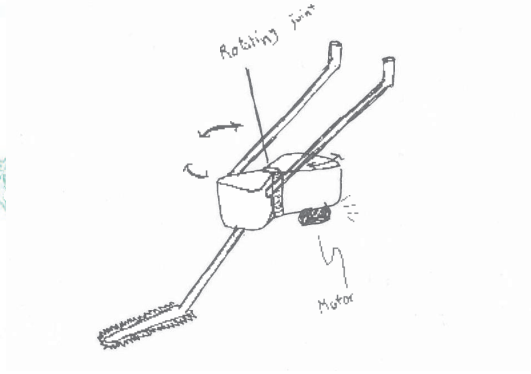
Environmental weed cutting entail that the stream worker is capable of sorting between which plant he want to remove. If the cutting tool has the same width as the stream is it impossible to pick between the plants.

A solution for cutting selective could be to use a water jet, as can be seen on the Ill. 1.31. The thoughts behind the idea are that the stream worker cut specific plants upstream. The cut off float downstream to a conveyor belt, with a hay tedder on, remove all the weed from the stream to the upland. In this idea the water jet is connected to a pump in a trailer.

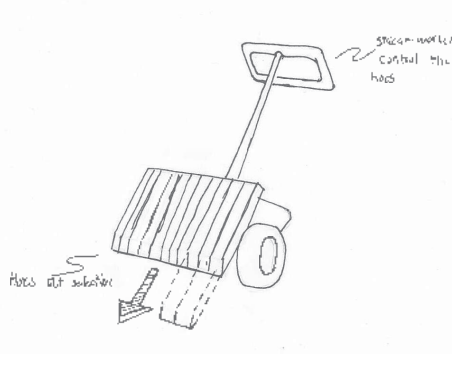
The second idea Ill. 2.31. reminds of the weed cutting moped. The difference is that the machine is divided in two. Between the two parts a rotating joint is attached, which make the machine much easier to control. Furthermore, the cutting blade is rotatable so the cutter can access thin narrows. The third idea Ill. 3.31. is to hack the weed. The stream worker is walking with the product in the stream while controlling separate hoes in order to decide which plants to keep and which ones to cut.



*Ill. 1.31. Pulled through plants*




*Ill. 2.31. Pulled through plants*

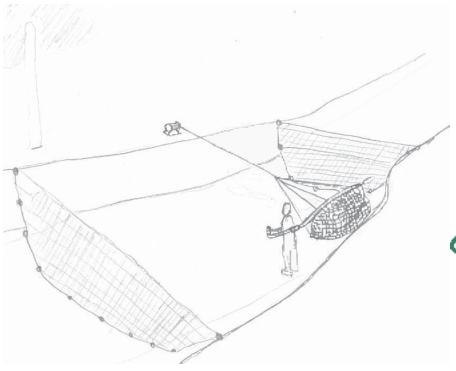


*Ill. 3.31. Pulled through plants*

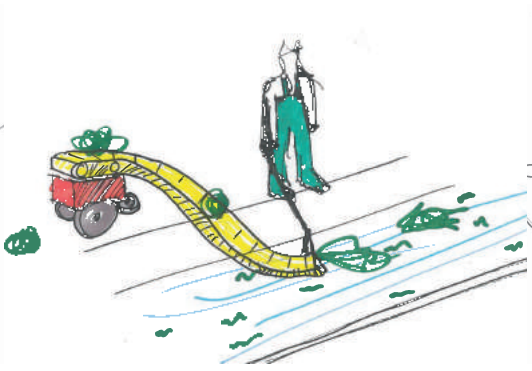
## Removing the cut off

It would be ideal if the product were capable of removing and cutting the weed. There are always two stream workers while cutting the weed. Therefore it is not excluded that the solution will consist of two products.

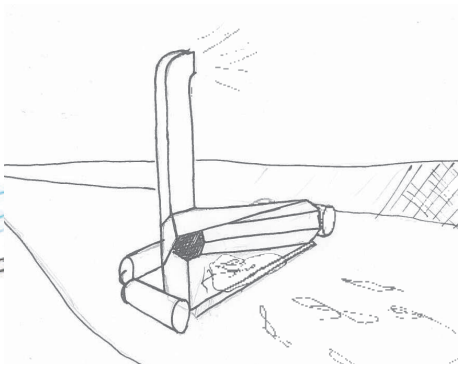
Below three ideas are drawn. The first idea Ill. 4.31. is that two nets are stretch out in the stream with a distance to each other. The first net is supposed to be set up at once when the stream workers arrive. One of the stream workers starts to cut the weed upstream while the other stream worker make sure the weed float down the stream to the net. When the stream worker has cut around 25m of the stream, the second stream worker sets the second net up, while the first stream worker continue cutting the weed on the other side of the net. The second stream worker make sure that all the weed have floated down to the first net. Afterward the second stream worker uses a net and a winch to remove the weed. To this idea Peter Munk explained that they have similar proceeder today, the difference is that the weed float down to a bridge where the weed are stopped by pillows and removed by an excavator. Peter explained that the biggest problem is when the water conveyance is low, so the water can not transport the weed down the stream. An idea for this can be seen on Ill. 5.31. where a stream worker walk next to the stream and remove the cut off with a flexible conveyance belt. Instead of transporting the cut off from the stream with a conveyor belt, a third idea Ill. 6.31. is to throw the cut off with a machine that reminds of a chip wood machine.



*Ill. 4.31. Pulled through plants*



*Ill. 5.31. Pulled through plants*



*Ill. 6.31. Pulled through plants*

# AUTOMATION MAPPING

A mapping of the automation in three different aspects have been made of the exciting solutions. Each of the excising solutions will be rated on a score from one to five in how automated they are, a score of one will be no automation and five will be autonomous. The rating has been made by the members of the team. The three different automations aspects are:

- Platform positioning (P)
- Tool point positioning (T)
- Cutting (C)

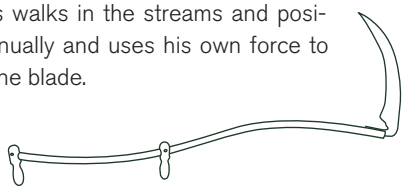
The platform positioning covers the automation of how the operator is moved. If the stream worker has to walk himself the automation is zero but if he is moved on a motorised vehicle it is rated high.

The tool point positioning is how the tool is operated. If the product is motorised and the operator controls it using joysticks like the excavator the level of automation will be three, but if the product had been fully automated it would score a five.

For the cutting it describes who supplies the energy to cut the plant. Either a motor or the operator himself.

## 1. The scythe

The manual scythe is scoring a one in all three factors. The stream workers walks in the streams and positions his scythe manually and uses his own force to cut the plants with the blade.

*Ill. 1.32. Scythe*

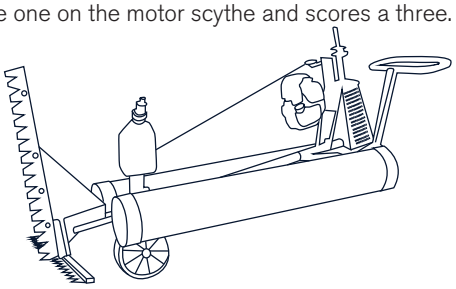
## 2. Motor scythe

The motor scythe also scoring a one in the platform positioning and the tool point positioning, because he also have to walk in the stream and move the tool around. In the cutting it is scoring a three because it has a motorised cutter.


*Ill. 2.32. Motor scythe*

## 3. The weed cutting moped

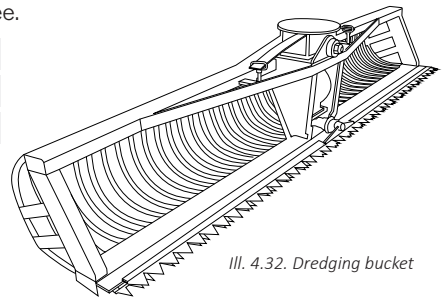
The weed cutting moped scores one in platform positioning, the entire tool is floating, but it still needs to be moved manually. For the tool point positioning it scores a two, because the adjustment of the cutter can be set on a dial by the operator. The cutter resembling the one on the motor scythe and scores a three.

*Ill. 3.32. Weed cutting moped*

## 4. The dredging bucket

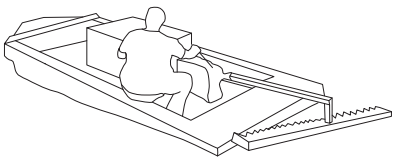
The dredging bucket scores a three in the platform positioning. For the tool point positioning it scores a 3 or 4 depending on the excavator, some excavators has a GPS system that allows them to see exactly how deep they need to cut. The cutting will be rated as a three.

*Ill. 4.32. Dredging bucket*

## 5. The weed cutting boat

The weed cutting boat is also scoring a three in platform positioning like the dredging bucket. The tool point positioning and cutting is both rated as a three.

*Ill. 5.32. Weed cutting boat*

The exiting solutions have been rated from one to five. The focus of this project is to develop a product for the smaller streams, where the boat, or excavator with a dredging bucket, can not access. Therefore the three primary competitors are the scythe, motor scythe, and the weed cutting moped. The three primary competing products are rated low in both tool point positioning and platform positioning. Therefore future concepts have an opportunity in adding value and functionality in these categories.

# PARADOXES

The ideation was as explained based on different user needs gathered through literature and several interviews. During the ideation it was difficult to combine the different needs into one single product. It can be explained by that some of the needs are paradoxes to each other. A paradox in this case means that two or more perspectives are conflicting on the same situation. (Hansen , 2017)

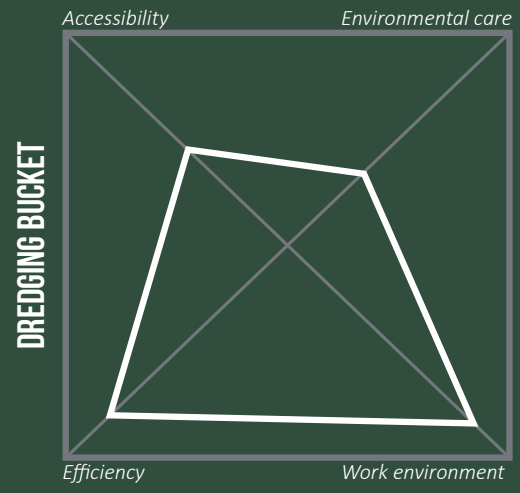
In order to understand the paradoxes a model has been made. The model consist of square, in each corner a need for the product is placed. These needs; accessibility, environmental care, efficiency, and work environment are one way or another paradoxes to each other. For instance, the product needs to be gentle to the environment, but at the same time it need to be really efficient, which stage for big powerful product. A big powerful product will make it difficult to do environmental weed cutting, and at the time will it be bad for the work environment, if a stream worker need to carry a big product around. A big powerful product where the stream worker could sit in would be durable, but then it will be difficult to move around, and access different areas of the stream.

Peter Munk from Aalborg municipality was asked to rate how good the motor scythe and dredging bucket meet the user needs. The rating Peter gave the two product can be seen on Ill. 2.33. and Ill. 3.33. The result of the ratings show that the dredging bucket is really efficient and accommodate good work environmental conditions for the stream worker, but has a bad accessibility and do not perform environmental weed cutting. The motor scythe is opposite the dredging bucket. The efficiency is low and conditions for the stream worker is bad, but it can access almost everywhere and take care of the environment.

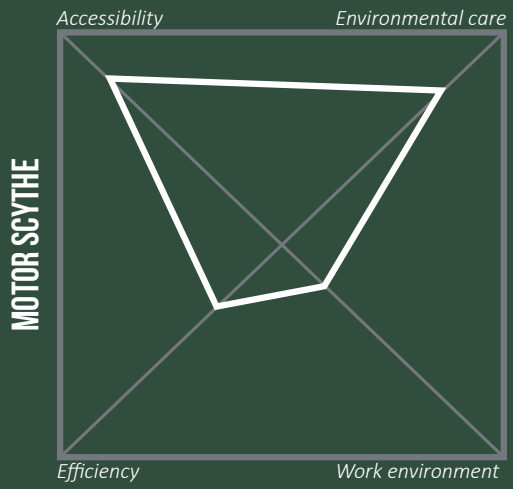
## Aspired value

The aspired value is to create a product that is at least as efficient as the motor scythe while giving more control to the operator, so the person is able to do environmental weed cutting. The goal is that the product will replace the motor scythe and take some market share from the dredging bucket. The product must be design so the operator is not exposed for physically demanding work.

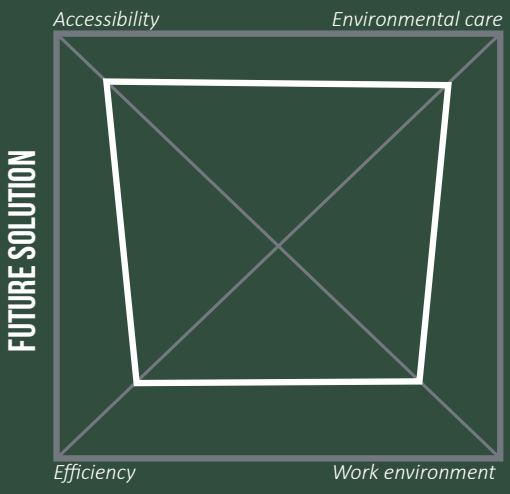
On Ill. 4.33. the goal for the future product can be seen in relation to the different paradoxes is mapped. When comparing the future solution with the motor scythe and the dredging bucket it can be seen that the future product is aiming to be between the two products. It is unrealistic that the future product can create a better work environment for the stream worker than the dredging bucket does, because the stream worker will most likely move around and interact with product. If the work environment was rated by psychical work and fresh air the future product would have been rated higher. The efficiency for the future solution is also rated lower than it is for the dredging bucket, because the goal is not to create a machine that smash up the stream, but a product that take care of the environment. The amount of money the stream worker receives from the municipality has decreased the last decades. It is therefore important to design a product that is more efficient than the existing solution.




*Ill. 1.33. Paradox dredging bucket*




*Ill. 2.33. Paradox motor scythe*




*Ill. 3.33. Paradox future solution*

Ill. 1.34. Mock up Bottom Crawler

Ill. 1.34. Bottom Crawler in water

# CONCEPTS

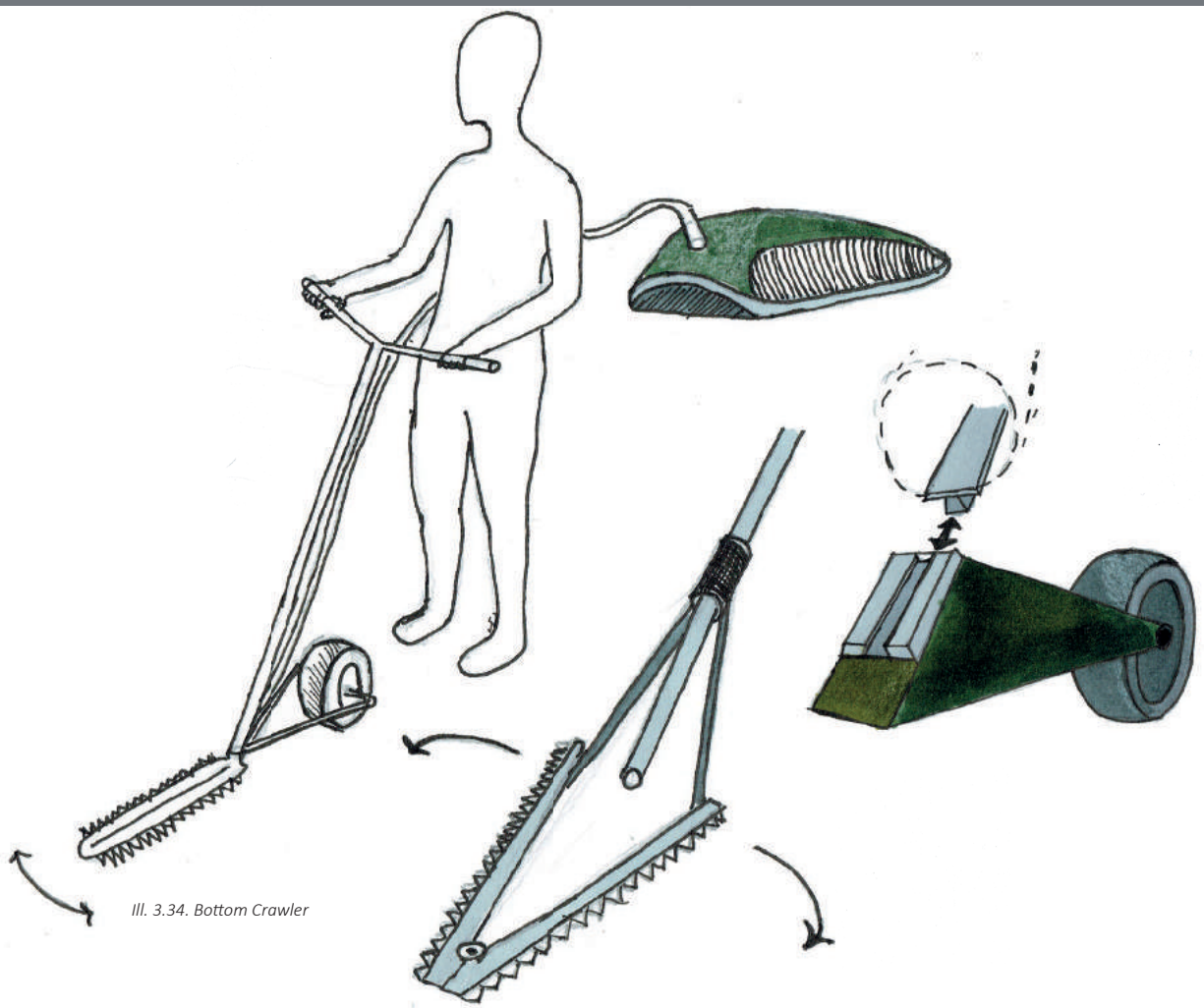
The concepts have been selected on the ground that they fulfilled different user needs. The concepts were showed and explained to Peter Munk technician from Aalborg municipality whereupon he explained pros and cons with each concept. Afterward, the concepts were mocked up and different functionalities were tested in the context.

## Bottom Crawle

The Bottom Crawler reminds of the motor scythe in the way it is cutting. The stream worker walks in the stream behind it and pushes it upstream, and is able to pivot the cutter because of the back wheel. The width of the cutter can be adjusted, which make it easier to cut selective in some parts of the stream and make it wide for efficiency in flat sections of the stream. The cutter can be detached from the wheel to accommodate places that the wheel can not access. The motor is flooding on a paddle board behind the stream worker, so minimal weight is added to the stream worker, he only has to move himself and control the Bottom Crawler.

***"Super interesting concept with the changing blade for different conditions and cutting methods***

*Peter Munk*



Ill. 3.34. Bottom Crawler

Peter saw the concept and could see the idea in having the blade that can change shape depending on the conditions. He said that it would be ideal for the combined thalweg cutting because it can cut a wide path in the pools of the stream and then do network cutting in the riffle and run.

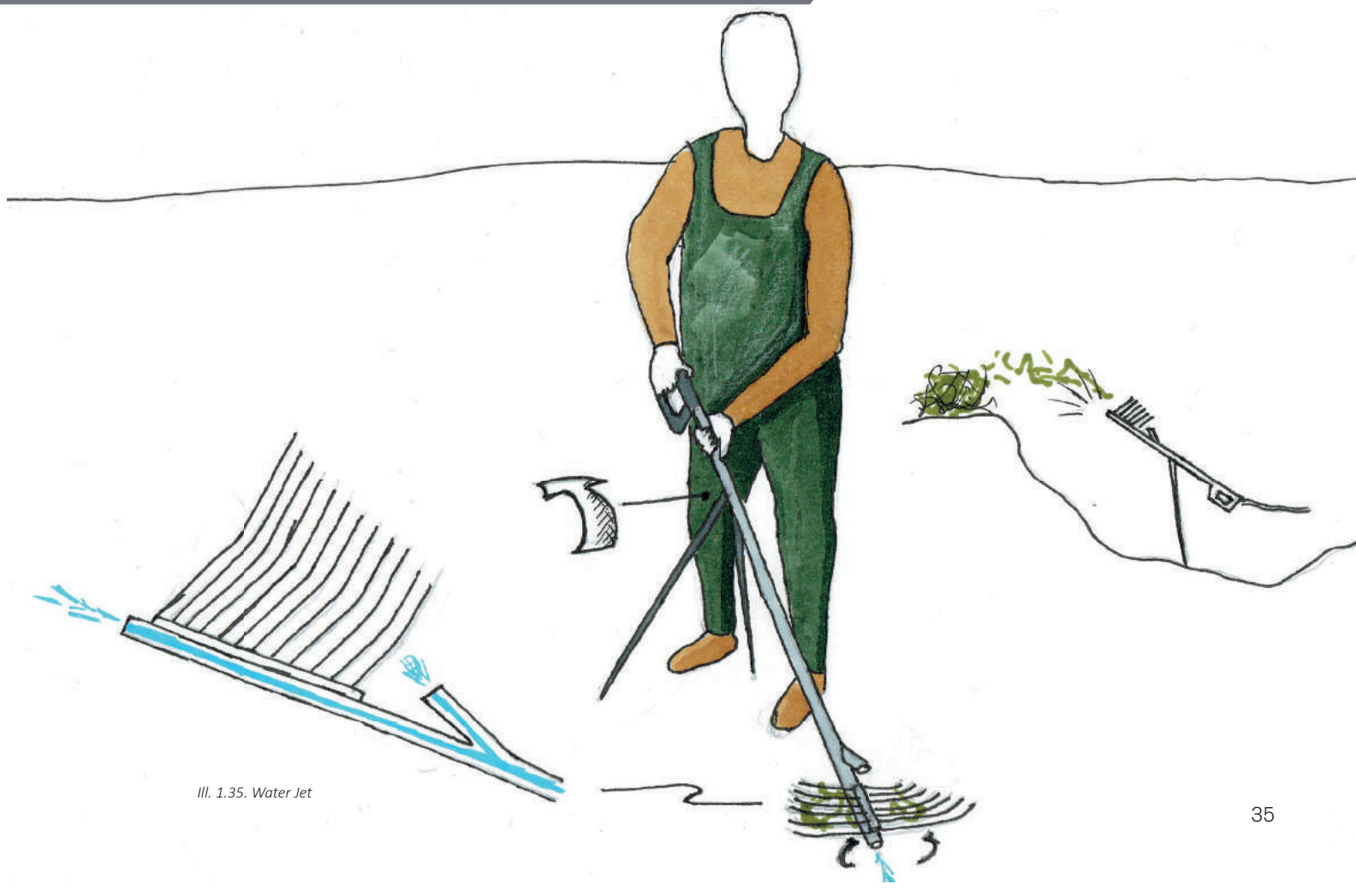
A model of the Bottom Crawler was build in order to test how the moveability is when the scythe is pivoting on one wheel. The stick was placed with a distance on 17cm to the wheel, this made it very sensitive when pivoting and hard to handle. The distance was changed to 25cm, which made the model much easier to control. The model can be seen on Ill. 1.32. The model was also tested in a stream, but because the model was made out of wood the buoyancy made it difficult to test, how it was to manurer on the bottom, and how easy it would be to moving around rocks and other obstacles.

## The Jet

Earlier in the research it was concluded that it is possible to cut weed under water with a water jet with a pressure of 400 bars. In this concept the stream worker moves around in the stream and uses a water jet to cut the plants. Furthermore, there is a rake that gathers the cut off. The idea is that the stream worker use the energy from the water jet to blast the cut off up on the riparian.
The reasoning and ideas behind this concept is not the blasting of cut off, but the thought on using the same energy source to cut and remove the weeds from the stream. The idea of using a high pressure water jet for cutting water weeds caught the attention of Peter and he thought is was smart to use the closest resource. The possible issue of how the water jet might disturb the bottom was discussed, where Peter said that it might be useful for cleaning the bottom gravel for old sediment to improve conditions for the fish population.

***"Cool idea with using high pressure to cut! Might also have other benefits"***

*Peter munk*



*Ill. 1.35. Water Jet*

## Weed Management Drone

The Weed Management Drone is controlled by a stick that a stream worker walks with next to the stream. The idea is that a sensor measure which direction the stream worker pushes the drone. Propellers are attached to the product and use the value from the sensor to move the drone in the direction the stream worker pushes, which make the manoeuvrability possible, even in strong current. The rotating cutter should be able to move up and down, due to the varying depth of a stream, therefore it is powered by an electrical motor.

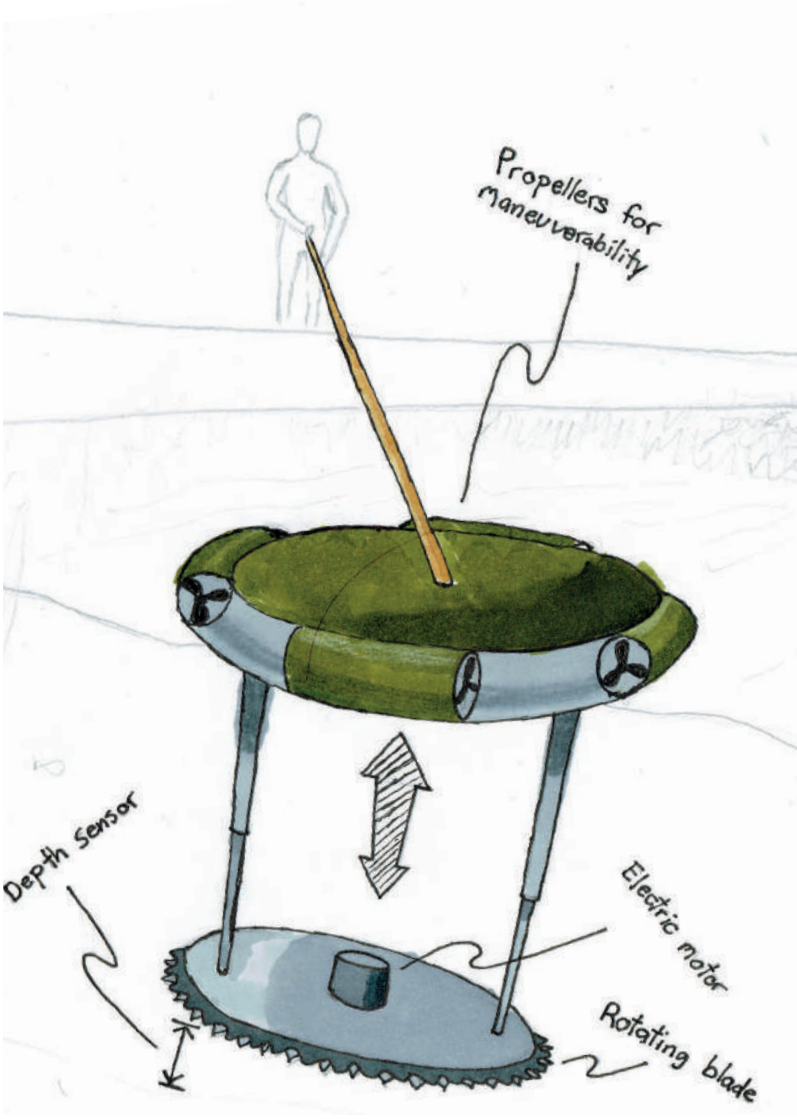
***"Exciting and innovative solution, but it is not always space for walking on the shore"***

*Peter Munk*

The idea was presented to Peter Munk. Peter was initially excited by the concept, he could see the potential in having something that was floating and had propellers so it could move. He was concerned about the stream worker walking besides the drone because sometimes there are trees in the way.

A model of the Weed Management Drone was made in order to test how it would be to move a object around in the stream with a lot of current while walking on the riparian. The model was made out of expanded polystyrene, with a top of 30 mm wood. To simulate the rotating blade, a wood plate was attached to the bottom. The model was controlled with a telescope broom handle that was connected to a plunger, which worked as a flexible joint to control and move the "drone".

It was possible to move the model around in the stream when it was close the operator. The further the model came from the user the harder it became, because of the strong current. Sometimes when the model was pulled upstream through the current it flipped around. It was maybe caused by that the rotating blade was made out of wood so the bottom had buoyancy. It needs to be considered on the final model.
The "drone" was also controlled by an operator down in the stream. The same difficulties with moving when it was far away occurred. The test of using it while walking in the stream, showed that the stream worker should be able to operate the drone without raising his arms above his shoulders.




*Ill. 1.36. Weed Management Drone*

*Ill. 2.36. Weed manamement drone in water*

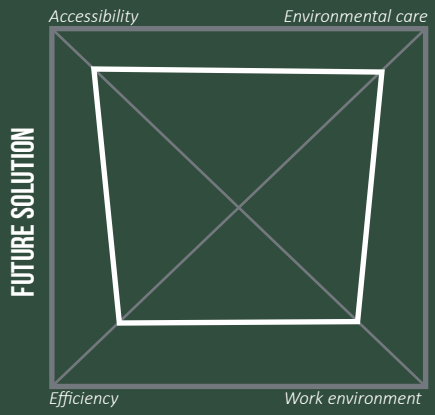
# AUTOMATION AND PARADOX MAPPING

The three concepts will be mapped in the previously used models: Paradox mapping and Automation mapping. The Paradox mapping will be rated on four parameters: Accessibility, Environmental care, Efficiency, and Work environment. The three different factors for the Automation mapping are: Platform positioning, Tool point positioning, and Cutting.

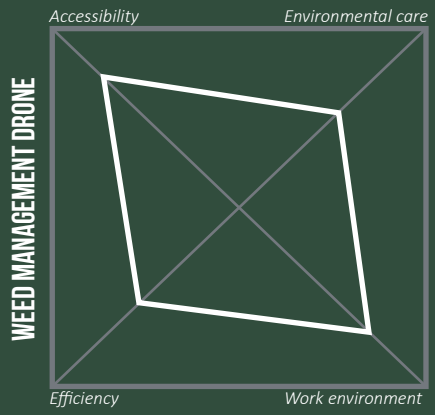
## Paradox mapping

For the paradox mapping the three concepts are rated the same in efficiency and environmental care. To rate these two parameters a simple sketch is not sufficient for valid data.
For the accessibility the Weed Management Drone is scoring the highest, because the stream worker has the option of using it while walking in the water or on the riparian. This allows the stream worker to cut in streams with fast currents, deep waters, or in streams with deep mud. The Jet is scoring higher than the Bottom Crawler, because it is using the bi-pod system while the Bottom Crawler has a wheel that can get stuck in mud or run into stones on the bottom.
For the work environment the Weed Management Drone scores the highest. This is again because of the ability to operate it from the riparian, eliminating the need for the exhausting task of walking upstream in the muddy water, the product is also able to propel itself. The Bottom Crawler is scoring higher than The Jet because it is driving on a wheel limiting the weight put on the stream worker, while The Jet requires the stream worker lift it around and place the bi-pod.

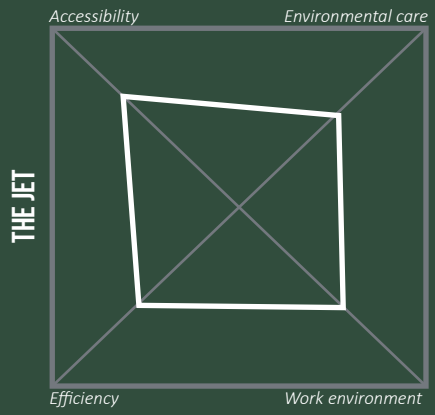
The paradox mapping of the three concepts shows that none of them meet the desired functionality for the future. This is partly because two of the criteria were not possible to rate based of hand sketches and mock ups. For the accessibility and work environment the concepts were rated on the intended use and mock ups. The concept that is getting closest to the desired accessibility and work environment rating is the Weed Management Drone. It is primarily because of the ability to operate the concepts from the riparian.



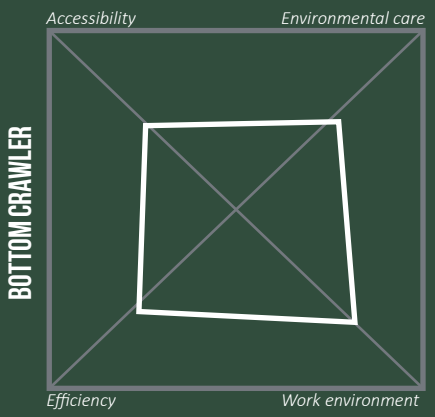

*Ill. 1.37. Paradox Future solution*




*Ill. 2.37. Paradox Weed Management Drone*




*Ill. 3.37. Paradox The Jet*




*Ill. 4.37. Paradox Bottom Crawler*

### Bottom Crawler

For the automation mapping the Bottom Crawler scores a one in platform positioning because the stream worker has to walk behind the product. For the tool point positioning it scores a three, it gets one point for having the wheel and therefore the ability to pivot the tool from side to side to cut, and one point for having the ability to change the shape of the blade. The cutting scores a three because it is motorised.




### The Jet

Like the Bottom Crawler The Jet scores a one in platform positioning. For the tool point positioning it scores a two because it has the bi-pot that allows the stream worker to pivot the tool from side to side and take some weight off the operator. The cutting scores a three, because the high pressure water cut the plants.


### Weed Management Drone

The Weed Management Drone scores a two in platform positioning, because the operator has the choice of either walking on the riparian or in the stream. The tool tip positioning is a four because the main body is controlled thought the stick and the cutter is autonomously moving in relation to the bottom. The cutting is also a three in this concept.


The aim for the concepts were to rate higher in the platform positioning and tool point positioning. The automation mapping of the concepts show that two of the concepts are rated higher than the existing solutions. The weed management achieves a rating of four in the tool point positioning, which is superior to the exiting solutions.

## CONCLUSION ON THE CONCEPTS

The three concepts have been rated in relation to how the concepts fulfil the user needs. See Appendix F - User need mapping of concepts. The rating was done by the members of the team based on the response from Peter on the concepts and the test with mock ups. It was difficult to rate the concept with the current knowledge, this might also be the reason why the rating of the concept are similar.

The Jet concept had some interesting potential with the new cutting method that would utilize the resources in the stream and possibly reduce the maintenance cost. This method of cutting was verified in the section Leif M. Jensen. When researching the equipment that is needed in order to generate high pressure for cutting, with the specifications needed for The Jet, Den-Jet was contacted. Unfortunately the equipment needed only one nozzle would weight above 400 kg. See appendix G - Weight of water jet.

The Weed Management Drone preformed best in the paradox mapping scoring higher in accessibility and work environment. In the automation mapping The Weed Management Drone scored the higher than the other two concepts.

The team sees the most potential and exiting challenges in the developing in the Weed Management Drone. Compared to the Bottom Crawler, which is resembling a redesign of the motor scythe. The core principle in the Weed Management Drone relies on the interaction through a stick. However this way of interacting with a product has immediately not been observed on any other product, and therefore it is hard to imagine the success of this. A test of the interaction method is needed in order to validate the success of the concept. If this test is successful the Weed Management Drone concept will be chosen for further development.

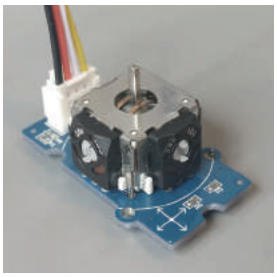
# INTERACTION TEST

The previous test with the Weed Management Drone showed how the concept was difficult to handle upstream, therefore another interaction test with the concept will have to be conducted. The new model will be motorised to test how it is to manoeuvre the product with a stick. The idea of controlling the product with a stick attached to a sensor is one of the main features of the concept, so the success of this interaction method is crucial for the success of this concept.

## Idea behind the model

The main design from the sketch with a round body and no immediate direction will be tested on this model. Motorised propellers will be distributed evenly around the edge. Construction of the model will be simplified to limit the time used, while still being able to test the interaction and the basics of the round design.

The sensor chosen to handle the interaction is similar to what can be found on joysticks for game consoles. This kind of sensor is sensitive, and can therefore give different signals depending on how the stick is positioned in both the x and y direction. The sensor outputs a signal from 0-1023, so when the stick is in resting position the output signal is x:512, y:512. When the stick is pushed around the output signal will constantly update, and alter the amount of voltage sent to the motors. This will allow the model to move with full speed in one direction and slower in the other direction, hopefully resulting in smooth and fluid movement of the model. For the propulsion four motors will power propellers mounted in pairs.



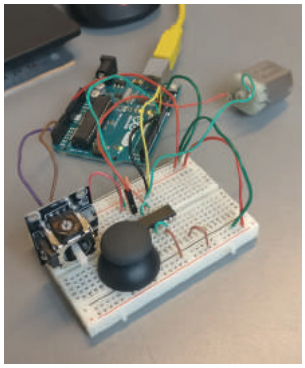
*Ill. 1.39. Joystick sensor*

## Construction of the model

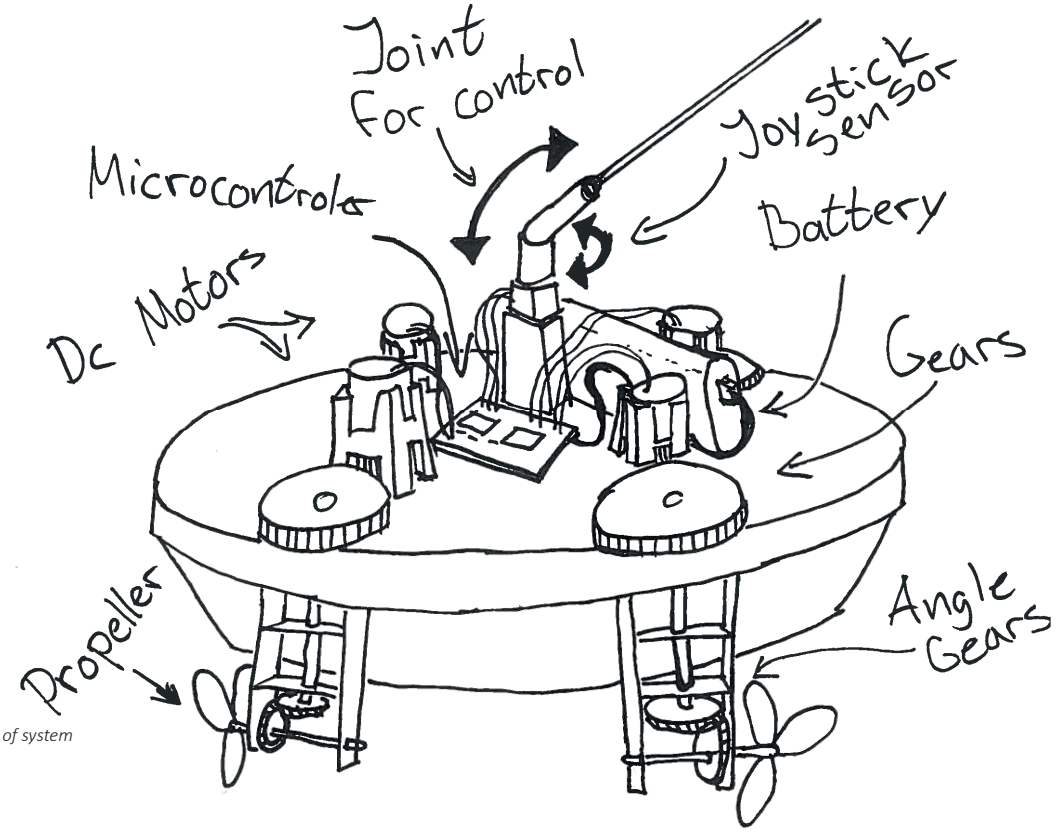
One of the most crucial parts of the model is the joystick sensor that communicates with a micro controller, in this case a Arduino. The code for the Arduino and sensor was therefore the first part of the build. Another aspect that was needed for the model was the ability to control the motors in different speeds in both directions. To control the motors and the direction of the power an h-bridge was used. The build of the model was divided into many small steps. One of the first breakthroughs was using the joystick sensor to control the motor in different speeds and in both directions, the setup can be seen on Ill. 3.39.

The next part of the build the construction of the model. A sturdy base of plywood was used and styrofoam was applied to give it more buoyancy.

The motors chosen for the model was 2.5-6v DC motors, because of the wide ability to change the voltage and therefore the speed. This ability was needed to be able to preform the precise movements intended for the test. The remaining parts of the build like gears and brackets were 3D printed.



*Ill. 3.39. Joystick, h-bridge and motor*




*Ill. 2.39. Sketch of system*

## Motor problems

After the initial testing of the different aspects of the model, everything was assembled on the plywood base, Ill. 2.40. Imitatively it became clear that there were problems with the model. The motor pairs were not running at the same speed and sometimes the friction of the gears made it impossible for the motors to start without intervening. It was clear that there was not enough power to run both motors.

An multimeter was used to inspect how much power the motors received, and it could be seen that something was wrong in the setup. The motors got around 1.2v while they should receive around 5v.

The solution to this problem was a redesign of the setup, as it was discovered that the h-bridges used for the setup was not meant for handling so powerful motors. Therefore it was chosen to use a power bank for the motors and another for the arduino and sensors. Powering the motors directly with a motor driver, gives more of the power from the battery directly without interference, Ill. 1.40.

After the improvement with motor drivers another issue was discovered. The 5v mobile power banks used for the system were still not able to deliver enough power to the motors. The system was working, but not convincingly.

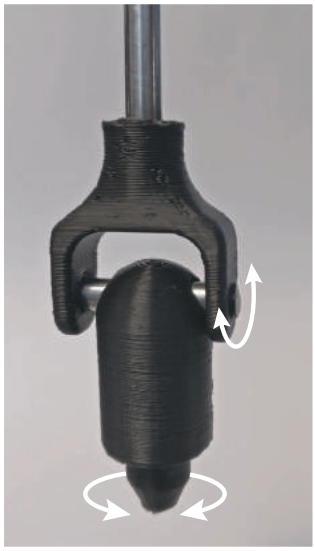
A powerful 11v lithium polymer battery was then used. This made the motors run at high speeds and the friction from the gears had much less effect on the system.

The product needs drivers and dedicated power supply to propulsion system and cutter

## Joint to the sensor

To be able to test the interaction through a stick, two different versions of a connecting joint have been developed. It is important that the operator feels in control and that the product becomes a natural extension of his body. Both joints were connected to 30 cm metal rods.

*Ill. 3.40. Cardan joint*

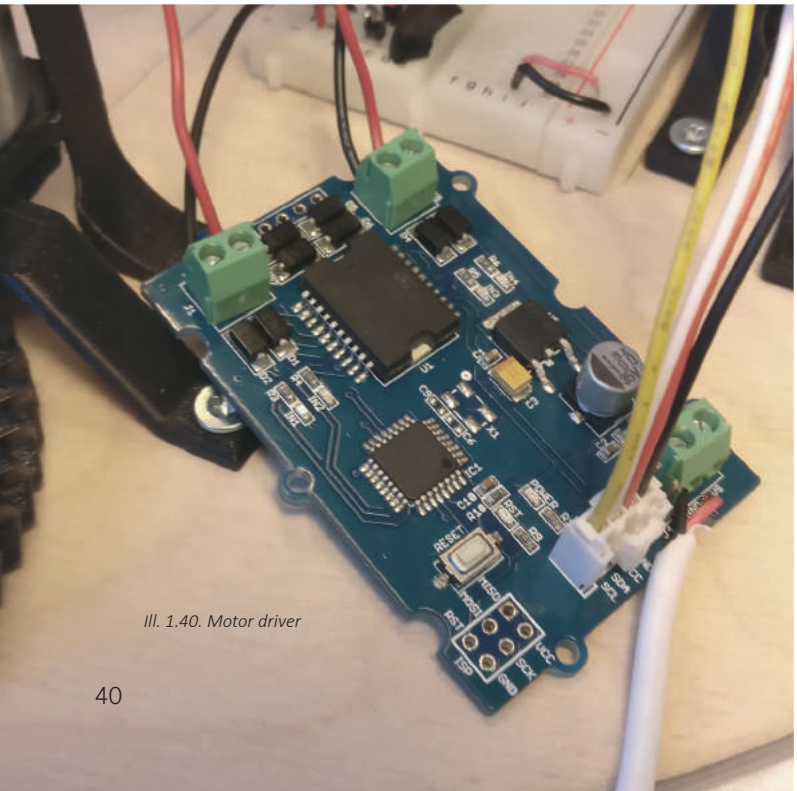


*Ill. 4.40. Rotating and pivoting joint*

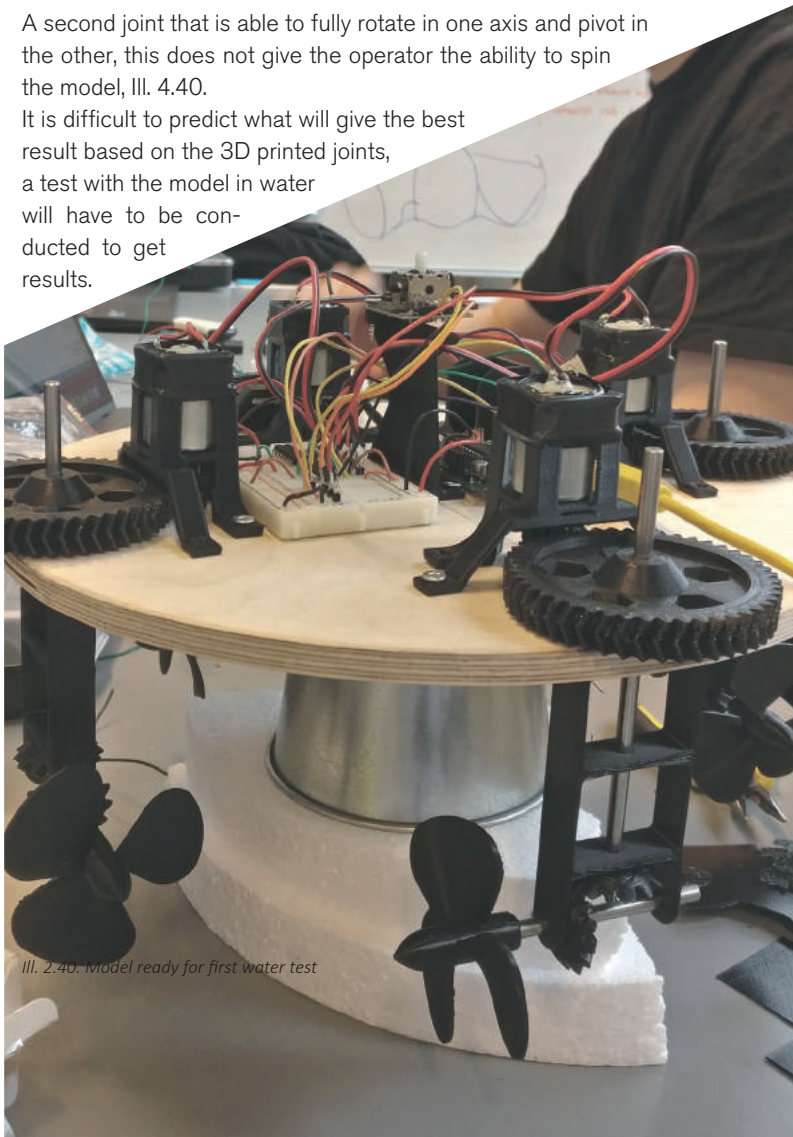
One with a cardan joint that gives the operator much control of the product and the ability to spin the product on its own axis, Ill. 3.40.

A second joint that is able to fully rotate in one axis and pivot in the other, this does not give the operator the ability to spin the model, Ill. 4.40.

It is difficult to predict what will give the best result based on the 3D printed joints, a test with the model in water will have to be conducted to get results.



*Ill. 1.40. Motor driver*



*Ill. 2.40. Model ready for first water test*

## Testing

After several upgrades and changes to model it was ready for testing in water. The electronic setup had gained some weight with the added battery and components, so when the model was put into the pool, water was flowing up on the plywood base. Extra styrofoam was added, this change made the model much more sturdy and limited the chance of ruining the electronics by splashing water, Ill. 1.41.

Now the model was ready for testing in a 2m x 1.5m pool. The first test with the model in water showed that the new batteries definitely delivered enough power to the motors, the model was difficult to handle, because it was moving faster than it was possible to push the joystick. After decreasing power and calibrating the motor pairs, so they were running at the same speed, it worked.

The model would move itself in the direction it was pushed, assisting the operator in positioning it. The motors was switching on and off and shifting direction rapidly depending on how the joystick was pushed. Even when pushing the model in directions that required both motor pairs to activate it worked. It was possible to feel when one set of motors were running at 100% and the other pair at 50%.

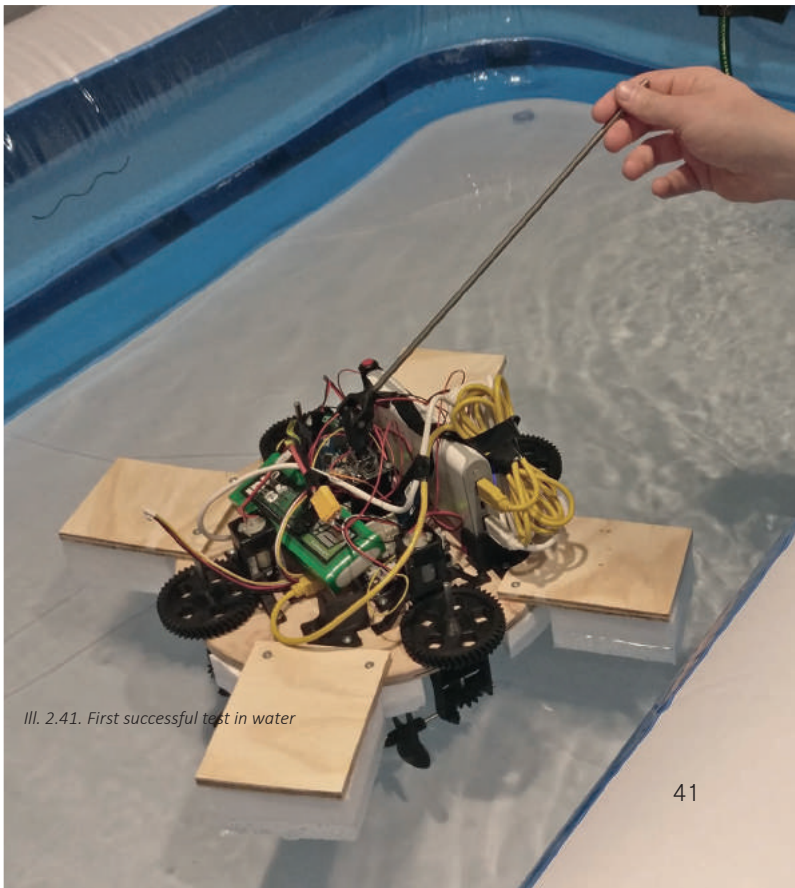
The two different joints were also tested on the model. These tests were difficult to preform because the connection between the joint and joystick sensor. It was challenging to make a sturdy connection because of the small rod going out of the joystick, illustrated on the previous pages. A solution to the problem could have been gluing the joints to the sensor, but that would require a new sensor for each type of joint. Nevertheless the tests were preformed and it was possible to feel the different in the handling, Ill. 2.41.

The cardan joint allowed the operator to spin the model on its own axis, this felt useful when it was desirable to test the motors in one direction. This ability to spin the model on its own axis should not be necessary because of the round no direction design.

The other joint was also tested and it worked well, it was easy to position the drone as desired as long as the rotation of the drone was not a problem.

To get a better feeling of how the real product might handle a longer stick was attached to the rotating joint, Ill. 1.41. The test with a longer stick gave a good feeling for how it might be to handle the finished product. The longer stick made it easier to handle because the quick movements of the model were suppressed. With the small 30 cm rod it was difficult to make it go into the exact path that was desired, because the motors were so powerful the model would always go a bit of the desired course. With the extension of the stick it was easier to guide it into an exact path and quickly change direction.

*Ill. 1.41. Test with a longer stick*

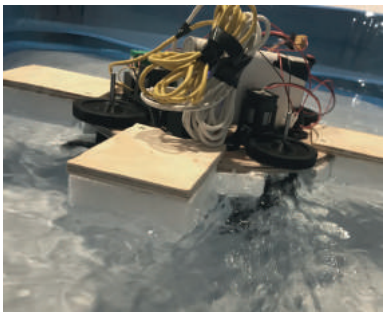


*Ill. 2.41. First successful test in water*

## Fighting the current

After the initial testing in the pool it was decided to make the conditions more like what is in the stream. This was done by adding an water pump to create a current to simulate cutting upstream, Ill. 1.42, Ill. 2.42.

The goal for this test was to test if the model would be able to stay in the same spot. Meaning that if the operator holds the stick in one spot if the model would move back, or if the resistance would push the model back activating the joystick and thereby propelling itself forward.



*Ill. 2.42. Model moving upstream*

This was also a successful test, the model was able to stay in the same spot even close to the pump where the current was strong. The joint used for this test was the rotating joint so when the current was hitting the side of the model was spinning on its own axis. It made the motors switch on an off and change direction quickly, ensuring that the model was always propelling itself forward upstream.

## Reflection on the test

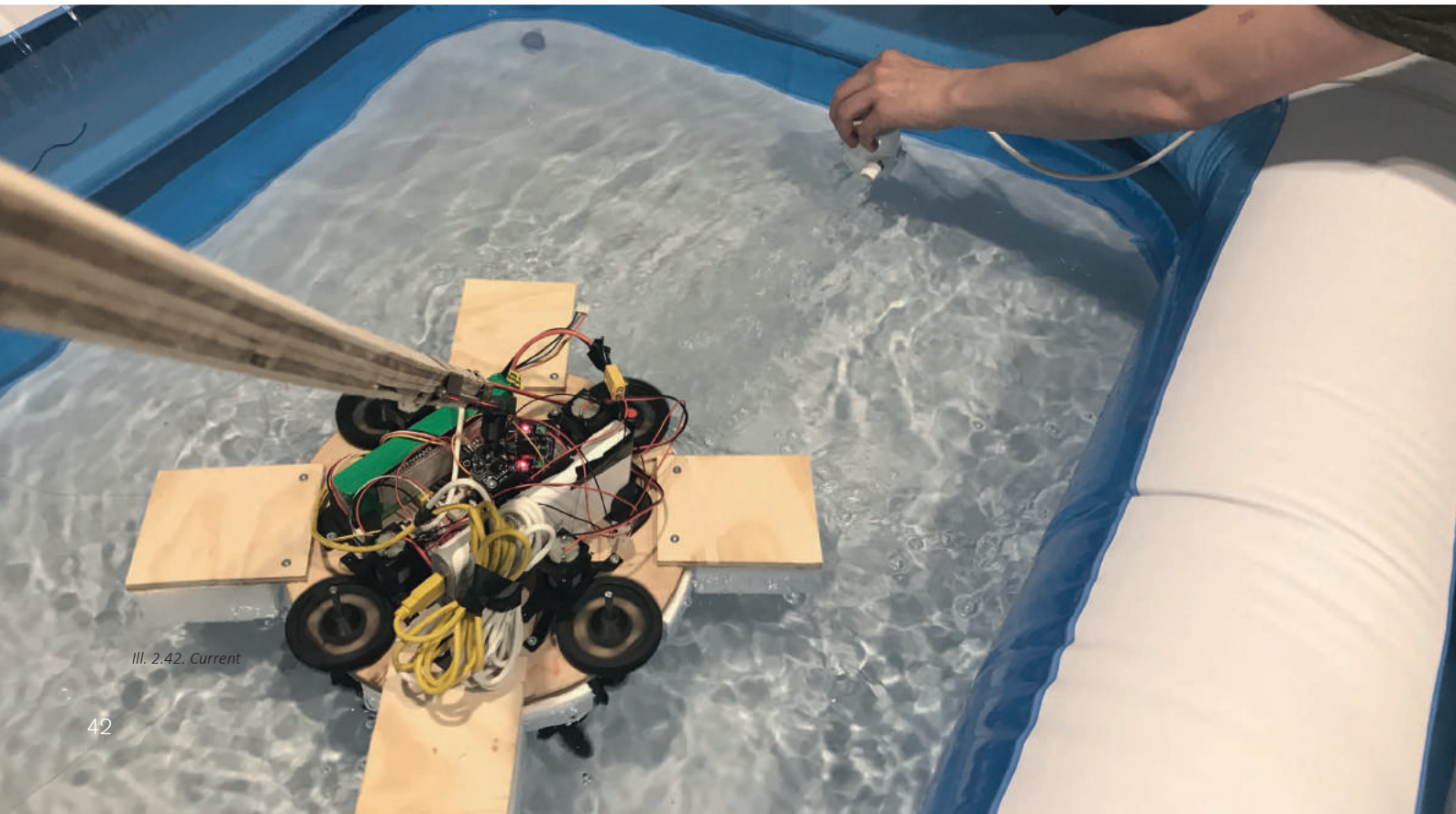
The initial purpose of this test was to evaluate the concept for interaction, and how a round design with two pairs of motors and propellers would handle. Before it was possible to get to the testing, many iterations on the initial design and electronic system were preformed.

Regarding the electronic system, many aspects that need further investigation have been acknowledged: Reading and processing the input data to output for the motors, powering the motors with individual motor drivers, and finding the right power source.

The round design and setup of the motors worked better than the team had expected. The success of the design was highly depended on the upgraded batteries that gave the motors the power needed to feel responsive.

The testing of the interaction method though a stick was an immediate success. The physical connection to the product worked as intended. The simple way of interacting with the model, made the operation effortless and the members of the team quickly felt fully in control of how the product was moving. The extension of the stick made the model even more reactive to the operators every movement. The precise control of the model exceeded the exportations of everyone on the team.

The test of moving against a current was an crucial part of the verification, if the concept had the possibility of becoming a success in real conditions. The testing went over all exportations, even though the rotating joint made the model spin when the current was hitting the sides of the model. However, because of the round design it had no effect for the operator, the programming made the motors shut on and off to stay on the desired course.



*Ill. 2.42. Current*

# CHOICE OF CONCEPT

The purpose of the Interaction test was to determine if the Weed Management Drone concept has potential for further development. The results from the test excited the expectation for the member of the team. The drone was capable of responding to the every movement made by the operator. The operation of the drone was effortless and simple due to the physical connection and tactile response from the model.
The Weed Management Drone will therefore be the concept for further development.

# Concept Development

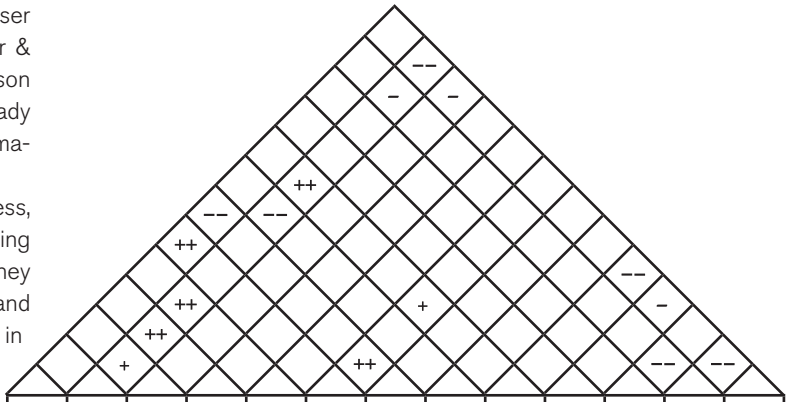
# HOUSE OF QUALITY

The House of quality is the tool chosen to convert the user needs to more tangible engineering characteristic. (Hauser & Clausing, u.d.) It is chosen not to fulfil the product comparison part in House of quality, due to some of the aspects already have been covered in the Paradox mapping and in the Automation mapping.

The user needs has been gathered throughout the process, from the early desk research phase and later when interviewing stakeholders. To identify the most important user needs they were rated by Peter Munk from the Aalborg municipality, and Lars and Ole from Sloth Naturpleje, their rating can be seen in Appendix H. The house of quality will ensure that all user needs will be covered in the final solution.

The engineering characteristic and the associated objective measures in the bottom of the table will be the guide for the future concept development.

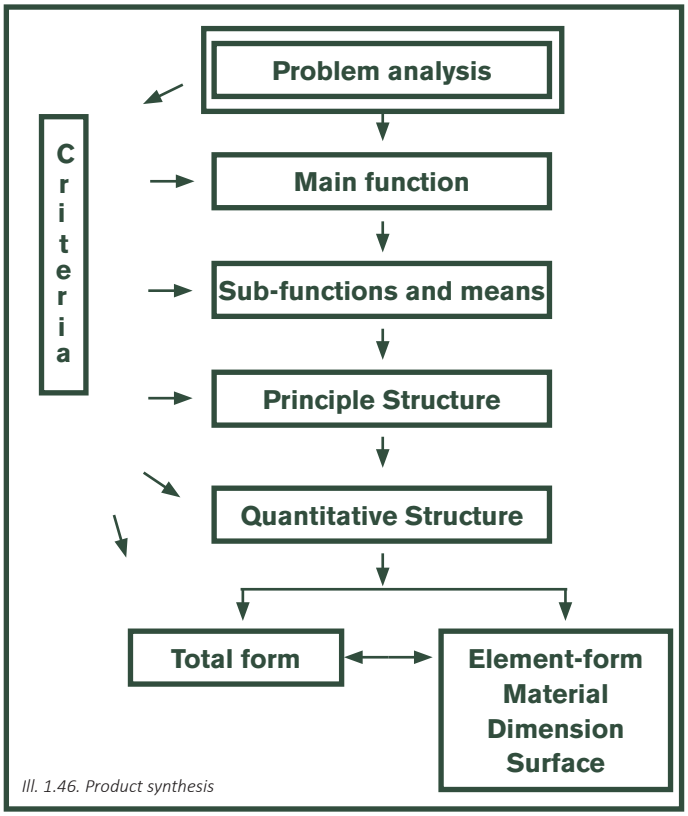
● = Strong connection between demand and user need
○ = Weak connection between demand and user need
++ = Strong connection between demands
\+ = Weak connection between demands
−− = Strong contradiction between demands
− = Weak contradiction between demands




| No. | User needs | Avg. user rating | The ability to cut close to the bottom | The product needs propulsion to move itself | The product is floating to remove the weight on the user | The stream worker is able to control the product from the riparian or in the stream | The product is controlled with a stick to give a tangible interaction with the product | The cutter must move autonomously in relation to the bottom | System to avoid rocks | Hours of operation | Effective cutting | The cutter head must be able to cut under water and above water | The dimension of the product | The draught of the product | The total weight of the product |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Engineering characteristic | | | | | | | | | | | | | | |
| 1 | The product needs to be able to cut close to the bottom | 5 | ● | | | | | ● | ○ | | | | | | |
| 2 | Solution for the exhausting task of moving in streams, especially upstream or in muddy streams | 4 | | ● | ● | ● | ○ | | | | | | | | ● |
| 3 | The product should not rely on the stream worker to work with their arms extended from their body or with the back bend | 5 | | | | ○ | ● | | | | | | | | |
| 4 | The product should be able to run 5.5 hours a day | 3.5 | | | ● | | | | | ● | | | | | |
| 5 | The product needs to be light and agile to access the smaller streams. | 4 | | ○ | ○ | | ● | | | | | | ● | ● | ● |
| 6 | Find cheaper cutting methods | 5 | | | | | | | ● | | | | | | |
| 7 | Manual tool must be more efficient than existing solutions | 4.5 | | ● | | ○ | | ● | ○ | ● | ● | | | | |
| 8 | Easy transportation from car to stream | 5 | | | | | | | | | | | ● | | ● |
| 9 | The tool must be able to cut a depths at 100-900 mm | 4 | ○ | | | | | ○ | | | | ● | | | |
| 10 | The product must be able to remove the cut off weed | 3 | | | | | | | | | | | | | |
| 11 | The product must be able to cut the riparian | 4 | | | | | | | | | | ● | | | |
| 12 | When operating the product from the riparian it must be able to cut in streams at a width of 3 m | 2 | | | | | ● | | | | | | | | |
| 13 | The product should be functional even in muddy water with plant debris | 4 | | ● | | | | | | | | | | | |
| 14 | The product must not be able to tip over during the operation | 3 | | | | | | | | | | | | ● | ○ |
| | Target | | 40 | Yes | Yes | Yes | Yes | Yes | Yes | 5.5 | 3.6 | 500 to -900 | 500 by 800 | 100 | 35 |
| | Unit | | mm. | Binary | Binary | Binary | Binary | Binary | Binary | Hours | m./min. | mm. | mm. | mm. | kg |

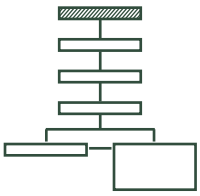
# PRODUCT SYNTHESIS

The Product synthesis, created by Eskild Tjalve, will be used as a tool to guide and track the drawing process through the concept detailing (Tjalve, 1976). The Product synthesis is divided into different steps, which are important to go through in order to design a product. The model can be seen on Ill. 1.46.



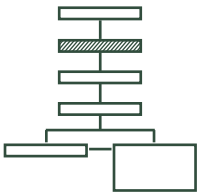

*Ill. 1.46. Product synthesis*

The Product synthesis is based on two outputs from the problem analysis, which are the main function and the criteria. The criteria in the Product synthesis are the engineering characteristic from the House of quality. As it can be seen on the model the criteria are involved through the whole construction process as a control for each step where a decision is made.
The concept can be divided into three main function: "Control of the product", "The movement of the product", and "The cutter".

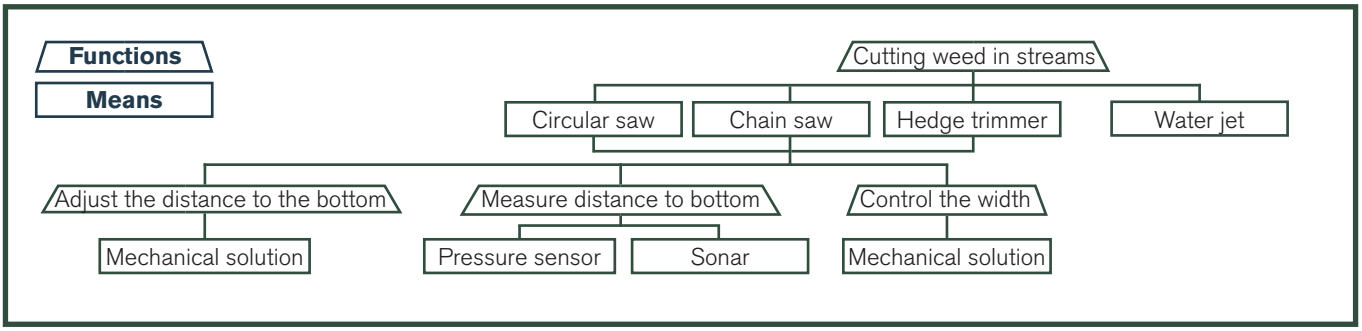


The cutter is the main function that is specified the least in the concept so far, but can be argued that it is the most important part of the concept. Therefore it is chosen to start specifying the cutter for the concept.

## The cutter - Function mean tree



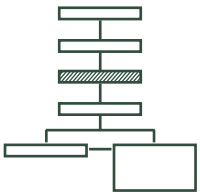
The main function of the cutter is to cut the weed under water the question is: How to do it?
The second step in the product synthesis model is the sub-function and means. The mean is to be understood in the sense of a solution or principle for how a function can be carried out where the sub-function is a deconstruction of the main function. The function mean tree will be used to explore different solutions for how the cutting process could look like. The means to cut will be held up against the demands that the cutter must fulfil.




*Ill. 2.46. Function mean tree cutting weed in stream*

The main function in The function mean tree above, is "Cutting weed in stream". The mean to cut the weed could have its starting point in how other tools cut plans, but must be explored in the next phase in the product synthesis model: Principle structure.
Regardless of which mean there is chosen, the solution must contain the three sub-functions in order to fulfil the demands for the product. The three sub-functions can be seen in the third row. The mean to "Adjust the distance to the bottom" and "Control the width" is anticipated to be a kind of mechanical solution, but it must also be explored. The third sub-function is that the cutter must measure the distance to the bottom, it can be done with a pressure sensor, sonar technology, or other sensor, but it needs to be researched.

## Cutter - Principle structure

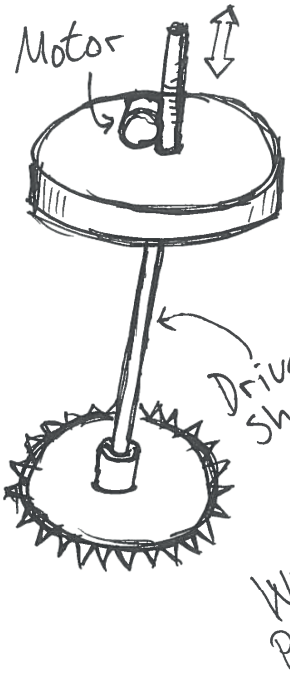


The third step in the product synthesis model is the principle structure. A mean from each sub-function from the function mean tree is combined to a solution, which is called the principle structure. The principle structure is characterised by simplified drawings where quantities and dimensions are not decided.

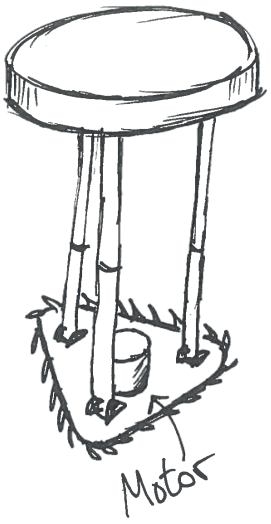
It was chosen first to draw different proposals for the main function “Cutting weed in streams” to open the solution space. The sub-functions will in the next steps be integrated in the solutions.

The first proposal Ill. 1.47. is to have a circular saw blade in the same size as the drone. The motor to run the blade is an electric motor, which is attached to the blade to avoid energy loss.
The second idea Ill. 2.47. is to have a triangle cutter. The cutter itself is a chain with knifes attached to. The chain is also driven by an electric motor.
The third idea Ill. 3.47. is to use a finger bar. This is the same method as a motor scythe use.
The fourth idea Ill. 4.47. is to use a band saw blade. The blade is pointing forward, and is spinning around the gears, which constitute a triangle.

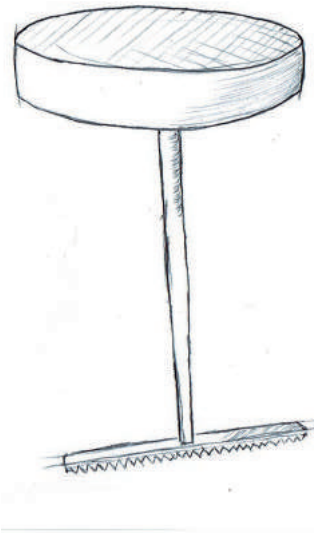
It is not possible to determine, which solution that is best. The four ideas only solve the main function. The principles in the ideas will be used as an inspiration when the main function is combined with the sub-functions.



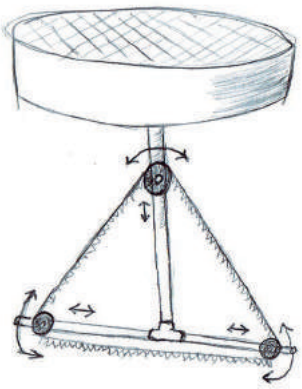

*Ill. 1.47. Buzz saw*




*Ill. 2.47. Triangular saw*

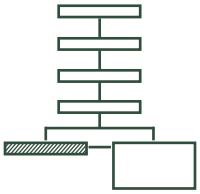


*Ill. 3.47. Finger bar*



*Ill. 4.47. Band saw*

## Total form



The form of the product is compiled in two parallel lines, due to that the total form and the element form are determine concurrent. The element form is conditioned by materials, dimension, and surfaces. The demands for the total form depends on which kind of product it is. If the aesthetic has a high value the elements form must fit the total form. If technical features and economy is prioritised the total form must depend on the elements form. (Tjalve, 1976)

It is important when designing a B2B product for stream workers that the product is infallible and the functions work after the intention. Therefore it is important that the total form fits the element form. The initial drawings of the concept seem to show that the mechanical component will be hidden under a shell. Therefore, the shell of the product have much influence on the total form and how the product is perceived. The production price of the shell do not vary in connection to how many convolution there is in the design. It is therefore chosen to use extra time on the shaping of the shell, since it will add extra value without raising the production cost.


*Ill. 1.48. Leaf blower Husqvarne*

## Form analysis

To get inspiration for the future design of the product, different products have been analysed. The first product is a Husqvarna leaf blower Ill. 1.48. The second product is a pressure washer from Stihl Ill. 2.48. The third product is a sweeper also from Stihl Ill. 3.48. The two brands Husqvarna and Stihl can both be found in the B2B market where the brands are reputable by professionals.

The chosen products have in common that they have the an engine and components hidden behind a shell. Each time a shell adjoin another shell, the colour of the shells switch, which amplifies the dynamic of the product. Furthermore, the colour indicate touch points and what areas to interact with. Between the shells there is space, which create a small shadow. It makes it easier for the person that observe the product to decode the structure, which make the product more honest.

The shapes are angular with soft edges, which gives the impression of robustness and it is strong.

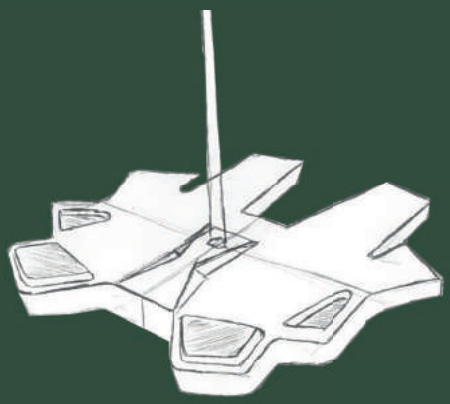

*Ill. 2.48. Pressure washer Stihl*

*Ill. 3.48. Sweeper Stihl*

## Total form - first round

With inspiration from the form analysis, different ideas for the form of the product were sketched. Beyond the inspiration from the form analysis, the ideas should contain the three main functions: “Control of the product”, “The movement of the product”, and “The cutter”.
The sketches are all inspired by the Weed Management Drone concept where the concept was completely round. The Weed Management Drone does not have any direction, which is durable, because the cutter is round. All of the ideas below are designed with a direction. All the ideas contain different surface levels. To make the change more clear different colours are used. Those change in surface level and colour creates a dynamic expression.

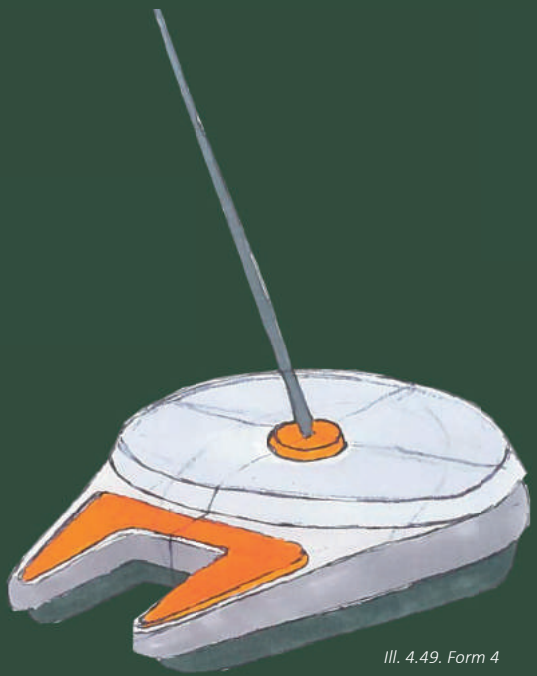
This ideation round on the total form will be kept in mind while developing the sub-functions. The total form will be developing throughout the product development.



*Ill. 1.49. Form 1*

*Ill. 2.49. Form 2*

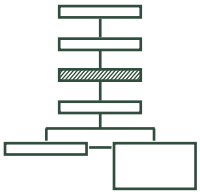
*Ill. 3.49. Form 3*



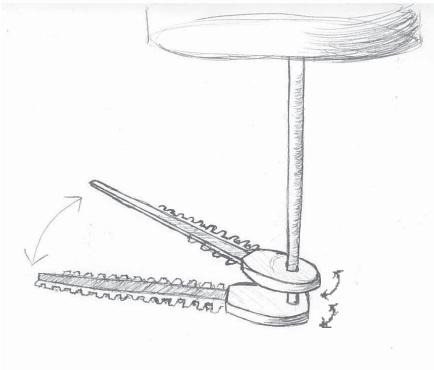
*Ill. 4.49. Form 4*

*Ill. 5.49. Form 5*

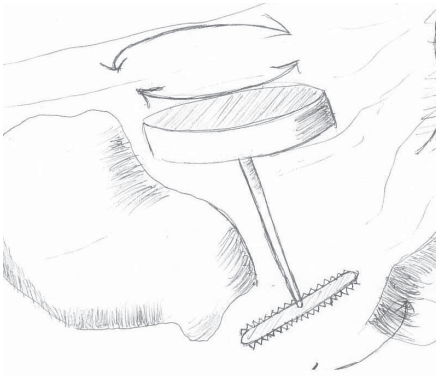
## Control the width - Cutter



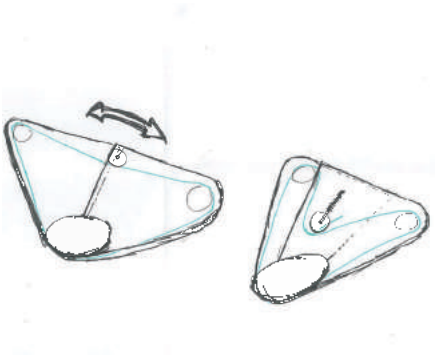
Control the width of the cutter is the first sub-function in the function mean tree Ill. 2.44. The width of the cutting area need to be able to change, because of the many obstacles in a stream. The mean to change the width was set to be a mechanical solution, which a vague term. The reason to that is that the changing of width depends on which weed cutting method that is chosen.
The first idea Ill. 1.50. is to use the principle with a finger bar. In this proposal there are two finger bars, which have the same pivot point around the axis. The two finger bars can turn around the axis, and thereby change the width of the cutting area.
The second idea was also to use a finger bar. This finger bar is attached to the axis. In this idea it is the boat that is turning around its own axis. When the boat is turning and sails in a direction the width of the cutting area change, as it can be seen on Ill. 2.50. where the boat avoid two rocks.
The third idea Ill. 3.50. is to have a triangle form that can change its angles and thereby change its own width. Along the edge of the triangle a chain is spinning with knifes attached.



*Ill. 1.50. Two finger bars*

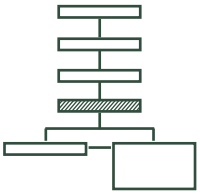


*Ill. 2.50. Rotating finger bar*



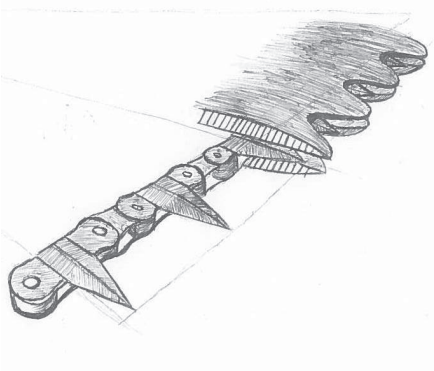
*Ill. 3.50. Control the width*

## Test - Cutter width



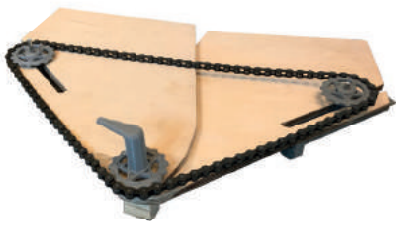
The next level in The product synthesis is quantitative structure. In this level the solution is optimised and important parameters specified, but the form of the elements are still not defined.
It was chosen to work further on with the third idea Ill. 3.50., because the construction seemed simple. It was chosen to build a mock-up of the idea in order to confirm the working principle.

The first step was to figure out how the knifes should spin. On Ill. 4.50. can it be seen that the knifes are protected between to pieces of metal. The metal pieces are longer than the knifes to avoid rocks. It was uncertain if it was possible to change the width of the form while the chain was spinning, so it was chosen to build a model to test it. The mock up consisted of two plates of wood, three gear wheels that a bicycle chain spun around. The mock up can be seen on Ill. 5.50. and Ill. 6.50.
It was important that the chain never became slack, therefore two tension spring were attached to the two gears, which pulled them back. A slit were cut out in the two plates, which the gear could drive in when the plates were pulled from each other.
The test showed that it was possible to change the width while spinning the chain. It is important that the two springs have a high resistance in order to avoid that the chain get slack and jump off.



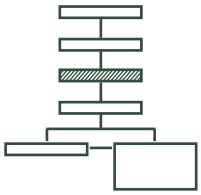
*Ill. 4.50. Chain drawing*

*Ill. 5.50. Chain wide*



*Ill. 6.50. Chain narrowed*

## Adjust the distance to the bottom

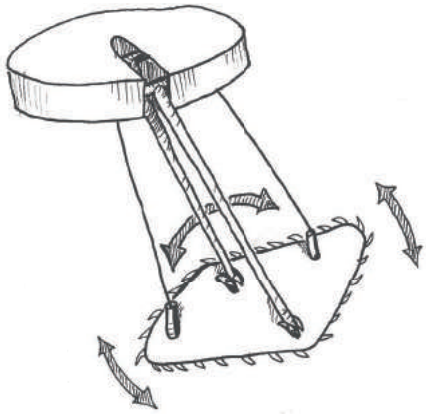


It is a demand that the product is able to cut with a distance of 40 mm above the bottom. In the research it is described how the bottom of a stream is not even. Therefore, it is important to find a solution for the cutter so it can adjust itself in relation to the bottom. The cutter must be adjustable in both the x-axis, y-axis, and the z-axis. This is the second sub-function in the function mean Ill. 2.44. The mean to the function is again set to be a mechanical solution to open up the solution space. The demands for the ideation were that the cutter should be adjustable and combine with a cutter from the main function.

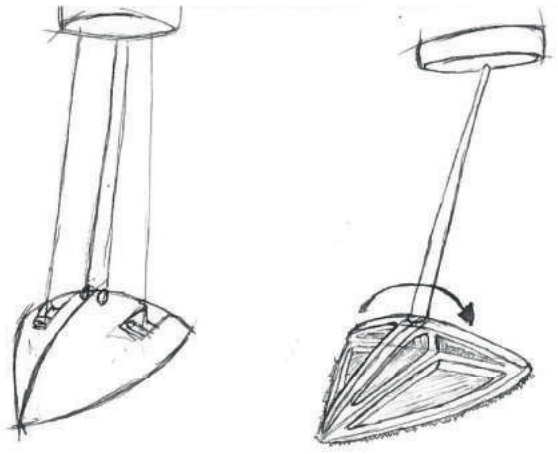
The first idea Ill. 1.51. was to have a finger bar upon a pair of ski, so the cutter would be able to ski upon the mud. Between the ski and the legs there is a rotating joint, so if the tip of the ski hit a stone the ski will glance off.
The second idea Ill. 2.51. was to have a chain as cutter. Two bars are attached to the cutter. The two bars control the hight of cutter, and furthermore control the rotation of the cutter in the y-axis. Two wires are attached in the side of the plate, which can control the rotation in the x-axis. The distance to the bottom is measured with sonar.
The third idea Ill. 3.51. was to have a triangle cutter. The cutter is connected to the boat with a bar and two wires. The bar control the hight of the cutter, and can furthermore rotate around its own axis so the cutter rotate in the x-axis. The two wires can be role in and out , which will change angle of the cutter in the y-axis. The distance to the bottom is also measured with sonar in this idea.

It was chosen to build the second idea, because this idea seemed to have the lowest complexity. The purpose of the test was to see how it would work to measure the distance from the cutter to the bottom, and use that input to adjust the cutter.

*Ill. 1.51. finger bar on ski*

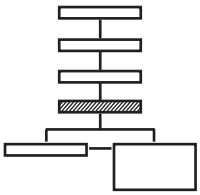


*Ill. 2.51. Sqaure cutter*



*Ill. 3.51. Triangular cutter*

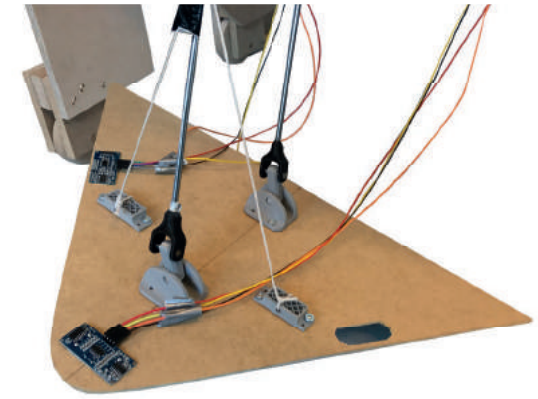
## Test - Cutter hight



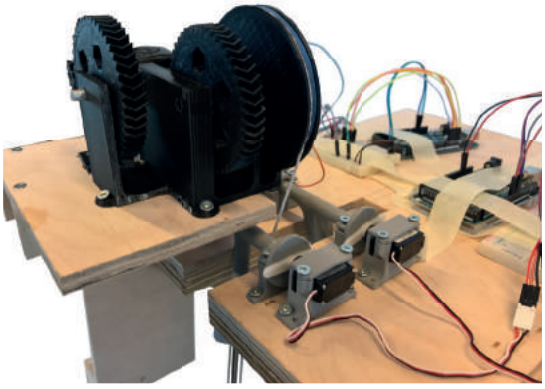
The purpose of model was to test if it was possible to have an uneven bottom that the cutter should adjust itself to, by using ultra sonic sensors to measures the distance to the bottom.
Each metal bar in the middle of the cutter was controlled by a servomotor. The servomotors were chosen, in order to be able to make precise adjustments. The joint between the bars and the plate was an universal joint, so the cutter had the freedom to rotate in all three dimensions. The two wires were attached to a wheel, which were controlled by a DC motor.

Unfortunately the servomotors did not have enough torque to move the plate. This could be because of the weight and the long distance between the servomotors and the plate. Even with bigger servo motors it would not work.

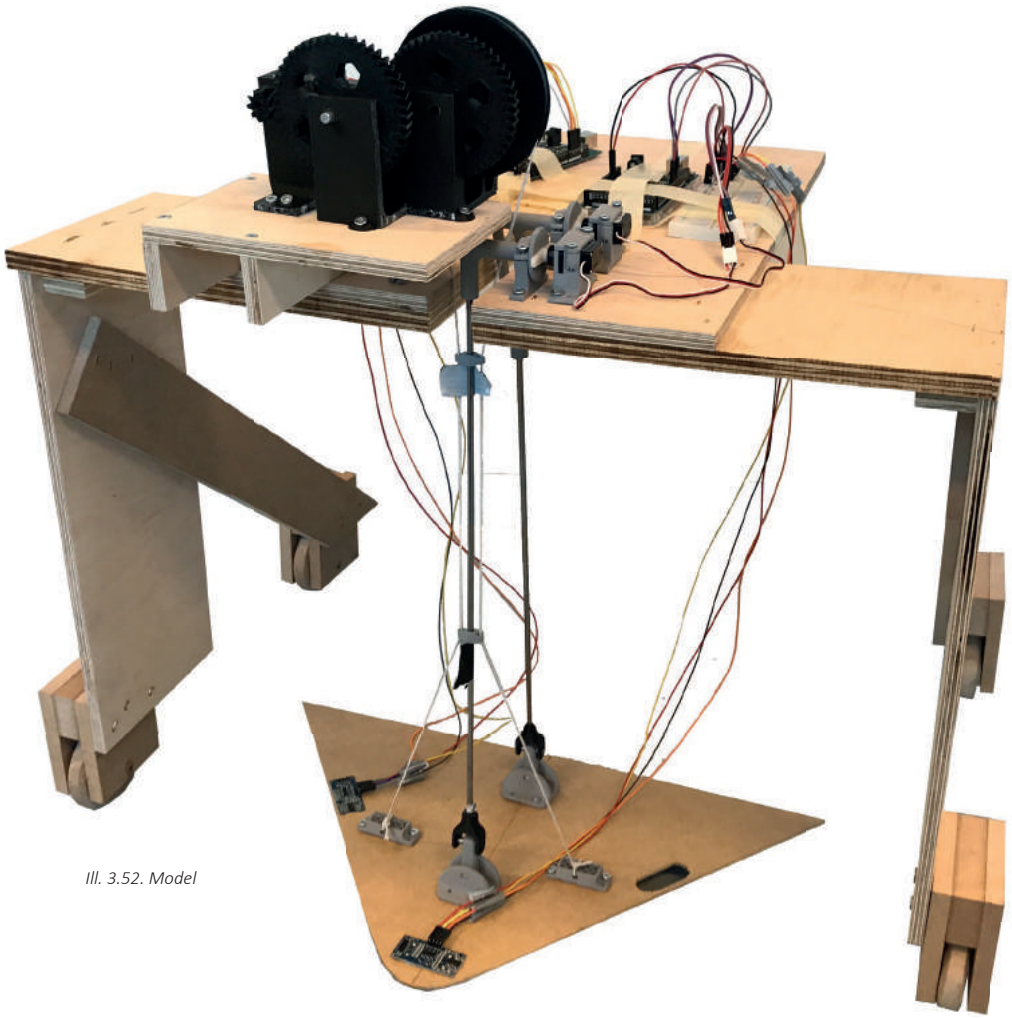
This was unfortunate as the code for using the ultra sonic sensor to activate the servo motors, seemed to work. When the components were laying on the table the servos would move as intended according to the distance to the ultra sonic sensors, but when installed on the model, the servos proved too small.
Nevertheless, the model seemed to be able to move in the intend way. The to bars would control the height and the angle of the cutter, while the wire would control the angle around the other axis.



*Ill. 1.52. Ultra sonic sensors*

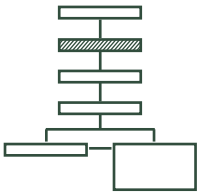


*Ill. 2.52. Servo motors and gear*

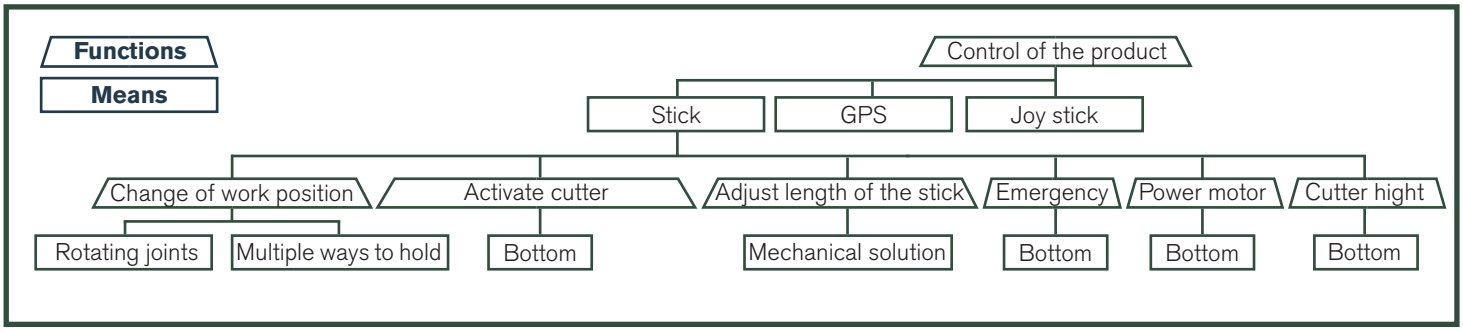


*Ill. 3.52. Model*

## Interaction

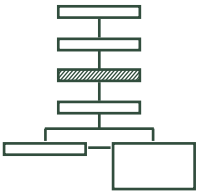


The second main function of the concept is the Control of the product. A function mean tree is again used to get an overview of the different sub-functions and means regarding the interaction Ill. 3.53. The main function is “Control of the product”. The control can be done in three ways. The first option is that the product is controlled with a remote controlled joystick. The second mean is to use GPS technology, so the product is self driving. The third idea is to use a stick to control the product with. It was chosen only to work further on with the stick as the mean to the control the product, because earlier research and tests showed that it worked well for the operator to have a physical connection to the product.




*Ill. 1.53. Function mean tree - Control the product*

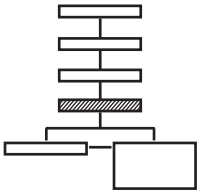
## Interaction - principle structure



It was chosen to sketch upon the sub-function “change of work position”, because of the importance of passing the ergonomic conditions the Danish work environment authority described in the injunction. On Ill. 2.53. an extract of the proposals can be seen. As it is not possible to fully understand the how the handle will be based on sketches it was chosen to build models. The models can be seen on Ill. 3.53. and consist of pole sticks of wood and 3D printed handles and joints.

*Ill. 2.53. Different form for handle*

## Interaction - test



The purpose of the test was to test different ergonomic potions and try out different handles. The test was to move a plate that was attached to the stick and hit paper plants, which can be seen on Ill. 4.53. and Ill. 5.53. Pros and cons were found in each model. Based on the test it was not possible to choose a handle, but the test showed pros from each solution. In Appendix I, Interaction, it can be seen how the styling of the handle could be.

*Ill. 3.53. Mock ups of handle*

*Ill. 4.53. Mock ups of handle*

*Ill. 5.53. Mock ups of handle*

# PRESENTATION FOR SLOTH NATURPLEJE

A second meeting with Sloth Naturpleje was arranged to present the current status of the project for the possible end user. The purpose of the meeting was to get their feedback on the concept, and on the solutions for the different sub-functions. The meeting was arranged at this time, because most of the essential functions had been considered.

## Meeting

The meeting started with a presentation of what had been done since the last visit. The three different concepts were presented and both Lars and Ole agreed in the reasoning for choosing the Weed Management Drone for further development.

The Interaction test with the motors were presented, where they were excited by the result and the solution. They pointed out that the motors would have to be powerful to move the product against the current. Another thing they mentioned was that the solution with walking on the riparian would only be useful in a few specific scenarios, as they determine it is easier walking in the stream.

The principle model of the cutter and how it changes width was presented. The response was positive as they could see the need for this function to make the rest of the concept function optimally. The comments regarding the choice of using a chain instead of a finger cutter was more positive than expected. As Lars Sloth had previously stated that rotation parts will end up being stuck in plant debris. The solution with having bigger fixed protection teeth under the moving knives, making the solution function in the same way as a finger cutter, was also a good choice.

The principle model of how the cutter is supposed to move in relation to the bottom was the last part of the presentation. Lars and Ole were impressed by the solution, but started expressing apprehension towards the entire concept. The reason for their concern was the complexity, with the different sensors and many moving parts. As the current solution with the motor scythe is very robust and a broken cutter is easy to fix in the field. They were also afraid that the complexity would result in an expensive product.

## New direction proposed

Lars and Ole saw a number of difficulties in the current solution for working in the rough conditions of a stream, but they could see the potential of the concept in another context where they also work. Cleaning of ponds and lakes, especially on golf courses is a big market and Sloth Naturpleje is often contacted to do those tasks. The job of cutting in lakes is expensive as the boat will have to be lifted from the trailer to the lake, which is a time consuming task. Furthermore, the client has many concern regarding damage on the golf course. Sloth Naturpleje was contacted by a client where they had 14 ponds that had to be cut every three to five weeks. Lars explained that transport from pond to pond would take around one hour and cutting would take around 30 minutes, resulting in a price higher than the client was prepared to pay.

Lars and Ole could both imagine the concept, and that most of the sub-functions would fit almost all the needs a greenkeeper would have to a product, which is intended to cut water weeds in lakes.

## Reflection

The outcome of the meeting was not as expected, the team had expected to get critique on the different sub-functions and discuss the different solutions for moving forward. Instead Lars and Ole suggested taking the existing concept and changing the context.

The concept and sub-functions are based on the different user needs gathered throughout the project. It can then be argued that the team should have predicted that the current concept was too complex for the use scenario, but with user needs like: *The product should not rely on the stream worker to work with their arms extended from their body or with the back bend* and *The product needs to be able to cut close to the bottom.* Sensors and actuators are needed to replace the human operating the product.

# A NEW DIRECTION ?

After the meeting with Sloth Naturpleje a big decision would have to be made. Continue working with weed cutting in smaller streams and redesign much of the product, or reframe to work with weed cutting in lakes on golf courses and redesign the product to fit new user needs.

Besides the comments made from Lars and Ole another factor that advocates for a change in direction is the potential market. In the search for competing products for cutting in streams, equipment for lakes was also search for. In this initial search no solution for cutting in lakes were preforming anything like the concept that has been developed in this project.
If it is chosen to reframe, new stakeholders with the problem of getting the ponds on their golf courses cleaned will have to be contacted. Both to verify the problem, but also to find new user needs. A new competitor analysis will have to be made to uncover the current existing solutions, and expose a potential gap in the market.
Additionally, it has been problematic to find information on how big the market is for manual weed cutting tools, as in most other countries they use bigger machinery for maintaining streams. Besides the initial verification of the problem and competitor analysis, the Danish and global market for cleaning lakes on golf courses will have to be investigated before taking the final choice.
If it is chosen to reframe one of the biggest changes to the concept will be the interaction with the product. The control though a stick will no longer be beneficial and principals from self driving lawn mowers might add more value in this context, but this hypothesis will have to be investigated.

# Research 2

# MEETING AT AABYBRO GOLF CLUB

The first step in investigating if the cutting of water weeds in lakes on golf courses, have more potential for the developed product, is to contact a greenkeeper. The greenkeeper will be able to verify or disprove if the initial ideas of the market and user needs is as Lars and Ole had described.
A meeting was created with Jens the head greenkeeper of Aabybro golf club, to explain how they deal with water weeds in the nine ponds they have, Ill. 3.57.

*Ill. 3.57. Jens the head greenkeeper*

## Tour of the golf course

Jens recognised the problem with water weeds immediately. They have many issues with their ponds and especially with keeping the water weeds away. At Aabybro golf club they have very shallow ponds at a maximum depth of 90 cm. This allows the water weeds to grow in the entire pond and not just around the edges.
In order to remove the water weed they use a sickle bar mower for keeping the plants down on the edges. For the plants in the water they use the motor scythe. Cutting plants in and around the lake is not part of the normal routine, as it is physically demanding and time consuming work. It is only done once or twice a year, because it requires two persons an entire day to clean one of the nine lakes. They had gotten offers from contractors to cut the weeds in the lakes, but the cost would be around 30,000 DKK for each lake.

*Ill. 2.57. Damage from excavator*

Once a year they use an eight ton excavator to clean out the ponds of water weeds. The procedure is only done late in the season because of the damage the excavator cause the golf course, and the extensive amount of repairs that will have to be made afterwards, some of the damage can be seen on Ill. 2.57.
The expenses associated with getting the ponds cleaned is also extensive. Last year Aabybro golf club had two ponds cleaned for 250.000 DKK. In this process the ponds were also dug a bit deeper, but for the small golf club this amount of expenses has a big impact on the entire budget.

## Response on the concept

Jens was positive towards a product made for cutting the plants in their ponds. This will allow them to have a good looking pond the entire year. It will also have the possibility of solving the issue with damage to the golf course and they will not have to hire external contractors. The idea of having a product using the same way of manoeuvring, as can be seen in self-driving lawn mowers, was also appealing to Jens.
Jens expressed a wish that the future solution should be able to cut the lowest area around the pond. When this area is not cut water weeds will grow like it can be seen on Ill. 1.57. and Ill. 4.57. leaving a unwanted messy look. The product should also be able to collect or remove the cut off plant material to limit the amount of plants decomposing in the ponds, releasing nutrients for more plants to grow.

*Ill. 4.57. Transition from pond to semi-rough*

## Reflection

The first meeting with a greenkeeper was very informational for the team. It verified the assumptions about the need for a solution that is cheaper than having external contractors and a solution that does not damage the fairway surrounding the pond. Meetings with more golf clubs will have to be arranged to verify that the needs in Aabybro golf club are not unique.

| | |
|---|---|
| The product needs to be able to cut the lowest area around the ponds | ✓ |
| The product should be able to collect or remove the cut off plant material | ✓ |

*Ill. 1.57. A typical pond on the Aabybro golf course*

# COMPETING PRODUCTS

The tools used for cutting water weeds in lakes and ponds are different for what have been found for cutting in streams. There are more equipment designed for home use, and a wider variety in how the tools cut the weeds. This search will serve to get inspiration for how the concept could work in different ways, but also to explore what solutions that might be on the market.

## Beachroller Weed Eliminator

One of the tools is the Beachroller by Scott Aerator, it is a manual tool that rolls along the bottom, Ill. 1.58. (aerator, u.d.) Different knives are attached to the roller, some of them will cut the plants others will pull them up by the roots. A long stick on 4.5m is attached to the roller so the product can be used in lakes as big as nine metre without entering the lake. It is a simple tool with only a few components and changeable blades. The price for the product is around 1,600 DKK.

*Ill. 1.58. Beachroller*

## Lake Groomer

The Lake Groomer that can be seen on Ill. 2.58. is a product by Weeders Digest. (Digest, u.d.) The product removes water weeds on the bottom of the lake by having a 6.4m roller rotate around one point. The rollers will kills the plants by rolling over them multiple times. The disadvantage of a product like this is that it only can remove plants in a perfect circle. Therefore the product will not be a viable option for irregular shaped ponds, like what was observed at Aabybro golf club. The product costs around 23,000 DKK.

*Ill. 2.58. Lake Groomer*

## WeedShear

The WeedShear is another manual tool for removal of weeds. It is a simple product, and the operation of the product is equally as simple. The way the product is used is by throwing it as far as possible into the lake see Ill. 2.58. Then dragging it back to shore. The razor knifes are mounted in an angle so when dragging it across the bottom all plants are cut close to the bottom. The price for the basic version of this product is around 1,200 DKK. (WeedShear, u.d.)

*Ill. 3.58. Throwing the WeedShear*

*Ill. 4.58. Amphibious weed cutting boat*

## Amphibious weed cutting boat

The only product found targeted towards golf courses is the amphibious weed cutting boat Ill. 1.58. (Naturpleje, u.d.) This product resembles the weed cutting boat seen in the stream cleaning industry. What is special about this product is the wide soft belt tracks, that allows the "boat" to drive across the fairway without leaving any permanent damage. The price for this product is around 710,000 DKK. (Gneckow, 2016)

## Market

With the only product targeted towards weed cutting on golf courses being, the amphibious weed cutting boat, there seems to be a market for a product targeting this issue. There might be solutions used in different areas of the world, but that does not seem to be the case based on this research. Jens the head greenkeeper of Aabybro golf club, does not have knowledge of other products for this task, and explains how he has observed the problem with water weeds on many golf courses around Europe.
In Europe there are 6.937 golf courses, 188 in Denmark, and 34.000 in the entire world. (LeadingCourses, u.d.)

## Sum up

It has been difficult to find products made specific for cleaning lakes and ponds on golf courses. One thing that this research has shown is how many other countries have a looser regulation regarding use of herbicides. Nevertheless, the market for a product for cutting water weeds on golf course seems bigger than for a product made for smaller streams.

The setup of the product needs to be quick and simple

# MEETING AT BLOKHUS GOLF CLUB

A meeting was created with the head greenkeeper from Blokhus golf club Henning to verify the statements from Jens and examine what difficulties they have with maintaining ponds.

## Tour of the golf course

Henning has many of the same problems as Jens managing the lakes on the golf course. Around the lake emergent plant are present and is disturbing the view of the well maintained golf course, Ill. 1.59. The lakes on Blokhus golf course are generally much deeper than the ponds in Aabybro, most of the lakes are 2.5m deep in the middle. This ensures that no emergent plants grow in the middle of the lake, but in some of them water plants are growing just under the surface, like it can be seen on Ill. 2.59.

*Ill. 2.59. Water plants floating in the surface*

Henning is using much manpower to keep the areas around the lakes nice and neat. On Ill. 3.59. it can be seen how a good transition is now, the grass is cut all the way down to the lake. This procedure is time consuming and difficult to preform therefore it is only done on selected areas. There are still growing water plants in the water that Henning would like to have removed.

*Ill. 3.59. Transition from lake to fairway*

## The solution

Like Jens, Hennings biggest wish for the solution is to be able to make a nice transition between the lake and the fairway. The bottom conditions is therefore important for this feature to succeed. A walk in the lake did not reveal anything unexpected. The bottom was covered with a few centimetre of mud and then a hard bottom Ill. 4.59.

*Ill. 2.59. Testing bottom conditions*

## Sum up

The issues with weeds in the lake is not as present as at Aabybro golf club, but it also has a higher priority and more time is used to manage them. Though they still have unwanted plants in the water that ruins the nice aesthetic of the well maintained golf course. The biggest lake on the course is 3000 $m^2$ and is one of the lakes they have the most trouble maintainng.

| | |
|---|---|
| The product must cut under the water level so the plants can not be seen. | |
| The product must be able to cut a pond on 3000 $m^2$ | |



*Ill. 1.59. Henning the head greenkeeper*

# SLOTH NATURPLEJE

As stated earlier Sloth Naturpleje are, besides the business of cleaning streams, also in the business of cutting weeds and dreading the bottom for sediments in golf lakes. After the meeting where they proposed the idea of changing context, a second meeting was arranged to get more specific facts about weed cutting in lakes.
The business with golf lakes is for Sloth Naturpleje only a small business area, because the clients have high demands for how little damage they are allowed to do to the golf course. Furthermore, the budget the greenkeepers have is also in most cases limited.

## Case study

Sloth Naturpleje showcased one of the jobs they had done on a golf course. This job was both to remove the weeds, but also to remove the bottom sediment. This was done with an excavator with a normal shovel attached. There were not used driving steel plates so the tracks were very deep into the golf course as it can be seen on, Ill. 1.60. and Ill. 2.60.
After the lakes bottom was cleaned for sediments the excavator could start covering its track marks, Ill. 3.60. .
The price for the removal of bottom sediments was 30,000 DKK, and another 30,000 DKK for the reconstruction of the damage made by the excavator. Besides the 60,000 DKK, the greenkeeper will have to do extensive work to regrow grass.
Lars has after two years talked with the greenkeeper that states that water weeds are starting to take over again.

## Interview

Lars Sloth was interviewed about the problems related to golf lakes. He estimates that every five years the sediments will have to be removed from a lake, but if the water weeds are cut and the removed, the period might be extended to eight to ten years. Lars emphasises that these numbers are examples, because many different factors have effects on how lakes and water weeds behave.
Lars states that a product that would be able to cut the water weeds more often would kill some plant types entirely. These plants are the emergent plants. Jens the greenkeeper from Aabybro golf club especially had many problems with these plants in the middle of his lakes. They will die because they will not have the opportunity to grow out of the water, which is essential for their survival.
Lars Sloth has knowledge of companies that specialises in cutting weeds on golf courses and know they have substitution agreements with the golf clubs. This means that the contractor will cut the weeds three to four times a year. The price for this service is around 10-15,000 DKK for each lake.

The product must not leave visible tracks on the golf course

*Ill. 1.60. Tracks from the excavator*

*Ill. 2.60. Tracks from the excavator around the lake*

*Ill. 3.60. Reconstruction of area around lake*

# REFRAMING

With the meeting at Aabybro and Blokhus golf club it was clear that there was a need for a product to cut water weeds in the lakes. There is a long time period between when the golf clubs have excavators come to dig out the bottom sediments and remove the water weeds. In some golf clubs the lakes are left as a wilderness in between these sediment removals. The lakes will be adding no real aesthetic value to the golfing experience. Therefore, there is an opportunity to develop a product to cut the water weeds to maintain a good looking golf course.

In Denmark there are 188 golf clubs, the Europe market is around 7,000 clubs, and on a global scale there are around 34,000 golf clubs.

The expenses associated to keeping lakes in a good condition is extensive. The chart below shows the average cost the different involved stakeholders has stated. Below the average yearly cost is calculated. The cost for cutting water weeds is on average 18,333 DKK. On both Aabybro and Blokhus golf club they have nine lakes, so the total yearly expense would be around 165,000 DKK. The 165,000 DKK is only for one cut a year with multiple visit the price would easily double or triple.

It is stated in the Danish Golf Unions regulations that: "*On the area around lakes that is part of the play area, it is desirable to have grass of fairway standard all the way down to the water surface" (Union, 2007)*

Jens nor Henning is using this amount of money on contractors, but it would be necessary to obtain the well maintained lakes they both strive to have.

| **Cutting of water weeds in one lake** | |
|---|---|
| Price | Source |
| 30,000 DKK | Jens head greenkeeper, Aabybro Golf club |
| 15,000 DKK | Henning head greenkeeper, Blokhus Golf club |
| 10-15,000 DKK | Lars Sloth |
| 18,333 DKK | Average cost |
| **Removal of bottom sediment in one lake** | |
| 125,000 DKK<br>Including metal driving plates | Jens head greenkeeper, Aabybro Golf club |
| 60,000 DKK<br>Including reconstruction | Lars Sloth |
| 92,500 DKK | Average cost |

# MARKET ANALYSIS

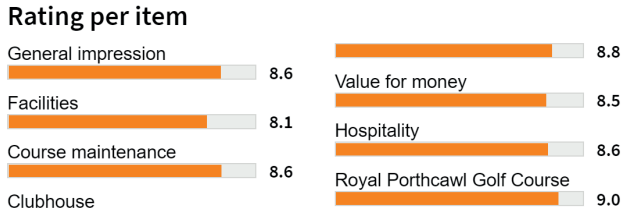
A market analysis is made by contacting multiple golf clubs all round Europe. It will be explored if maintaining lakes for water weeds is an isolated issue in Denmark.

## Result

More than 30 clubs have been contacted by Email, but only one club has answered. Multiple clubs have been contacted by phone, but only very few had the time to answer.
Nevertheless all the contacted clubs that answered, either maintained the lakes manually or used contractors. The manual tools used were the motor scythe or regular scythe. When using contractors they used the amphibious weed cutting boat, normal weed cutting boat, or excavator.
On the map the different statements from different countries can be seen.
A solution that is different from what else have be discovered is from Italy. Head greenkeeper Giorgio Marcolongo, from Golf Club Paradiso del Garda in Italy, mentioned that because the overflow from the lakes on his golf course runs out in the Garda lake, he does not have the permission to use chemical products as other golf clubs in Italy does.
Though, it is not certain if Giorgio Marcolongo refereed to removing plants or algae with chemical product, due to difficulties in communication.
Based on statements from golf clubs in Europe, it indicate that there is a market potential in other countries for a new solution.

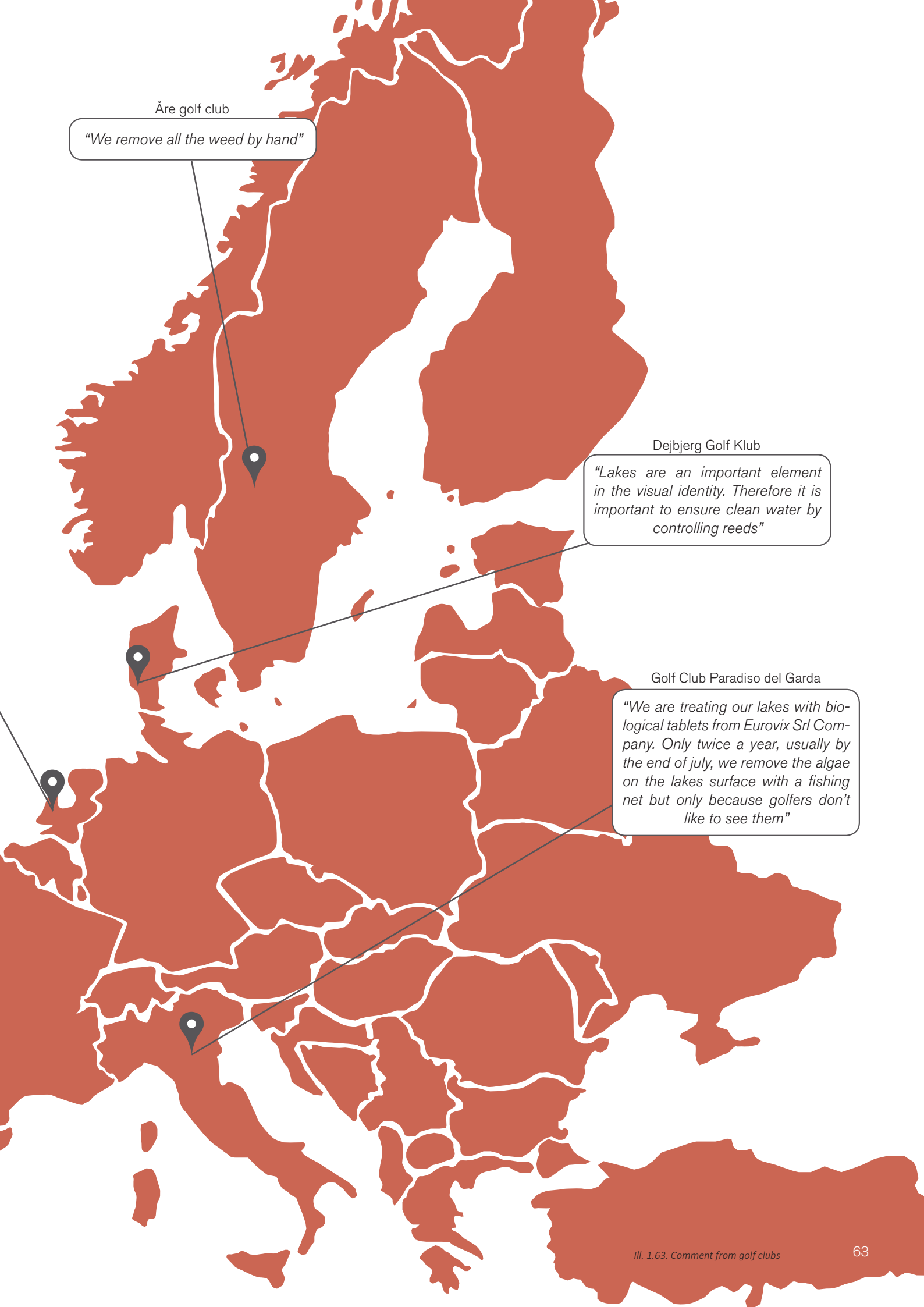
## Rating of golf courses

During the market analysis many different online user driven ranking systems for golf clubs were discovered. The higher the rating, the more likely golf players are to visit the golf club. The rating of the course depends on multiple different factors including course maintenance. On Ill. 2.62. the rating of Royal Porthcawl Golf Club can be seen. The rating is from Leadingcourses who compares ratings of golf clubs from all around the world. (LeadingCourses, u.d.)




*Ill. 2.62. Rating of Royal Porthcawl Golf Club*

The ratings indicate the aesthetic and the hole experience matter for the golf players, but also that the golf clubs must try their best in each category, to attract new players.




*Ill. 1.63. Comment from golf clubs*

# Ideation 2

# USER NEED

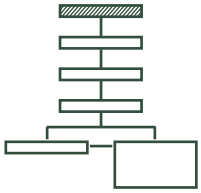
The user needs from the previous section: Research 2, will be summarised and used for this ideation phase. The user needs are mainly derived from interviews with the greenkeepers and the contractor.

The research has given insights into what functions the product needs to have. Both interviewed greenkeepers had little time, so the lack of maintenance of the lakes was more a issue of time and budget management, than an active choice. From this the team leaned that the product needs to be simple to deploy and use.

For the cutting of the plants it also became apparent that the cutting will only be for aesthetic improvement of the golf course, therefore it will not have to cut along the bottom, which makes the product simpler.

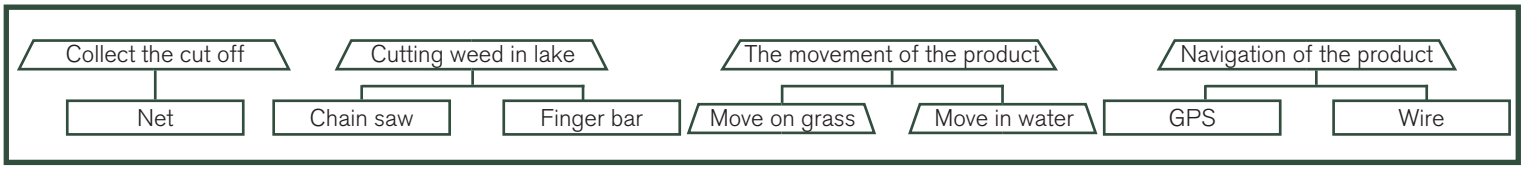
| User needs |
| --- |
| **Cutting weed in lakes** |
| The product needs to be able to cut the lowest area around the ponds |
| The product should be able to collect or remove the cut off plant material |
| The setup of the product needs to be quick and simple |
| The product must cut under the water level so the plants can not be seen. |
| The product must be able to cut a pond on 3000 $m^2$ |
| The product must not leave visible tracks on the golf course |

# PRODUCT SYNTHESIS



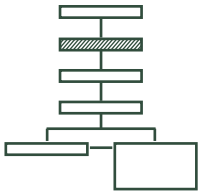
The re-framing affected the user needs. The function mean tree was updated as the functions in the product needs to be different. Two out of the three main function remain the same: “The cutter” and “The movement of the product”. The third main function was before the re-framing “Interaction with the product through a stick”. This main function is changed to “Navigation of the product”, because the context is changed from streams to lakes, which is a much more controlled environment.

A fourth main function is added, which is “Collect the cut off”. It is important that the cut off are removed from the lake, due to that it will not look good to have cut off in the top of the water, but also because it will increase the amount of nutrients in the water, which cause algae and faster regrowth of the plants. This is information the team received from Jens, the greenkeeper of Aabybro golf club.




*Ill. 1.66. Function mean tree main functions*

## Combine main functions



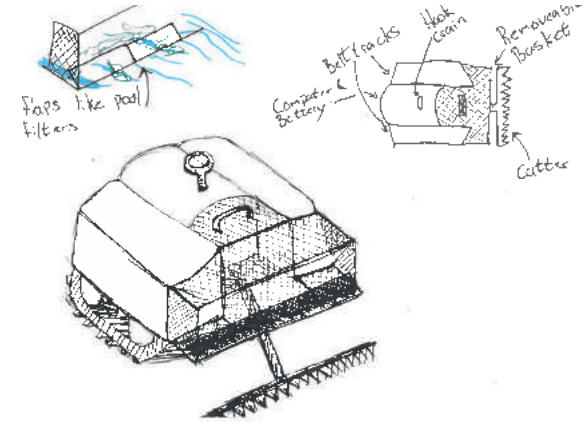
All four main functions is listed in the top of the function mean tree on Ill. 1.66. Three of the main function have different means to solve the problem listed below them except from “the movement of the product”. Under the main function two sub-function are listed, due to that the product need to be able to move on the grass and in the water.

It was chosen to sketch on all four main function at once to open up the solution space after the re-frame. The sketches did not have to take into account how the navigations should work, only that the product should be full automatic.

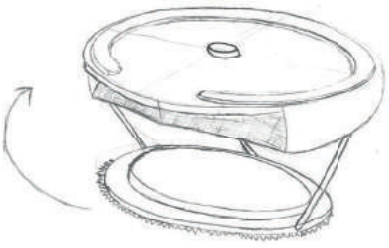
The update user needs open up the possibility of designing a larger product than for the streams. The idea on Ill. 2.66. uses crawler tracks to create thrust in the water, but can still drive on the grass. The product use finger bars to cut the plants. In the front of the product there is a basket that collects the cut off. To avoid the cut off to float back to the lake two flaps, like what can be seen on pool filters, are used.

The next idea’s main principle is that the cutter is turned up and down Ill. 3.66. When the product cut grass on the riparian, the cutter is up under itself as can be seen on Ill. 4.66. This is positive, because is not possible for the product to cut any person, while the product is active.

The idea on the sketch is also propelled by crawler tracks. The crawlers tracks are attached underneath the cutter part, to get a low centre of mass in order to avoid the product to tip over.




*Ill. 2.66. Cutter tank*



*Ill. 3.66. Drone with rotating cutter*

*Ill. 4.66. Drone with rotating cutter section view*

# SELF DRIVING TECHNOLOGY

The navigation is the first of the main functions that will be explored. The navigation part is a crucial part of the product, due to it was one of the features both of the greenkeepers preferred. Different technologies in similar products will be researched in order to find the best match with the demands for this concept.

## Robotic lawnmower

When the topic of reframing and redesigning the Weed Management Drone to work in lakes, the future solution was immediately explained as a robotic lawn mower for lakes. The primary technology that is used to keep robotic lawnmowers within its boundaries is a simple wire that is connected to the charging station that outputs an electromagnetic signal. The lawn mower picks up this signal, which signals the mower to turn and cut in another area of the garden. Most of the current robotic lawnmowers are using a random cutting pattern. This technology is cheap, but it requires installation of the wire that has to be connected to a base station. (Einecke, Deigmöller, Muro, & Franzius, 2018)

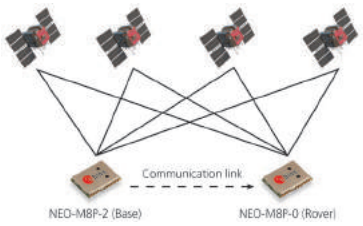
*Ill. 1.67. Honda robotic mower*

## Wheel Odometry

A technology that does not require any instantiation or exterior products is wheel odometry. Most robotic lawnmowers have two motorised wheels. What wheel odometry requires is encodes in each motor, that measure the velocity of the wheels. The wheel velocity is used to calculate the precise movement of the product. One of the big flaws in using this technology is that if a wheels slips on wet grass, it will lose track of where it is. (Einecke, Deigmöller, Muro, & Franzius, 2018)

## GNSS

The NEO-M8P module is based on the global navigation satellite systems (GNSS). The NEO-M8P is made specially for unmanned vehicles that require centimetre accuracy. The way the system reaches this level of accuracy is by having two GNSS modules, one on the "rover" and one on a base station. The base station will communicate its position to the rover. The rover will combine the information from the two modules to precise location information. The NEO-M8P has the option of using an moving base station, adding more flexibility to a setup utilizing this technology. (u-blox)

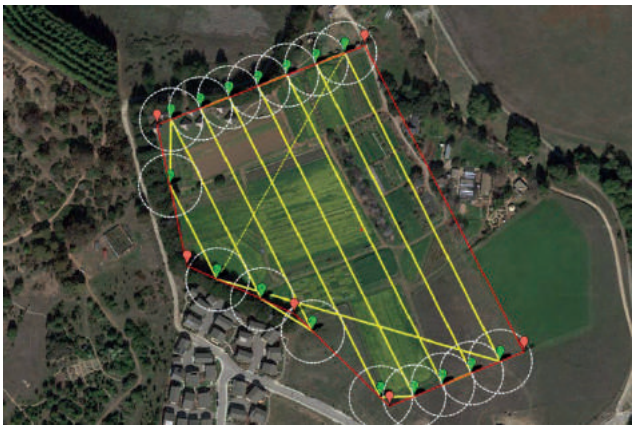



*Ill. 2.67. GNNS-M8 prnciple*

One of the downsides of the GNSS system is that it requires visibility to satellites. The context at a golf courses near lakes is therefore near ideal conditions for visibility. (Einecke, Deigmöller, Muro, & Franzius, 2018) The price for the NEO-M8P moduels for both "rover" and base station is around 106 DKK. (u-blox)

## Choice of technology

For the future product it is chosen to use the NEO-M8P GNSS modules. The main reason for this choice is the possible ease of setup as it requires no installation of permanent equipment. This decision is based on the user need that : The setup of the product needs to be quick and simple.
Though when the boundaries of a wire are removed the product will need some other input to know what boundaries to cut within.



*Ill. 3.67. Flight plan example*

## Path planner

With the choice of using the GNSS modules there is a need for how to input the boundaries into the product. A solution similar to the DJIFlightPlanner could be a viable option. (djiflightplanner, u.d.) The smart thing about this is that the greenkeeper can control exactly where the product cuts, unlike the random patterns a normal robotic lawnmower make. This means that the greenkeeper can choose that the products need to be extra thorough in specific areas of a lake or leave other areas to make the playing experience more difficult for the golf players.

# USER SCENARIO

Based on the statements from the interviewed greenkeepers and the research into the available technology a user scenario is developed. The user scenarios will illustrate which steps will be involved in using the product.
The user scenario will help guide the future development of the product, by ensuring that the different steps of using the product will be covered in the product.

*Ill. 1.68. Overgrown lake*

1. The greenkeeper observes that one of the lakes on the golf coruse needs to be cleaned for water weeds. Instead of contacting a contractor he decides to use a new product on the market, a self-driving mower for cutting water weeds in lakes.


*Ill. 2.68. Mapping cutting area*

2. To use the product the greenkeeper has to use a map to select where the product needs to cut. He can deside how much times the product need to use in each lake, and how the product should cut it.

*Ill. 3.68. Product cutting weeds on the edges*

5. The product is cutting everything in the selected area. It is able to sail and cut the plants in the water, and drive up on land to make a nice transition between water and land.

*Ill. 4.68. Product being loaded on a golf cart*

6. When the product is done with the cutting, it notifies the greenkeeper and he can pick it up.

*Ill. 1.69. Installation of GPS base station*

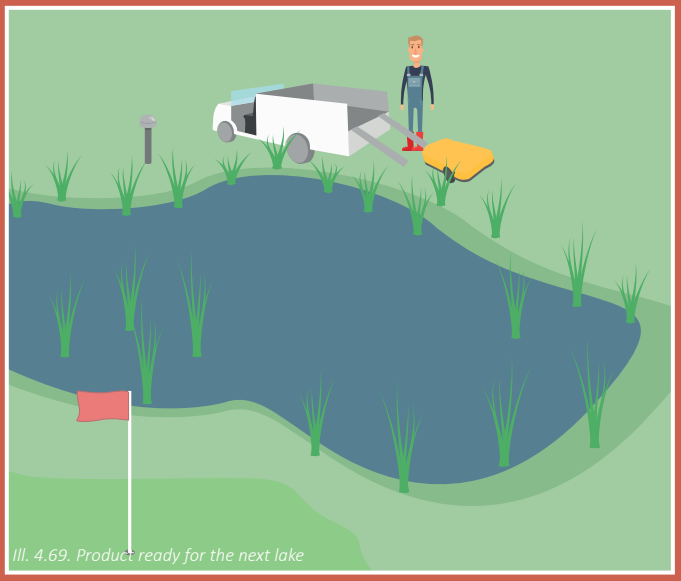
3. Before the product can be used a GPS base station will have to be installed near each lake. This will improve the precision of the product to be within a few centimetre.

*Ill. 2.69. Start up of product*

4. The greenkeeper drives the product out to the lake and activates it. When it has been connected to the GPS it will start cutting according to the selections made on the computer in step 2.

*Ill. 3.69. Charging and empting product*

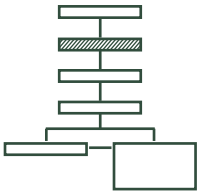
7. After cutting a lake the batteries in the product will have to be charged and the collection basket for cut off water weeds will have to be emptied.



*Ill. 4.69. Product ready for the next lake*

8. After charging the batteries and emptying the collection basket, the product is ready to cut the next lake. Near this lake another base station is mounted to ensure precision.

# THE MOVEMENT OF THE PRODUCT



The product is using GNSS modules to navigate itself. In this section the purpose was to find solutions for how to create thrust. The demands for this function is that the product must be able to drive on the grass, and float in the water.

The first idea Ill. 1.70. takes inspiration from a ZVM-2901, which is a Russian military vehicle that is made for all kind of terrain including water. The principle is to have two screws that spin and in that way create movement. The disadvantage with the principle is that it will tear up the ground, which is not optimal on a golf course.

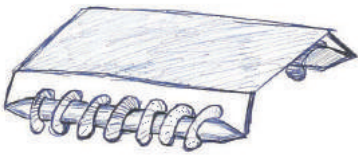
The second idea Ill. 2.70. takes inspiration from a hovercraft. A hovercraft is known for being able to driving upon land, mud, water and so on. The hovercraft use a big propel to blow air in order to create thrust.

The third idea Ill. 2.70. uses caterpillar tracks. Caterpillar tracks are used in many vehicles that must be able to drive off road. Some snowmobiles are even able to drive upon water by way of using caterpillar tracks.

The fourth idea is to use paddle wheels, which is used on wheel boats. The idea is that the wheel can be used to paddle water, but it is also able to drive on land.

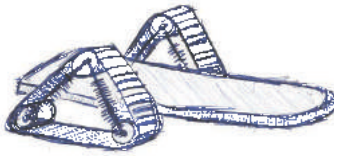
All four ideas use the same function to move in water and drive on land, rather than having a separate motor and propeller, which is smart due to that it lower the complexity of the product.
It is chosen to work further on with the idea with the paddle wheels. The first idea was excluded, because it will tear up the groud. The second idea will most likely not work, because of the slanting edges. The caterpillar tracks will possibly work, but the complexity and weight is high, so it is not chosen to work on with this principle to begin with.
The complicity of a wheel is relatively low, but test most be carried out in order to validate the principle as a successful solution.

| Test if paddle wheels are a good solution for the future product | !! |
|---|---|

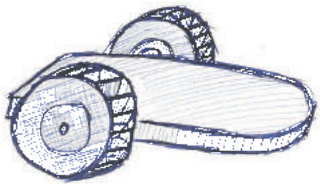


*Ill. 1.70. Spinning screws*

*Ill. 2.70. Hovercraft*

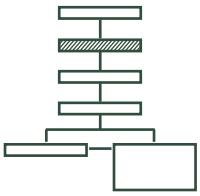


*Ill. 3.70. Caterpillar track*



*Ill. 4.70. Mill*

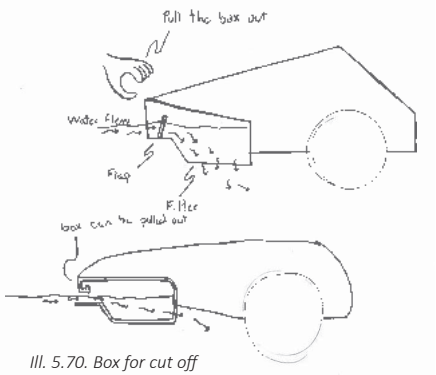
# COLLECT THE CUT OFF



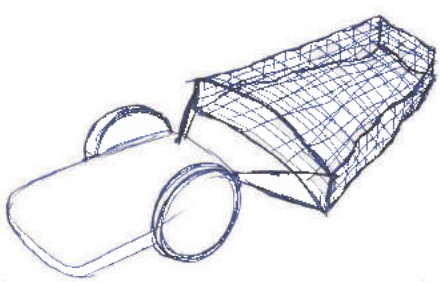
A demand for the product is that it must be able to collect the cut off. The purpose of this ideation round was to find different solutions for how this task can be done.
Many of the ideas drawn was similar to the idea on Ill. 5.70. where a box collects the weed that is floating op top of the water. In the bottom of the box there is a filter. The filter make it possible for the water to float through, but stops the weed. The weed can neither swim back, because flaps make sure the flow only is in one direction.

Different ideas explore the possibility to attached an extra component. The idea is that the product have two programs. A program where the product cut all the weed, and a second program where the product collects the weed. After the product is done cutting, a net or a sweeper is attached, and the second program is started.
To determine the most optimal solution, it must be researched how much weed the product have to collect.

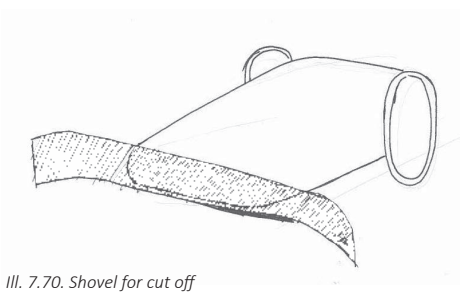
| Investigate how fast the plant regrowth, and how much plant mass there is in a lake. | !! |
|---|---|




*Ill. 5.70. Box for cut off*



*Ill. 6.70. Net for cut off*

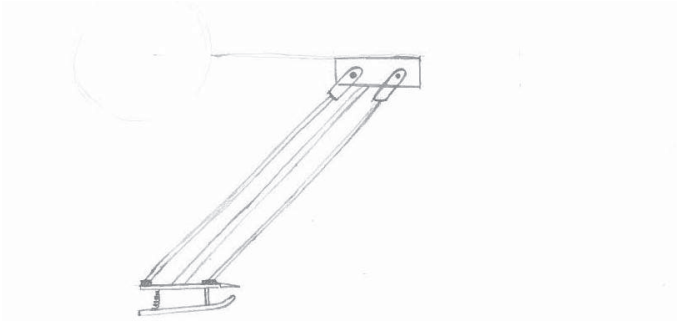


*Ill. 7.70. Shovel for cut off*

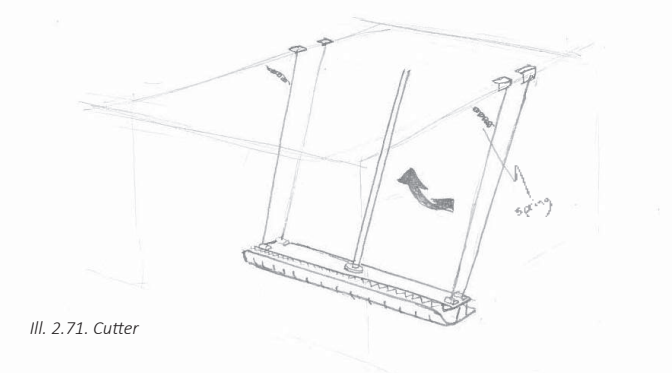
# FINGER BAR UP & DOWN

A wish for the product is that the complexity of the product is low as possible. Furthermore, it is desirable that standard components can be used for some of the functions in order to lower the production cost. It is therefore chosen to find a mechanical solution for how a finger cutter can move up and down. When the cutter is up, it is important that the cutter is hidden by the product so it can not hurt anyone like on the sketch is on Ill. 4.64. page 64.

Different ideas were drawn. The solution that seemed to be the best can be seen on Ill. 1.71. and Ill. 2.71. Four bars are attached to the bottom of the product, and hold up the cutter. The bars can swing, so the cutter can move up and down. There are no motor that adjusts the hight of the cutter. A ski is attached under the cutter. When the ski hits the bottom the ski will follow the bottom. To make the cutter more or less weightless under water a spring is attached. The spring should helt prevenmt the cutter getting stuct in mud.

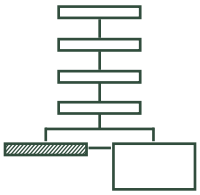


*Ill. 1.71. Cutter from the side*




*Ill. 2.71. Cutter*

# FORM



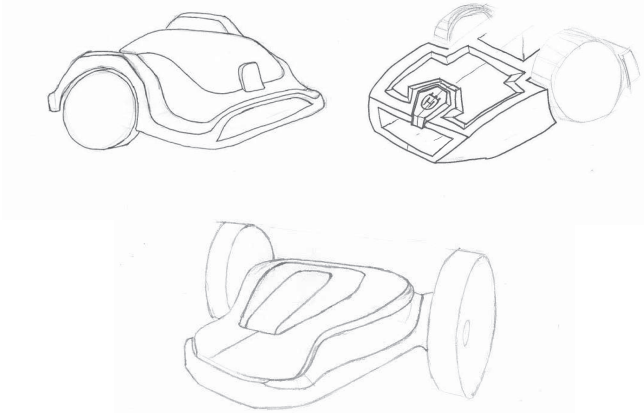
In this section the form language of the product was in focus.

The ideation round were divided into three. What all three ideation rounds had in common that the ideas should have interoperated either paddle wheels or caterpillar tracks.

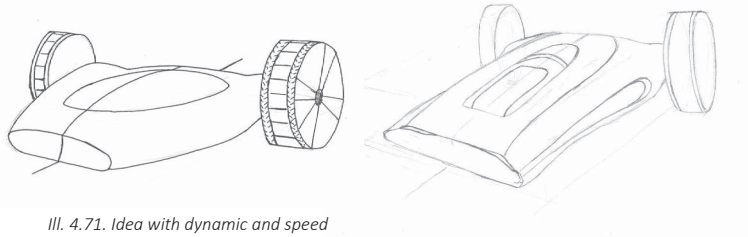
The purpose of the first ideation round was to take inspiration from earlier form analysis on page 46 where different product from the brands Husqvarna and Stihl were analysed. Some of the ideas from this ideation round can be seen on Ill. 3.71.

The second ideation round focused on giving the form some more dynamic. The wheels are a big part of the design, due to the size of them. Instead of hiding the wheels with skirts the wheels have been put into focus by letting them stand alone. The form goes from being wide in the back to be more narrow in the front, which give the product dynamic.

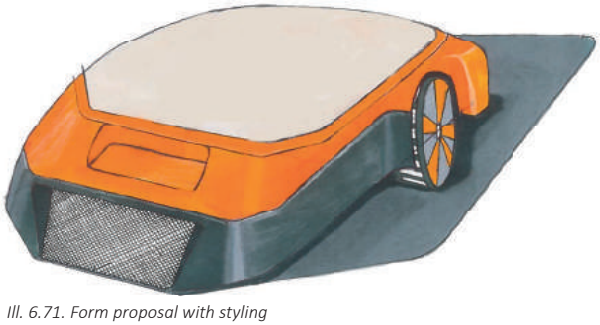
In the last ideation round the form language is change from being dynamic to sturdy.



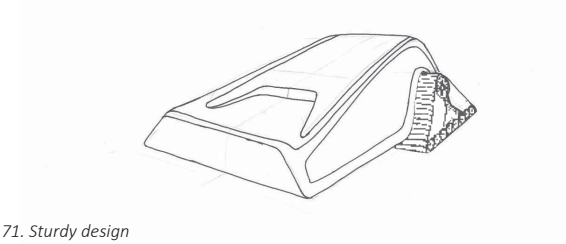
*Ill. 3.71. Idea with inspiration from form analysis*



*Ill. 4.71. Idea with dynamic and speed*



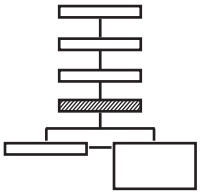
*Ill. 6.71. Form proposal with styling*



*Ill. 5.71. Sturdy design*

# Concept Development 2

# MODEL TEST



A model of the sub-functions from the previous pages was build in order to test different functionalities. The model consist of a plate of wood where two wheels made of plastic are attached. The wheels have a dimension of 400 mm in diameter and a width of 100 mm. It is important that the wheels are big, due to that a paddle wheel with a larger diameter are more efficient and create more forward thrust. (Gary, u.d) The wheels are spun with a crank handle. It had been optimal with two motors to provide the energy, but the size of motors needed require big batteries, and motor drivers, which would have taken to many resources to provide and build at that time in the process.

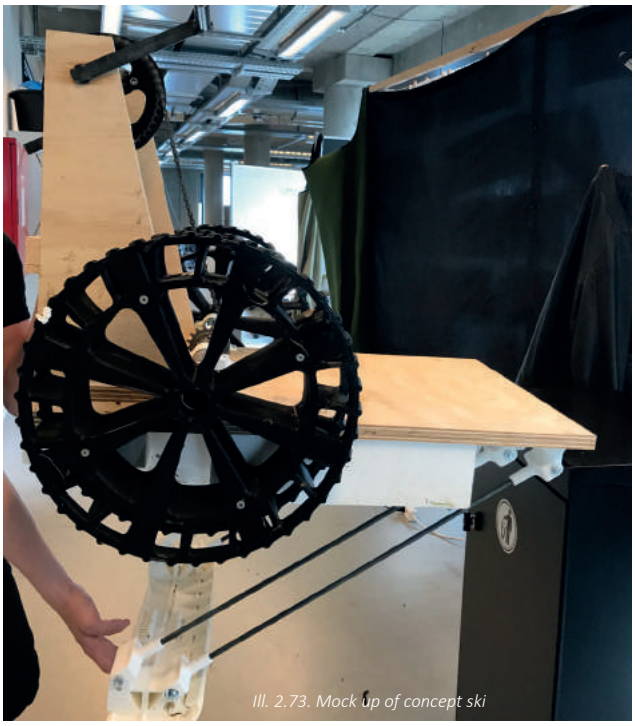
Below the wood plate the finger bar cutter is attached Ill. 2.73. The idea is that the finger bar will be connected upon a pair of ski. Four bars on 620 mm connect the cutter and the mount on the wood plate. Springs are holding the bars up, so the skis only can go 300 mm down below the bottom of the product. The reason for the springs is that if the skis hit the bottom or obstacles in the lake the skis will easily glance off, due to that the springs make the cutter more or less weightless under water.

Foam was glued to the bottom of wood plate in order to create more buoyancy. It was calculated that the foam alone was able to carry 28 kilo.

The idea behind the test was to discover how the concept behave in the transition from water to grass. The concerns are that the skis will not follow the bottom and get stuck in the mud, and furthermore that the wheels and product will sink into the mud and create to much friction for the product to move.

The test was carried out at Aabybro golf club in the lake that can be seen on Ill. 3.73. below. In the lake there was vegetation around in the edge mainly reedmace in a early stages. In the middle of the lake water thyme was laying below the water surface, which is hard to spot on the image. If the test should have been optimal the water weed should have been cut like intended. The land around the lake was not muddy, but was not dry either.

*Ill. 1.73. Mock up of concept*



*Ill. 2.73. Mock up of concept ski*

*Ill. 3.73. Lake Aabybro golf club*

## Result of test

The first function that was tested was how the product was laying in the top of the water. It can be seen on Ill. 1.74. the centre of mass was laying in the back of the product, where the wheels are attached, which made the product lay askew in the water.

The second function that was tested were the paddle wheels. Even thought that the paddle wheels were spun manually with a crank handle, which easily could have an effect on the movement, the test showed the paddle wheels created thrust. The design of paddle wheels must be redesigned to get better efficiency. It can be seen on Ill. 1.74. and Ill. 3.74. that water is coming out from the sides, creating unnecessary drag.

The scenario of when the product goes from water to ground was also tested. The test showed that it was not possible for the model. It was not possible, because the wheel did not have any contact with the ground, due to that the product was rear-wheel driven. When then foam, in the front of the product, hit the ground the wheel just spun as it can be seen on Ill. 2.74.

A fourth test was made in order to test if it would work better if the wheels were in front. The mock-up was not made for this test, and the position for the operator was awkward. Even thought, it gave an indication that it was a better solution with the wheels in the front. Another observation was that the wheels needs to be further forward than the edge of the model, in order for the wheel to get grip when hitting the ground. Furthermore, it is important that the foam in the front is curved, so the foam does not prevent the product from moving or creating drag.

Before the test the team was at uneasy about if the cutter would get stuck in the mud during the test. This was not the case, but it was difficult to inspect as the water was muddy. When the product was driving on the grass the skies created friction. It can be avoided with small wheel attached below the ski, so the cutter get lifted a bit from the ground.

*Ill. 1.74. Test image 1*

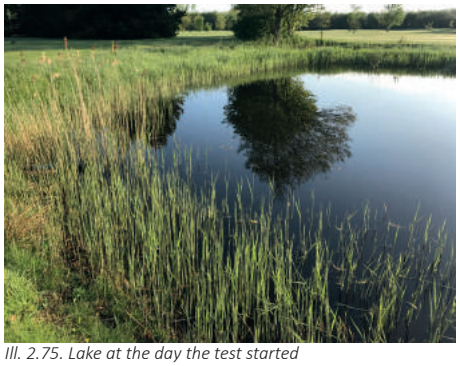
*Ill. 2.74. Test image 2*

*Ill. 3.74. Test image 3*

# PLANT GROWTH

In this section the purpose is to investigate how much a plant in the lake grows. This information will be used to determine how much plant mass the product must be able to collect.
The test was made in Aabybro golf club where the first meeting with the greenkeeper Jens took place 14 days earlier. As it can be seen on the Ill. 1.75. and Ill. 2.75. the plants in the lake have grown drastically in the 14 days. On Ill. 3.75. it can be seen how much the plants have grown in just one week

*Ill. 1.75. Lake in Aabybro golf club taken 14 days earlier than the test*



*Ill. 2.75. Lake at the day the test started*

*Ill. 3.75. Lake at the day the test ended one week later*

To test more precise how much the plants grow a test was made. The length of a plant was measured to 740 mm. 75 mm of the plant was above water. The tested showed that after one week the plant had growth 335 mm. Another plant was measured. This plant was standing 200 mm below the water level, and had a total length of 500 mm. After a week the plant had growth 370 mm.

The further product will work by cutting the plants continiously and keeping them down. To discover if the plants grow faster or slower when they are cut, 15 plants were cut down so they stood 50 mm above the water level. The plants stood close to the edge in shallow water, which mean that the hole stem got sunlight. The growth condition increase the more sunlight the plants get, which is why those plants were chosen. After a week the 15 plants had in average growth 39 mm.

The lake was mapped in order to calculate how much weed the product must be capable of collecting. On Ill. 5.75. the map of the lake can be seen. The plants are reaching 2m out from the edge of the plants, and cover an area of around 365 $m^2$. In an area of 400 mm x 400 mm, where the plants were standing close, 39 mm of the plants were cut off. The 39 mm cut off was put into a measuring cup. As it can be seen on Ill. 6.75. the measuring cup was filled up with 1,4 decilitre cut off.
With this information it was possible to calculate roughly how big the bucket for weed needs to be.

40 cm * 40 cm = 1600 $cm^2$

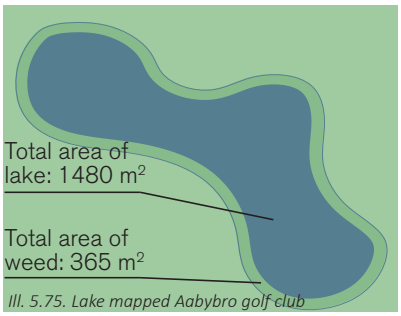
1600 $cm^2$ / 10000 = 0,16 $m^2$

1/0,16 $m^2$ = 6.25

0,14L * 6,25 = 0.875 $L/m^2$

0.875 $L/m^2$ * 365 $m^2$ = 319,4

| Plant test - not cut down | |
|---|---|
| 12.05.2018 | 19.05.2018 |
| Plant hight: 740 mm<br>Plant above water: 75 mm | Plant hight: 1075 mm<br>Plant above water: 410 mm |
| Plant hight: 500 mm<br>Plant under water: 200 mm | Plant hight: 870 cm<br>Plant above water: 170 mm |
| **Plant test - cut down** | |
| 15 plants cut down to 50 mm above water | Average growth: 39 mm |




*Ill. 5.75. Lake mapped Aabybro golf club*

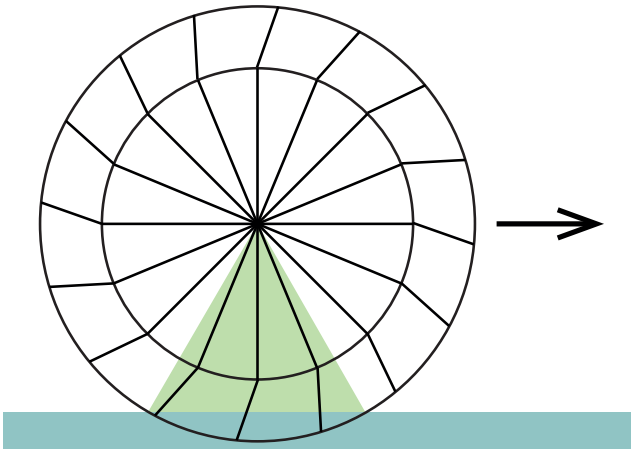
*Ill. 6.75. Cut off*

The calculation shows that the bucket must be 320 litre. A bucket that would be able to contain 320 litre would be far too large for the product, this means that the user need expressed by Jens, “the product must be able to collect or remove the cut off plant material”, will not be able to solve by collecting of the plant material.
To find out how deep the product must be able to cut, due to the visibility of the plants under water, a test was made. The day the test was preformed was a sunny day, which made the plants difficult to see, because of the reflection. It was concluded that it was not possible to see the plants when they were 15cm down standing a metre away. To ensure that it not possible to see the plants in other weather conditions a demand was set on 30cm.

| | |
|---|---|
| The bucket needed to be 320 litre to pick up all the cut off, a new solution must be found | ! |
| The product must be able to cut 30 cm down in the water | |

# PADDLE WHEEL CONSTRUCTION

The design of the wheels needed for this amphibious product is curial, in order to get a good performance in water and on ground. The paddle wheels from the previous full scale test worked well. Though, will this section research into the design of a paddle wheel will be made.



*Ill. 1.76. Illustration of paddle wheel*

## Dimensioning of paddle wheel

The paddle wheel was a popular technology on marine vessels before the invention of the screw propeller. It is used on very few applications today because of different limitations. One of these is the intolerance to changes in the drought of the vessel to maintain efficiency, another is the low efficiency at high speeds. The benefits of using paddle wheels are that is can be used in shallow waters, and the velocity of the wheels is low. (Carlton, 2007) Another is the simpler installation and water proofing because the axle is above water and not submerged as for most propellers.

When dimensioning a paddle wheel there are multiple different aspects to consider: Diameter of the wheel, immersion in water, number of paddles, and other factors. On Ill. 1.76. some of the different guidelines can be seen. The green triangle illustrates how much of the wheel that is recommended to be submerged into the water. The triangle is 60 deg and this recommendation is what makes paddle wheels so big to get more paddle under water. The reason why the angle is so narrow is for the wheel to create the most forward momentum and not waste energy on creating up or down force. On the illustration it can be seen that the paddles are angled, this is to make less of an splash when the paddles are entering the water. (Carlton, 2007) (Morton)

# DIMENSIONING OF DRIVE MOTORS

The product need to be able to cut the edges around the lake. Therefore, it is important that the motors are strong enough to pull itself up the edges. The required torque to pull up these inclines is the most important factor when choosing motor and gearing.

## Calculation for choosing motor

A few estimations will be made before calculating the torque required. The weight of the product is estimated to be around 30kg, this estimation is based on that robotic lawn mowers weight 8 to 14kg. The reason for the roughly double of weight is based on the choice of the finger bar cutter, big paddle wheels, and an increased battery capacity.

The product will have to be able to climb inclines of 25deg and have a speed of around 0.25m/s while driving on land. It is estimated that the efficiency of the system is 65%, with power loss in the gearing and motor itself.

As it can be seen in the chart, the torque needed per motor is 37.69Nm and the motors will be rotating at 5RPM while driving on land, but when the product is in water the RPM will need to be closer to 60, in order to get momentum.

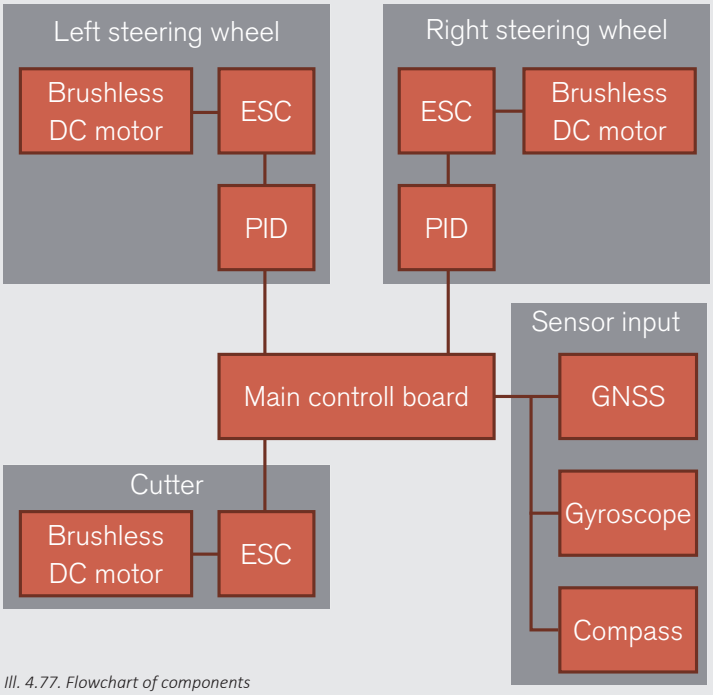
A motor that fits these requirements is the ZD1633L 12V 100W worm gear motor. It spins at 55RPM and has a stall torque at 50Nm. (Dynamics, u.d.)

*Ill. 2.76. Worm gear motor*

| Motor dimensioning calculations | |
|---|---|
| Known factors | |
| Weight of the product (M): | 30kg |
| Radius of the wheel (R): | 0.4m |
| Max incline(I): | 25° |
| Revolutions per minute (V): | 5RPM |
| Efficiency of the motor system | 65% |
| Calculations | |
| Max incline in radians | $\theta = I*\pi*180 = 0.436$rad |
| Wheel rotations in radians per s | $\omega = V*\pi/30 = 0.52$ rad/s |
| Force pulling the product down from the incline | $f := M*\sin(\theta) = 12.67$g |
| Torque needed to stall up incline | T= f*R= 5.07 kg/m - 49.73Nm |
| Torque needed when adding the energy loss | Te= 100/E*T= 75.38Nm |
| Power needed to drive up incline | $P=T*\omega$= 39,2W |
| Torque needed per motor | Tmotor=Te/2= 37,69Nm |
| Power needed per motor | Pmotor=P/2 = 19,6W |

# ELECTRONIC SYSTEM

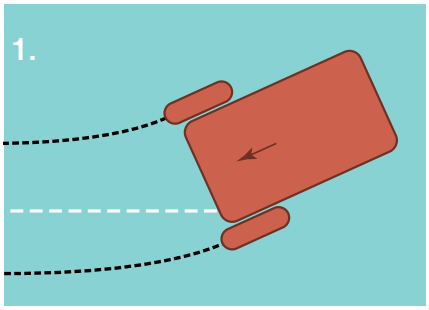
When developing a robotic product that will be operating without supervision there are many different scenarios the product itself needs to be prepared for. The electronic system for the product requires multiple sensors and components to control the steering of the product. Another challenge is to develop the product to be efficient both on ground and in water. A diagram of the most important sensors and components is made to give an overview Ill. 4.77. The diagram illustrates which components is related to the different functions, and who they communicate with.



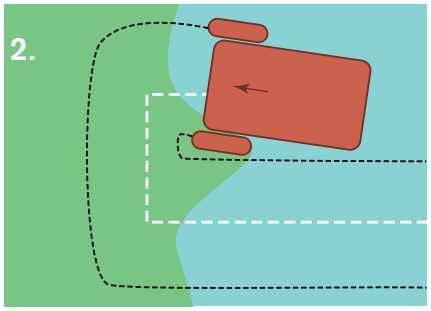

*Ill. 4.77. Flowchart of components*

## Scenarios for the product

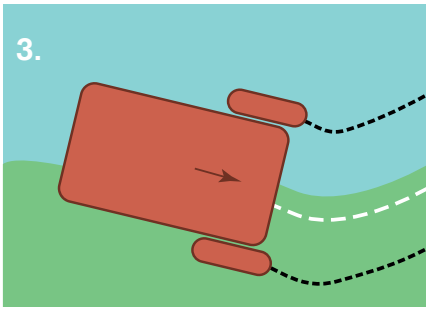
When the product is cutting water weeds in the lake and on the ground around the lake, the product will encounter different scenarios that requires that the product reacts. These scenarios will be used to describe what the individual components do, and how the product will react.




*Ill. 1.77. Off course and trying to get back*




*Ill. 2.77. Transition from water to ground*




*Ill. 3.77. Driving with one wheel in water and one on ground*

## Scenario 1

On Ill. 1.77. it can be seen how the product has gone off course. The white line is the desired path that is mapped on the computer, and the black lines is how the product is planning to move each wheel to get closer to the desired path.

The way the product knows its location and where the desired path is, is by using the information from the GNSS module and compass. If the product gets off course the product will have to make corrections by decreasing the speed of one of the wheels. This information will be sent to the proportional integral derivative controller (PID).

The PID is what makes the corrections and generates a smooth path, and sends the signal to the electronic speed controller (ESC). The PID uses three different calculations to guide the product back on track if it gets off course. The PID is eliminating overshooting while still being able to make swift reactions to new inputs. The elimination of overshooting means that the product will not be “vibrating” when trying to get back on the desired course. On Ill. 1.77. the effect of the PID can be seen in how the black lines are getting closer to the white line until they are parallel to each other.

## Scenario 2

In scenario 2 on Ill. 2.77. it can be seen how the product is about to get up on ground. The product is transitioning from water to ground so it has the wheels spinning at high revolutions per minute (RPM).

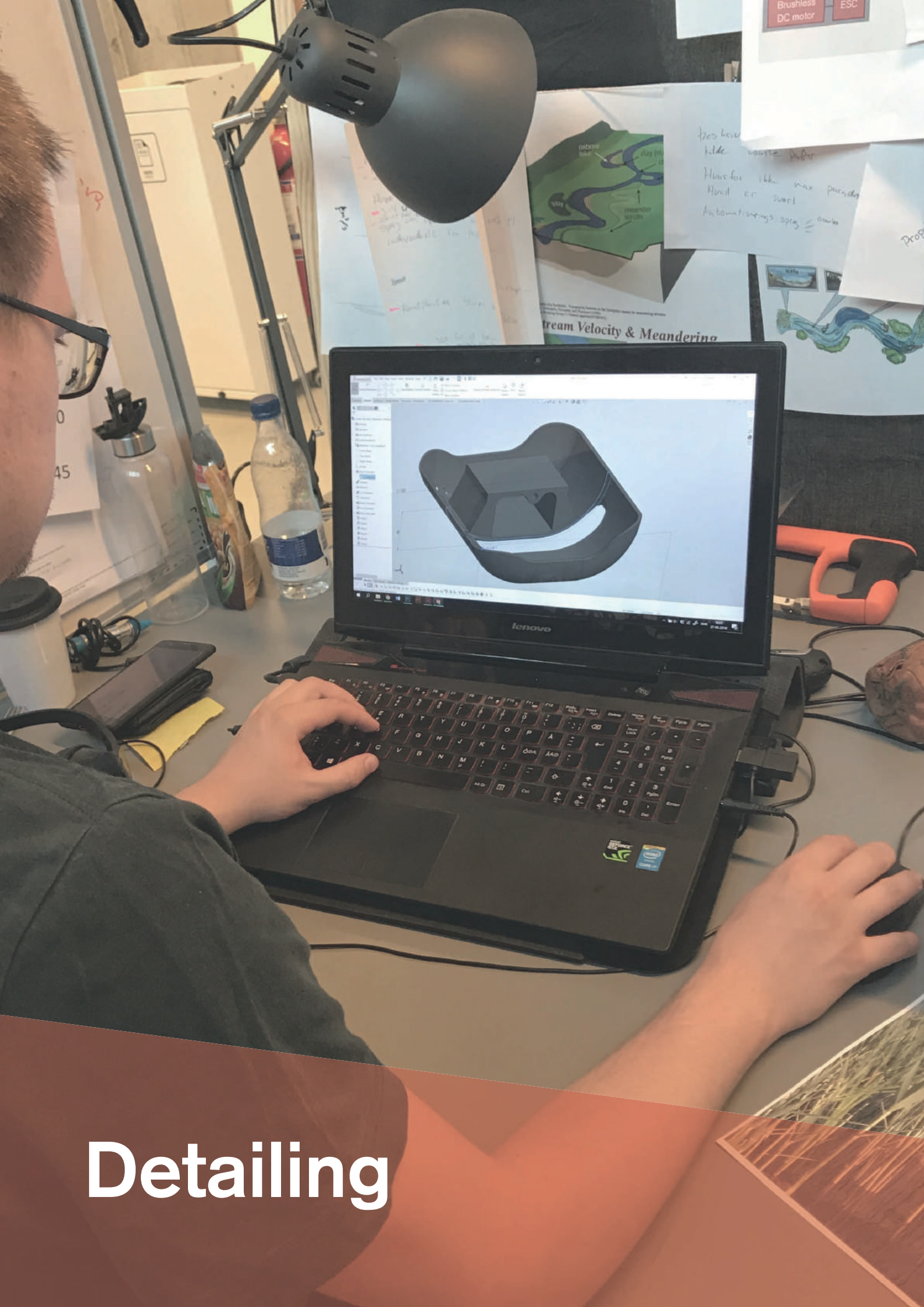
When the left wheel is hitting ground the ESC will detect a change in power draw from the motor, because of the increased friction. If the product did not have a ESC module the wheels would spin with the same speed, which would make the product spin around itself on Ill. 2.77., because the wheel on grass would have much more traction. The ESC will communicate the change in power draw to the PID which then sends a signal back to the ESC to lower the duty cycle, resulting in a lower wheel RPM. The ESC also used to brake and make the motors spin in reverse.

## Scenario 3

On Ill. 3.77. scenario 3 can be seen. In this scenario the product is in the middle of cutting the edges around the lake. It drives with one wheel in water and one on land, this means that they will have to drive at very different RPMs to go forward in a straight line.

When the desired path is curved like in the scenario the ESC will constantly be changing the speed of the wheels, to follow the path and still maintain the desired speed for the entire product.

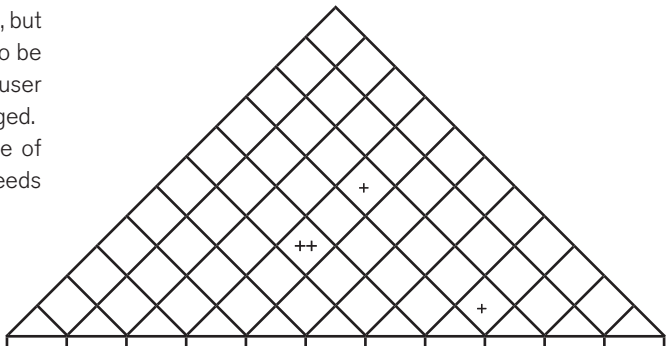
When the product is cutting the edges it will be operating on an slope, here the gyroscope will play an important role of shutting off the cutter if the product tips over.




# Detailing

# UPDATE HOUSE OF QUALITY

After the reframing new user needs have presented themselves, these will have to be integrated into the house of quality. Most of the user needs from weed cutting in lakes has been deleted, but some of them have been changed, because they would also be relevant in this new context. In Appendix J - Redefinition of user needs, it can be seen how the user needs have been changed. The user needs have not been rated in this second house of quality. Though, it would have been relevant to know what needs the greenkeepers think is the most relevant.

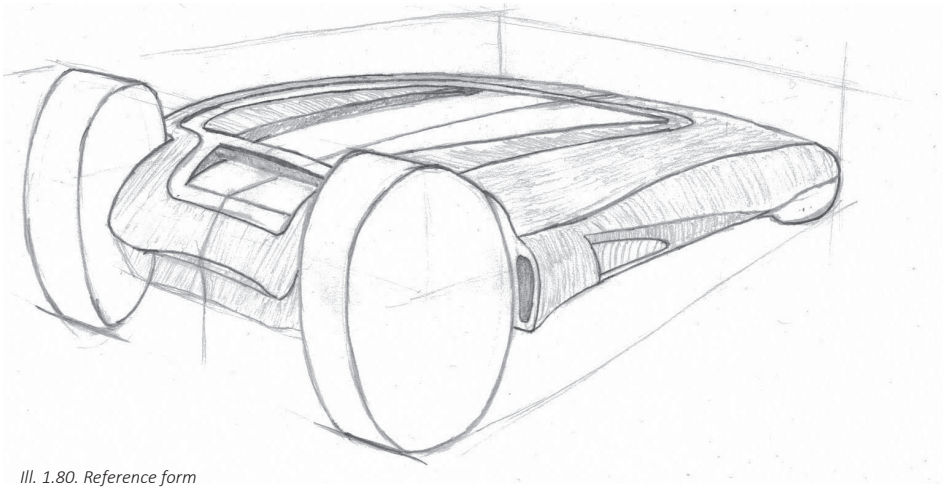



● = Strong connection between demand and user need
○ = Weak connection between demand and user need
++ = Strong connection between demands
\+ = Weak connection between demands
−− = Strong contradiction between demands
− = Weak contradiction between demands

| No. | User needs | Engineering characteristic: The full weight of the product should not be lifted by the greenkeeper | The product should be able to propel itself | Gyroscope sensor to stop the cutter, if the product tip over | The propulsion of the product must functional even on wet grass or in mud. | The product must be able to drive on slopes | The product must collect weed | The product must cut under the water level so the plants can not be seen | Operation time | Cutter width | The product must float | The product must not leave visible tracks on the golf course |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **User needs - Smaller streams** | | | | | | | | | | | | |
| 1 | The product should not rely on the greenkeeper to work with their arms extended from their body or with the back bend | ● | | | | | | | | | | |
| 2 | Easy transportation from golf cart to the lake | ● | | | | | | | | | | |
| 3 | The product should be functional even in muddy water with plant debris | | ● | | | | | | | | ● | |
| 4 | The product must not be able to tip over during the operation | | | ● | | | | | | | | |
| **User needs - Golf clubs** | | | | | | | | | | | | |
| 5 | The product needs to be able to cut the lowest area around the ponds | | | | ● | ● | | | | | | |
| 6 | The product should be able to collect or remove the cut off plant material | | | | | | ● | | | | | |
| 7 | The product must cut under the water level so the plants can not be seen | | | | | | | ● | | | | |
| 8 | The product must be able to cut a lake on 3000 $m^2$ | | | | | | | | ● | ● | | |
| 9 | The setup of the product needs to be quick and simple | ○ | | | | | | | | | | |
| 10 | The product must not leave visible tracks on the golf course | | | | | | | | | | | ● |
| | Target | Yes | Yes | Yes | Yes | 25 | Yes | 300 | 7 | 50 | Yes | Yes |
| | Unit | Binary | Binary | Binary | Binary | Degree | Binary | mm | Hours | Cm | Binary | Binary |

# FORM REFERENCE

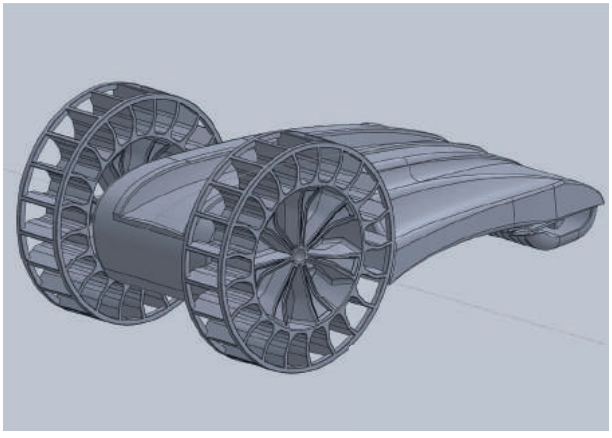
After the update of the house of quality the final demands were set. The demand: The product must be able to drive on slopes, and the test on page 71 and 72 resulted in a change of the design. The product went from rear to front wheel driven. A new ideation round were needed to define a reference form before starting on the CAD model.
The chosen reference form can be seen on Ill. 1.80. The design has inspiration from the form analysis of products from Stihl and Husqvarna. The form's lines are stretched out, and goes from a taller point in the front to a lower point in the back, which gives the design a dynamic expression. A detail that is worth pointing out is, when the product is driving on ground the cutter fades into the form of the main body, which is the curve that can be seen in the back. This detail must be detailed further.
In the middle of the product, there is a cut out in the surface, which give the form dynamic, but also allow a handle to be attached. The handle will be useful for different attachments.



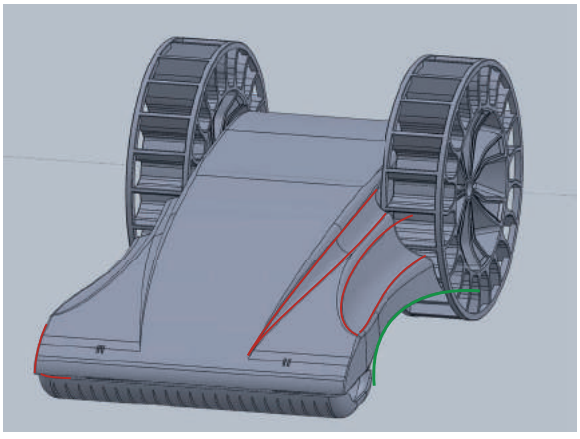
*Ill. 1.80. Reference form*

# SPECIFICATION - FIRST 3D SKETCH

On Ill. 2.80. and Ill. 3.80. the first draft of the 3D model can be seen. The size of the wheels are large in relation to how big the main body is. Furthermore, the design of the wheels do not match the form of the body, because the wheels have to many geometric details that attract to much attention compared to the main body. It is not possible to change the size of the wheels, neither the flaps, due to functionalities. An ideation upon how the centre of the wheel can get a more calm expression needs to be made.
The form of the main body has pros and cons. The pros are indicated on Ill. 2.80. and Ill. 3.80. with a green line and the cons are indicated with a red line. In the reference form on Ill. 1.80. the focus was that the lines should not go in many different directions. The CAD model did not succeed in this. The four red lines in the right side on Ill. 2.80 shows it clearly that the lines are going in different directions, which disturb the form language.
It was also mentioned in the form reference that there will be focus on integrating the form of the cutter in the form of the body. This did not succeed either. As the red lines in the left side on Ill. 2.80 indicate does the form of the body have a sharp edge, whereas the cutter have soft rounding.



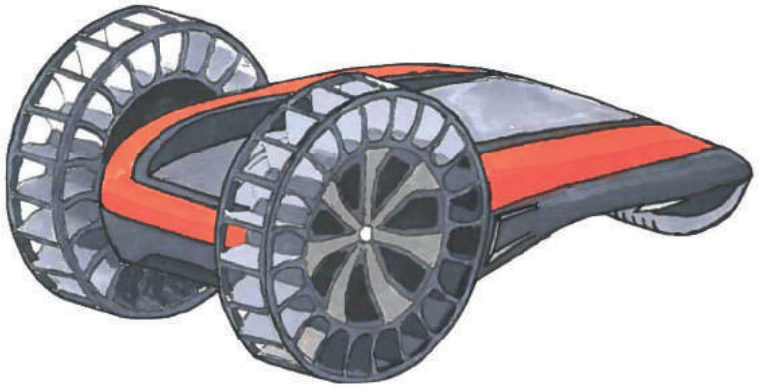
*Ill. 2.80. First 3D model*



*Ill. 3.80. First 3D model 2*

# FORM REFERENCE 2

A new form reference was drawn in order to repair the cons from the earlier proposal. This drawing has also been styled in order to make it easier to understand the form language and different parts. The  idea is that the black bottom part is a kind of foam, and the orange part is plastic.
The form of the product is this time much more simple. The lines are going in the same direction, which make the form more elegant.



*Ill. 1.81. Reference form 2*

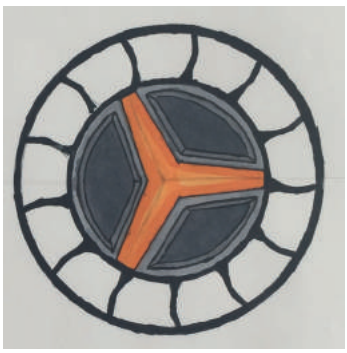
# SPECIFICATION - WHEELS

Different proposals for wheels were drawn, due to that the wheel on the CAD model is too disturbing. On Ill. 2.81, Ill. 3.81, and Ill. 4.81, different proposals from the ideation can be seen. In all the designs it recur that it is the centre of the wheel that changes form. The wheel that can be seen on the CAD model Ill. 2.71, have holes that goes through the wheel, in comparison to the wheels from the ideation that have the surface in the centre closed. The reason for this is that the closed wheel will create less drag and resistance in the water.

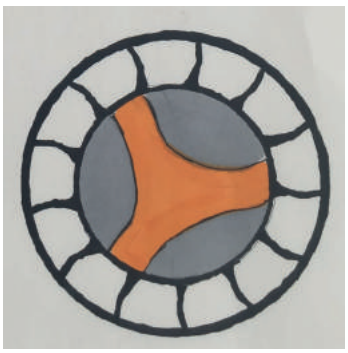
On Ill. 5.81 it can be seen how much of the wheel that should be submerged, in order to be the most efficient. As it can be seen it is not that much the wheel is submerged. This is a problem because the product requires ground clearance to work on ground. Therefore a compromise between efficiency on water and efficiency on ground needs to be made.

## Placement of the wheels

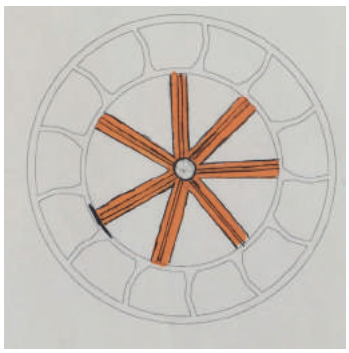
In order to get the most efficient paddle wheel, many factors have influence. One of the factors is how much of the wheel that is submerged of water, which also is described on page 74.



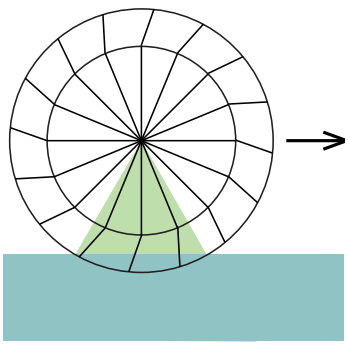
*Ill. 2.81. Wheel proposal 1*



*Ill. 3.81. Wheel proposal 2*



*Ill. 4.81. Wheel proposal 3*



*Ill. 5.81. Wheel proposal 4*

# CUT OFF COLLECTOR

One of the user needs were: The product should be able to collect or remove the cut off plant material. This user need was presented by Jens from Aabybro golf club. It is important to remove the cut off both to get a nice aesthetic, but also to reduce the amount of plant material decomposing releasing nutrients to the water.
As shown in the previous section: Plant growth on page 73, the amount of cut off will be too much for the product to contain all off it.

## Cut off test

As part of developing a solution for collecting the cut off it was important to find out how the plants behave after they are cut. It has been observed that leafs and other plant material has a tendency of collecting in one end of the lake, as it can be seen on Ill. 2.82.
A test of how long time the plant material floats has been conducted to find out how long time there is to remove the plant material before it drops to the bottom. After three days it has still not fallen to the bottom. For the project this is a good result as it means that the greenkeeper will have more than three days to collect it. In the test two different plant types were used.

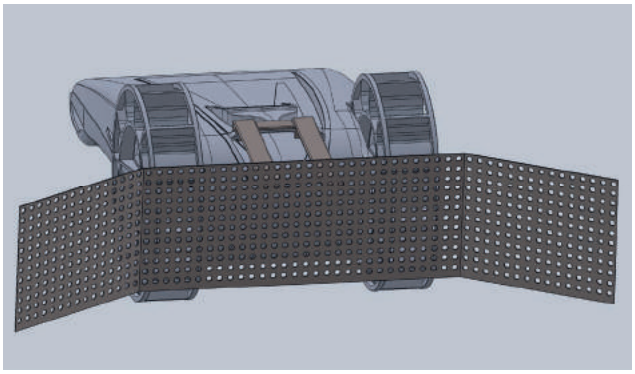
## Solution for collecting the cut off

One of the first ideas was to collect the cut off inside the product, but after calculating how much plant debris cutting one lake creates other solutions has been explored.
The concept chosen is something that resembles a snowplough that can be attached to the product, Ill. 3.82. and Ill. 4.82. The idea is that the plough is attached to the handle on top of the product. After the plough is attached the product has to be controlled manually to push all the weeds together in one end, where the greenkeeper then can remove it with an rake or fork.
An idea of how the product can be controlled would be an app connected to the product. This will allow the greenkeeper to push all the weed cut off in one end of the lake.

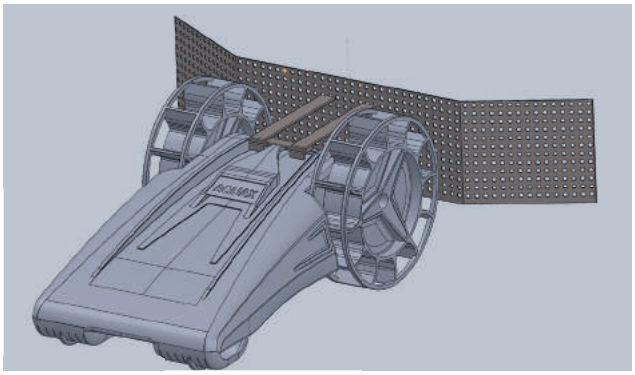
This solution is only a rough concept, more time will have to be used to develop this solution. The idea of having an app connected to the product will give the user some added benefits. The ability for the greenkeeper to follow the progress of the product even when working in the other end of the golf course will be beneficial so the product can be moved to the next lake .

*Ill. 1.82. Floating plant debris*

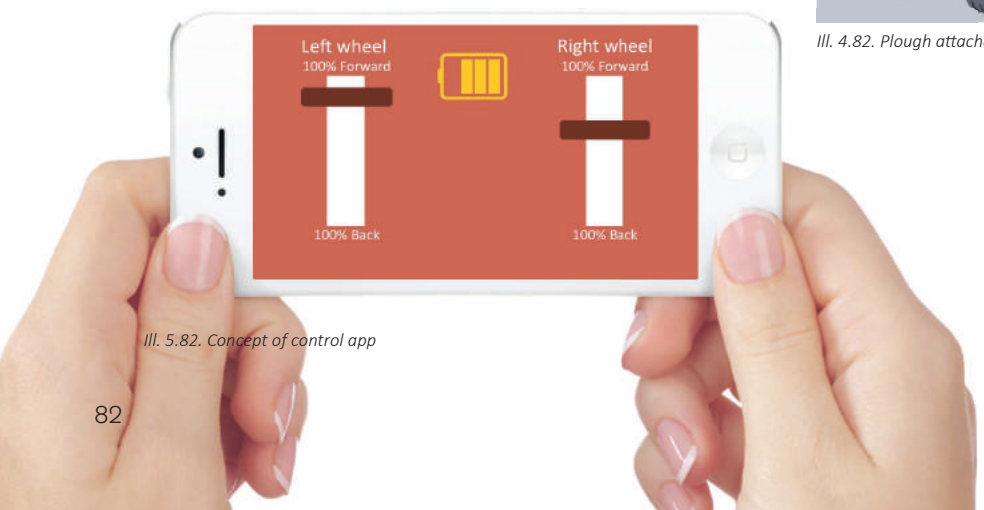
*Ill. 2.82. Debris collecting in one end*



*Ill. 3.82. Plough attached to the product*



*Ill. 4.82. Plough attached to the product*




*Ill. 5.82. Concept of control app*

# TRANSPORT TO THE LAKE

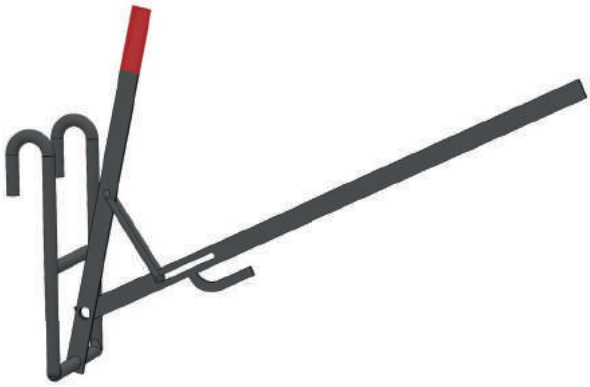
As shown on the user scenario on page 66 and 67, the idea is that the greenkeeper has to transport the product from lake to lake. This is done to simplify the product, so it does not have to drive from the clubhouse out to the lakes. On golf courses it is not unlikely to have a lake more than one kilometre from the clubhouse. With the desired speed of 0.25 m/s it would take over one hour for the product to drive one kilometre and this would use much of the battery capacity. This could be solved by having multiple charging stations but that would require power cords throughout the golf course. Therefore it is chosen to propose a solution for transporting the product.

## Transportation of the product

At both golf clubs it was observed that the greenkeepers use golf utility carts to drive around the course. It was decided to make an attachment for this type of vehicle. Common for the golf utility carts is that they have a cargo space in the back like a pickup truck. It was observed that this space is often filled with tools or equipment, so the solution should not take any of this space like it does in the user scenario on page 66 and 67. The solution principal relies on utilizing lever action to lift the product, so the user does not have to lift the entire weight. The front of the robotic lake mower is not lifted as much from the ground, because of the exchange in the lever arm. The reason why it is designed that way is due to that most of the weight of the product is in front of the product.
On Ill. 1.83. and Ill. 3.83. it can be seen how the product is picked up. The lever with the red handle is moved down and the hook on the bar is connected to the handle on the product. Afterwards the orange strap is tightened around the cutter to keep it up and to lift the product while driving. On Ill. 2.83. and Ill. 4.83. the lever arm is up and the product is ready for transport.

This solution is still in the sketching phase, and testing will have to be made to find the right exchange between the lever arms. It is important that it easy to lift the product while creating enough clearance so the product does not hit the ground while transporting it. The solution with attaching the back end of the product with the orange strap will also have to be revisited and tested.

*Ill. 1.83. Lever down when picking product up*



*Ill. 2.83. Lever up when transporting product*

*Ill. 3.83. Lever down when picking product up*

*Ill. 4.83. Lever up when transporting product*

# GNSS BASE STATION

As described in the user scenario on page 66 - 67, a base station is needed to ensure high precession location information.
It is chosen to design a portable base station, to make the setup of the product as simple and affordable for the greenkeepers. Permanent base stations near each lake would be ideal, but would require a power cord to each lake which would make the implementation of the product more complicated.

## Portable base station

A portable base station will require batteries and a wireless connection to the robotic lake mower. The battery could be a lithium battery as they are light, compact and rechargeable.
The base station will have to be easy to move around, so it can be moved together with the product. The construction will have to be sturdy as it will most likely be transported in the back of the utility cart.
The base station will need to have the most of the weight in the bottom to make sure it does not tip over and breaks the line of sight to the robotic lake mower.

The portable base station will not be developed further, but the design could be like what can be seen on, Ill. 1.84.

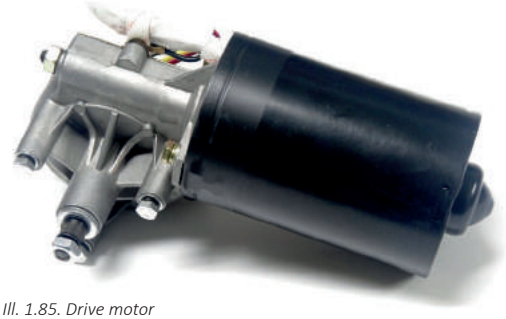
*Ill. 1.84. Portable base station*

# COMPONENTS

A list of standard components will be compiled, and the requirements for each component is described. This list will contain standard components that has to be bought and installed on the product. A list can also be seen in Appendix K, Components.

## Drive motors

The choice of motors for driving the wheels is previously described in the section: Dimensioning of drive motors, on page 74. The motors chosen are the ZD1633L and ZD1633R, Ill. 1.85. They are 12v motors with an worm gear that outputs 50Nm at 55 RPM. The weight of each motors is 2.80 kg per item, and the price is around 570 DKK.



*Ill. 1.85. Drive motor*

## Cutter motor and gear

For the cutter it is chosen to use a GPG 90mm 60W DC Motor ,Ill. 2.85. This motor spins at 3200 RPM so a gearing will have to be added to get a lower cutter speed. The motor has a weight on 2.84 kilogram and a price of around 570 DKK. (Dynamics, 60 Watt, u.d.)

The optimal speed for the cutter needs to be found though testing. Normal hedge trimmer has a cutter speed of around 1300 RPM, but as the cutter on the product needs to work under water a lower speed might be desirable. This is based on statements from Lars Sloth, that cutting plants under water does not require much speed, and high speeds will create much turbulence.

The gearing for the cutter could be a 1:10 gearing, this would result in a cutter speed of 320 RPM. The gearing could be a ACP-G-5U10-K that is rated for 3.7 NM, and has a price on 718 DKK and a weight of 1.2kg, Ill. 3.85. (Automation, u.d.)

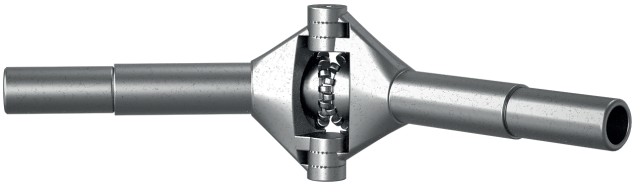
*Ill. 2.85. Cutter motor*

*Ill. 3.85. Cutter gear*

## U-Joint

Ever since the first sketches on the Weed Management Drone is has been a challenge of how to get the energy down to the cutter.

The solution chosen for the product is to have two u-joints that allow the axel and thereby the cutter to move up and down, while having the motor above the water line. The u-joints needed for the product are not ordinary, as most u-joints has a limitation of around 25deg. What it needed on the product is a 90 deg u-joint, a product like the, Extreme-Angle Geared Single U-Joints, could be a solution, Ill. 4.85. It has a maximum operating angle of 136 deg. The price is 925 DKK and the weight is 0.7Kg.



*Ill. 4.85. U-joint*

## Electronics

The electronics board will have to have incorporated all the different components described in the previous section: Electronics system on page 75. The price of the different components can be seen in Appendix K, Components. For the main control board a Raspberry Pi is chosen, this components is used for price reference, as it contains many of the needed features.

It is estimated that the total power consumption of the electronics will not exceed 5 Watts. The total price for the electronic components is 2,095 DKK.

## Batteries

The capacity for the battery needed for the product is highly depended on how much power the three motors are drawing. As it is hard to estimate how much resistance the motors are exposed to, a worst case scenario is made.

| Calculations | |
|---|---|
| Component | Power usage |
| 2 x Drive motor | 39,2 watts |
| 1 x Cutter motor | 60 watts |
| 1 x Electronics | 5 watts |
| Total power consumption | 104,2 watts |
| Desired operation time | 7 hours |
| Battery capacity at 12v in Amperes | (7h*104w)/12v= 60,6 Ah |

A battery that fits the requirements could be the 12V 60AH lithium battery pack from Sky Technologies, Ill. 5.85. (Technologies, u.d.)

It is a 4 kilogram battery and has a price of 1,816 DKK.


*Ill. 5.85. Battery*

# PRODUCTION OF COMPONENTS

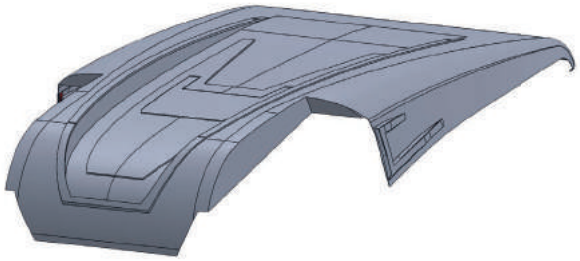
The purpose of this section is to describe which materials and what production method that should be used for each component.
There are several demands for the product, but two of the most important ones are that the product must float and be able to withstand exposure to water and sunlight. To obtain buoyancy the materials used must be light weight.

## Shell

The shell of the product will be vacuum formed, this production method is chosen as it is a relative cheap when producing large plastic parts. When designing for vacuum forming there are different factors to take into account. The draft angle is an important factor, and when using a female mould it is recommended to have a taper of 2°-3°. The reason why it is chosen to use a female mould is to get the thickest part of the plastic near the edges, Ill. 1.86. Because of how vacuum forming works the plastic thickness will not be evenly distributed as it can be seen on the picture. The reason why the thickest plastic is wanted near the edge is because it is the most exposed to damage when driving. (Formech) (Lefteri, 2013)


*Ill. 1.86. Female and male mould*

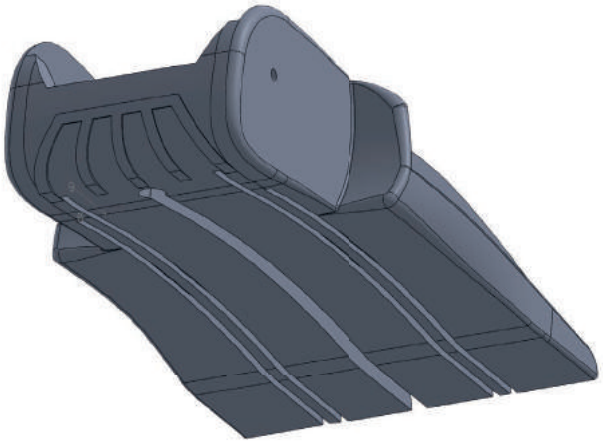
The material used for the vacuum forming will be Acrylonitrile Butadiene Styrene (ABS). ABS is a rigid material with good impact resistance, and resistance to sunlight and weather exposure. (Formech)
The shell designed for the product can be seen on Ill. 2.86. In the current design there are some challenges in vacuum forming the shape. The detailing on the sides behind, the cut outs for the wheels, will be problematic to make with vacuum forming. A redesign will have to be made if the component will have to be vacuum formed or the detail will have to be attached in a later process.



*Ill. 2.86. Shell of the product*

## Bottom part

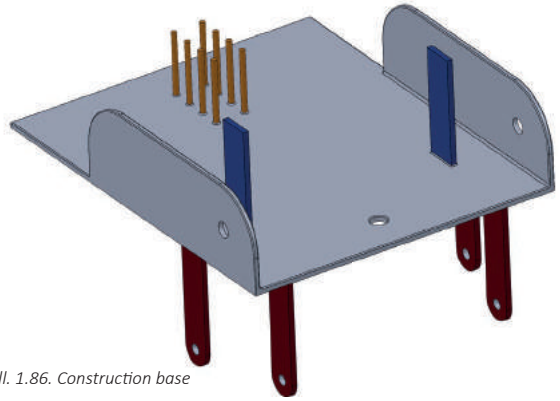
The demands for the bottom of the product is that it has to be sturdy and impact resistant, but most importantly light to create buoyancy for the product.
The production method used for the bottom of the product is foam moulding. The manufacturing process resembles injection moulding, but the material used is expanded plastic beads. The process of manufacturing expanded foam is rather complex because the beads have to go through multiple different processes before getting injected into the mould. (Lefteri, 2013)
The material used for the bottom is expanded polypropylene (EPP). This material fits the context, due to that it is resistance to jolts and damage, which the product will be exposed to when driving around on its own. Besides the impact resistance the material is also water and chemical resistant. The material weight of the material can be as low as 0.02g/cm$^3$. The low mass will be providing the product with much buoyancy. (Federation)
The material and manufacturing process is known from automotive bumpers, bike helmets and surfboards. (Federation)
The bottom part of the product can be seen on Ill. 3.86. In the bottom the cut outs for the cutter bars and the cutter drive axle can be seen.



*Ill. 3.86. Bottom of the product*

## Construction base

The different components in the product are mounted to the same sturdy base. This involves the shell and bottom part, but also the three motors, battery, electronics box, and the connection bars to the cutter.
For this construction base, it is chosen to use a 5 mm aluminium plate. The plate has to be sturdy enough to withstand the forces generated by the motor. As it can be seen on, Ill. 1.86. there are different rods and bars connected to the plate. These are what connects the base to the rest of the components.



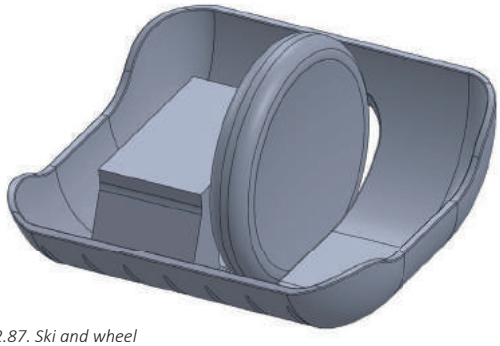
*Ill. 1.86. Construction base*

The blue bars and yellow rods are what connects the handle and screen component on top of the shell to the base. It is important to get a sturdy connection here, as the handle will be

used for different activities like transport and attachments.
The red bars are the connection between the cutter and the base module. Strength is also a requirement here as it can be expected that the cutter will bump into stones and generally be exposed to rough handling.
It was considered using reinforces plastic, because of the low weight of the material compared to aluminium. The reason why it was chosen to use aluminium over an reinforces plastic sheet was general strength, and the possibility to get strong welds for the attached rods and bars. (Lefteri, 2013)
The specific alloy used for the construction base will be the 5052 alloy. The material properties that are appealing is the good weldability, excellent corrosion resistance, and medium to high strength. This aluminium alloy is preferred within the marine industry. (ESAB, u.d.) (MetalsSupermarket, u.d.)

## The ski and wheels

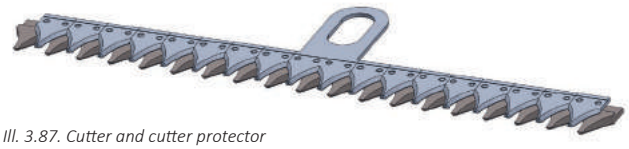
The skies beneath the cutter ensure that the cutter is not getting stuck in mud or hitting stones when moving in water. The wheels will take over when the product is on ground to lower the friction. The wheels will also make it easier for the greenkeeper to move the product around.
This solution has not been fully developed as it is expected that a standard component from a snowmobile or snow scooter can be used, and thereby lower the tool cost. For the wheel a standard component also has to be found. Though it is important when choosing wheel that it should have plain bushings rather than ball bearings. As ball bearings designed for the rough conditions underwater will be expensive and not add much value, compared to something like an igus iglide® H bearing designed for underwater applications. (Igus, u.d.)



*Ill. 2.87. Ski and wheel*

## The cutter

For the cutter inspiration has been drawn from the cutter seen on the dredging bucket and the weed cutter boat. The feature that was appealing to get on to the product are the changeable blades. On Ill. 3.87. the small triangle knives can be seen, they are attached to the moving cutter bar that make all the knives move. Because these blades will be cutting in muddy water and eventually hit rocks, it is important to be able to change the knives to ensure that they leave a clean cut. When cutting on ground it is important to leave a nice cut as it will be visible for the golf players.



*Ill. 3.87. Cutter and cutter protector*

Underneath the cutter bar and knives, a fixed cutter protector is attached. This will protect the knives from the largest rocks and assist in cutting the plants as they are part of preforming the scissor action.

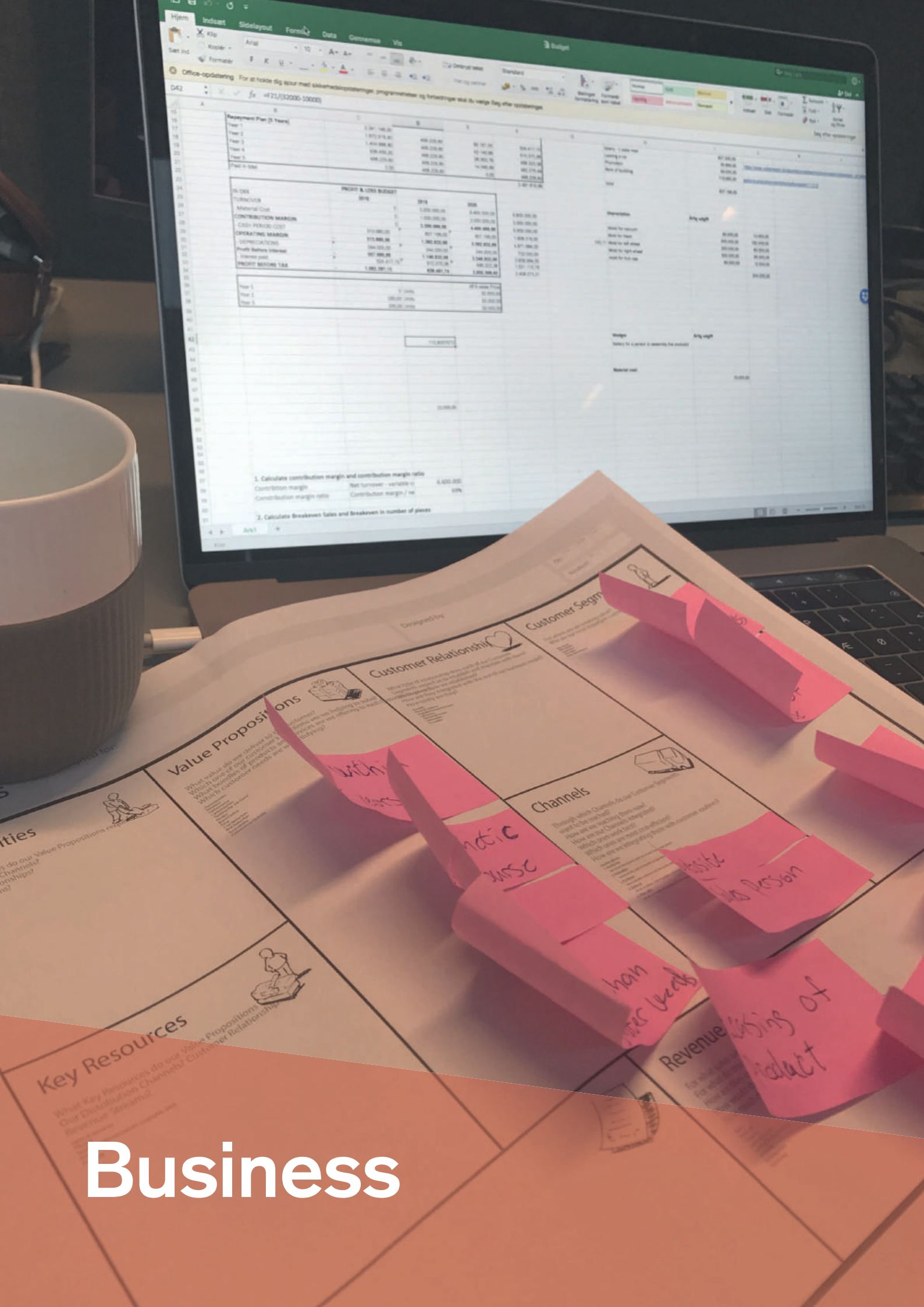
## Reflection

The components and the different requirements have been described for selected important parts. The manufacturing process and material choice for the rest of the components will have to be decide at a later stage. In Appendix K - Components, a list of every component is compiled where the estimated weight and production price is stated.

In Appendix K, it can be seen that the price for the standard components is estimated to be 6,094 DKK for the motor, gears, and batteries, and 2095 DKK for the electrical components. The components and price are found online at a single unit price. It is expected that cheaper components can be found with higher production numbers.

The production price of each component in the “Production components list” section of Appendix K, are rough estimations and it is expected that the price of each component may vary much. The price is estimated to be 7,550 DKK. The total production cost for the product is 15,739 DKK

An issue that became obvious after compiling the three different lists were the estimated weight of the product. The weight with the current components is 27.4 kg. Buoyancy is created by water displacement, and the components that is the most underwater is the bottom part. This components will be able to make 28 kg float but the bottom part is not designed to be fully submerged.
To solve this issue a revision of the chosen components and materials may be enough, as the motors and battery is accountable for 12.6 kg. If lighter components can not be found a redesign of the bottom part might be a solution.




# Business

# NAME AND LOGO

For a product the company name and logo can have great effect on how customers will preserve a product. It is important that the name and logo communicates what the company is about and users can interpret it. (Entrepreneur, u.d.)

## Company name

The name Aquax is a combination of aqua and the letter x, aqua is used to let the customer understand in what context the product is target for. The x represents a crossroad from normal manual tools to intelligent products.
The company name Aquax was also the name under the development of the Weed Management Drone. The company name is still used under the development of the robotic lake mower.

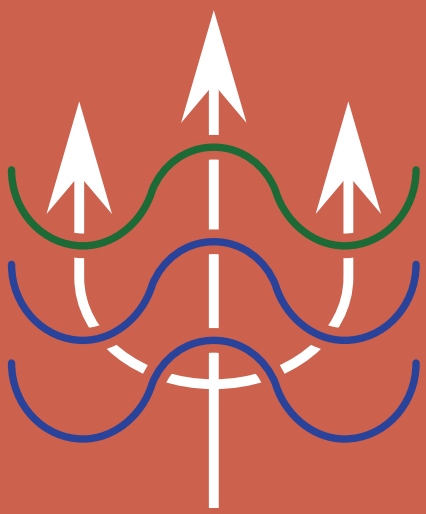
## Product name

The product name is Amphitrite. Amphitrite is known from the Greek mythology as the wife of Poseidon. The product will spent most of its time cutting weed in the water, which is why the name was appropriate.
In the process of selecting name it was important to incorporate something that is unique about the product. (Entrepreneur, u.d.) The feature of being amphibious is one of the things that is unique about the product. It is incorporated in the beginning of Amphitrite. Furthermore, the product can be associated with a ship. Ships do always have women names, which is also why Amphitrite fits the product.

## Logo

It was chosen to create a simple, but recognizable logo. The waves illustrate the water and the trident illustrates the connection to Poseidon.

AMPHITRITE BY
**AQUAX**



# BUSINESS MODEL CANVAS

In this section it will be described how the company will create, deliver, and capture value. To do this the nine business blocks from business model canvas have been used. *(Osterwalder & Pigneur, 2010)* The model can be approached differently according to where the company have its focus. In this project the focus is on the costumers needs, which fits to the approach "*Costumer driven*". "*Costumer driven*" has its starting point from the right side of the model, as the arrows indicate on Ill. 1.89. The illustration is a process image from the early stage of the development of the business model.

## Costumer segment

The first building block in the model is costumer segment. A profitable costumer is important for any organization, in order to survive. The costumer segment for this company is golf clubs. The costumer segment can be divided into different types of categories. The golf clubs fit into the category "*Niche market*" *(Osterwalder & Pigneur, 2010).* This mean that the solution is tailored for golf clubs to fit their needs and values. Different types of golf clubs exist, in relation to how expensive a membership is, and how much money and time the golf clubs invest in maintaining their golf courses. Inside the golf industry there can therefore be different kind of segments to target.

Amphitrite will target all the segments inside the golf Industry. The reason why Aquax is capable of this, is because golf clubs that normally not have the money in their budget to maintain their lakes more than one time every second year will afford Amphitrite, due to a short return of investment. Golf clubs, where money is not an issue, will benefit from Amphitrite, because the process of cutting weeds will be much simpler than earlier.

In the long term it is not improbable that the costumer segment will change from "*Niche market*" to the category "*Segmented*". In this category their can be different markets and segments. The segments have similar but varying needs. *(Osterwalder & Pigneur, 2010)*

The reason for this is that the product may in the long term also suit ponds in parks for an example. Even thought, this will not be investigated further in this report.

## Value propositions

The next building block is the value proposition. The value proposition is the reason why golf clubs will invest in Amphitrite instead of other solutions.

There are two main reason why the golf clubs should buy Amphitrite, which is that Amphitrite will get the job done, and at the same time reduce the cost in the golf clubs.

**"Getting the job done"**

Value is created by helping the greenkeepers maintain their lakes. The procedure in the golf clubs is now that they walk in the lake with tools like a motor scythe to keep the plants down. Around once a year contractors are hired to clean the lakes. With Amphitrite it wont be necessary for the greenkeepers to use contractors to maintain the lakes. Furthermore, Amphitrite will reduces the frequency of when an excavator is needed to dig up the bottom.

**"Reducing the cost"**

Reducing the cost in a golf club is another way of creating value. As it can be seen later in the report, the return turn of investment is short. This mean that the golf club will have money for other projects.

## Channels

It is chosen to use a salesperson as the channel to the golf clubs. The product is designed for the niche market to a well-defined costumer: Golf clubs. Knowing the specific segment, it is easy for a salesperson to drive out to golf clubs to display and sell the product.

## Customer relationship

The model distinguish between different types of relationships a company can have with their costumer. *(Osterwalder & Pigneur, 2010)*

Amphitrite is a product for a niche market, and will have a relatively high price. When buying the product the costumer has the opportunity to buy a service agreement, which will ensure that the greenkeeper will only have to do regular maintenance. If the product unfortunately have breakdown, a technician from Aquax will be summoned to fix the problem. This agreement will also include installation of the product. This kind of relationship is under the category "*Personal assistance*". If the golf clubs install the products themselves the costumer relation ship will be in the category "*Self-service*". This kind of relationship means that the costumer can buy all necessary means of Aquax, in order to help themselves.

## Revenue streams

The model divides the revenue streams into different ways a company can get an income from the costumer. *(Osterwalder & Pigneur, 2010)*

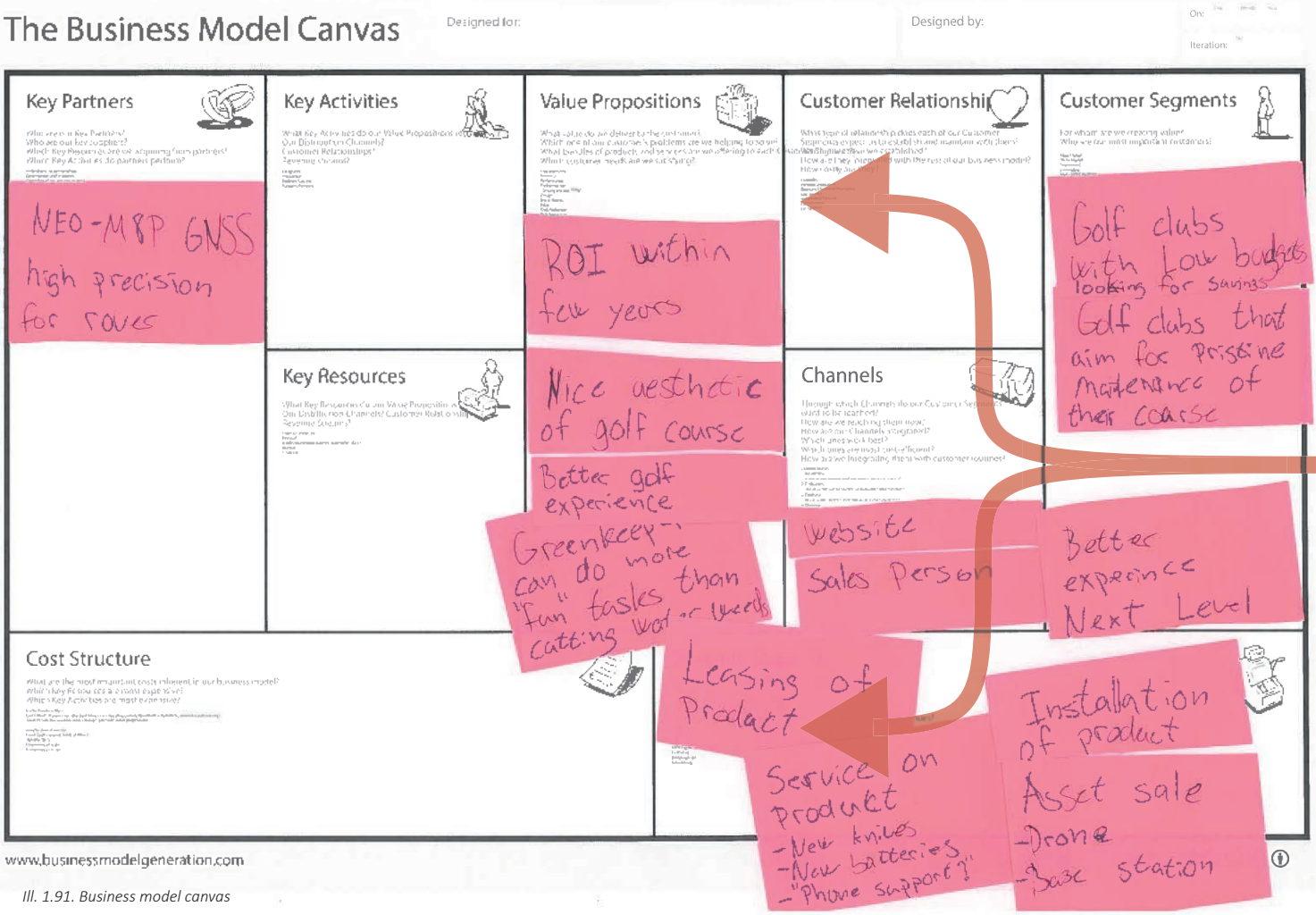
**"Asset sale"**

Aquax will sell the product to the golf clubs. This is the most common revenue stream, which is called "*Asset sale*"

**"Leasing"**

In order to get into the market the first couple of years Aquax will offer the golf clubs a leasing agreement. The golf clubs will pay an amount of money each quarter of the year. Hopefully the golf clubs will then after a period of time buy the product.

The leasing agreement will probable only be an offer for the golf clubs until the company have established a business on the market.




*Ill. 1.91. Business model canvas*

## Key Resources

A company need to ask itself what kind of resources are needed to fulfil its value proposition, distribution channel ext. *(Osterwalder & Pigneur, 2010)*

**"Software"**

Aquax need to buy the technology used to navigate Amphitrite, which are the GNSS modules, and the software that can program it.

**"Finance"**

To start the production the Aquax need financial support. How much needed will be explored in the budget on page 90.

## Key Activities

Aquax will focus on specific Key activities, which are important in order to fulfil the Value propositions, Channels ext.

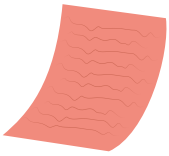
**"Product development"**

A key activity for Aquax will be to continue development of the product portfolio. This will allow Aquax to enter new markets and other customer segments, like public parks.

## Key Partnership

A key partnership for Aquax will be with the developers of the software for the product. As stated earlier a program for easy setup of the cutter area is needed to make the product successful. Software for the product itself will also have to be coded to ensure a user friendly experience for the greenkeeper.

## Cost structure



The Cost structure can often be divided into two different categories: "*Cost-driven*" and "*value-driven*".

Amphitrite is a "*value-driven*" *product for the golf clubs.* There is focus on getting the production cost as low as possible, but the product will not have any real competitors on the market, which makes it possible to charge a higher price for the product. The most important aspect is, that the product solves the problem and fulfils the value proposition for the golf clubs.

# PROFIT AND LOSS BUDGET

| Year | Pieces sold | Sales price |
|---|---|---|
| 2018 | 0 | 32.000,00 |
| 2019 | 100 | 32.000,00 |
| 2020 | 200 | 32.000,00 |

| IN DKK | 2018 | 2019 | 2020 |
|---|---|---|---|
| **TURNOVER** | 0 | 3.200,000.00 | 6,400,000.00 |
| - Material Cost | 0 | 1,573,900.00 | 3,147,800.00 |
| **CONTRIBUTION MARGIN** | 0 | 1,626,100.00 | 3,252,200.00 |
| - CASH PERIOD COST | 313,980.00 | 807,168.00 | 807,168.00 |
| **OPERATING MARGIN** | -313,980.00 | 818,932.00 | 2,445,032.00 |
| - DEPRECIATIONS | 244,000.00 | 244,000.00 | 244.000,00 |
| **Profit Before Interest** | -557,980.00 | 574,932.00 | 2,201,032.00 |
| - Interest paid | 524,417.15 | 510,370.26 | 496,323.38 |
| **PROFIT BEFORE TAX** | -1,082,397.15 | 64,561.74 | 1,704,708.62 |

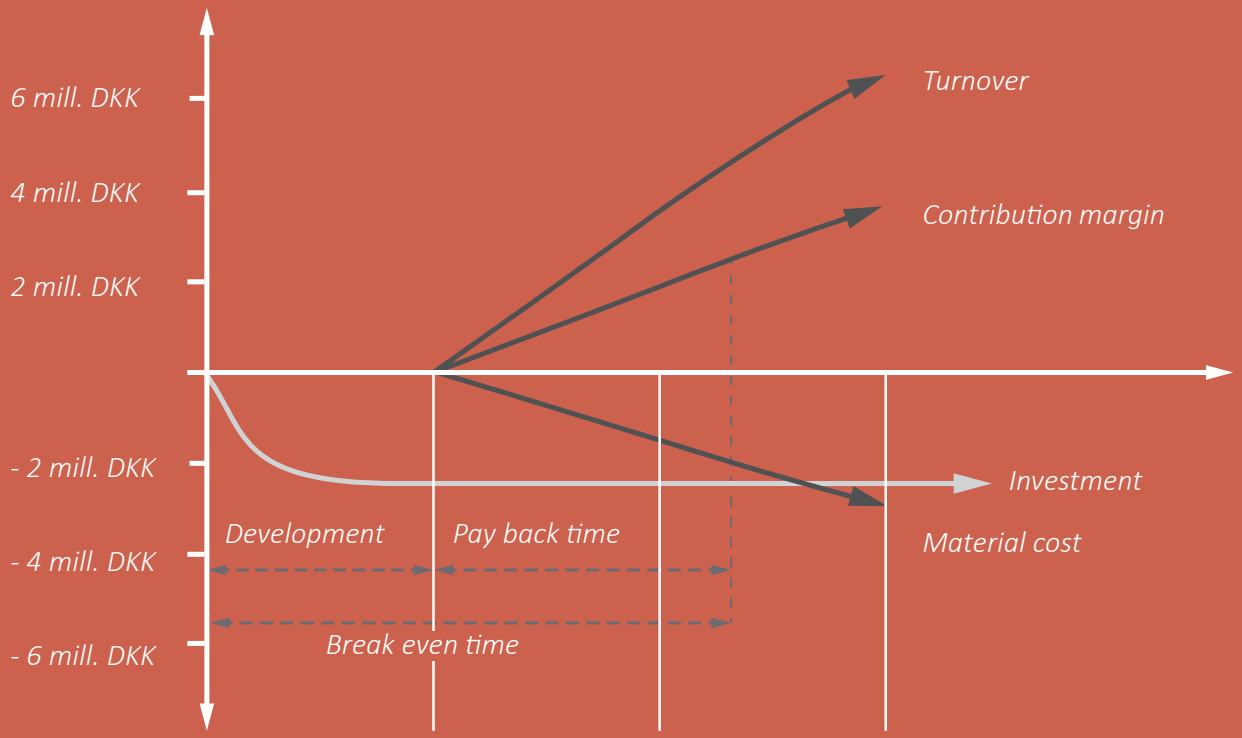
*Ill. 1.92. Profit & Loss Budget*

## Profit and Loss Budget

In this section, the budget for Amphitrite will be explained. The budget will clarify the business potential and give an overview of how the product will be financed. The budget is composed of a Budget and Loss Budget, which is build on multiple calculation that can be seen in Appendix L - Budget, and Appendix K - Components.

It is estimated that it will take approximately a year to finish the development of the product, before it can be launched. On Ill. 1.92. a Profit and Loss Budget can be seen. In the first year, Aquax will not sell any products, which is why the Contribution Margin in year 2018 is 0. Money is needed in order to pay for facilities and the development, which can be seen under the Cash Period Cost, Appendix L - Budget. The first year, five moulds will be bought. Two moulds for each wheel, a mould for the hub cups, a mould for the shell, and a mould for the foam. All five moulds will be depreciated over a period of five years.
To get the initial capital for development and investments, a loan of 2,3 million DKK is needed, Appendix L - Budget. The loan covers the investment of five moulds, and the cash period cost for the first two years.
It is estimated the interest of the remaining loan is 3 %, which is why the interest paid is decreasing each year.
At the end of year 2018, Aquax will have a deficit of almost 1,1 million DKK.

There are approximatively 40,000 golf facilities in the world. 22 % of those facilities are located in Europe. The second year, Aquax will launch the product. It is estimated that the Aquax will be able to sell the 100 units on the European market. The sales price of the product is 32,000 DKK. The 100 units, which is estimated to be sold, multiplied by the sales price give the Turnover. The Material Cost for one unit is 15,739 DKK (Appendix K - Components), which is subtracted from the Turnover, which gives the contribution margin. The Cash Period Cost, for the second year when the product is launched, can be seen in Appendix L - Budget. The Cash Period Cost is subtracted from the Contribution Margin and gives the Operating Margin. From the Operating Margin, the Depreciations are subtracted. For year 2019, Aquax will end with a Profit Before Tax on 64,512 DKK.
In year 2020, it is estimated that Aquax will be able to sell 200 units. The expenses from year 2019 will remain the same in year 2020, but due to the increased Turnover, Aquax will end with a Profit Before Tax of 1,704,709 DKK.




*Ill. 1.93. Breakeven analysis*

## Breakeven analysis

The time period for how long time it will take Amphitrite to break even is calculated, which means how long time it will take before the Contribution Margin covers the Investment.
(Kamuff, 2010)

Breakeven point = Fixed cost / (Turnover - Variable cost)

Breakeven point= 2.481.616,88 / 32,000 - 15,739= 153

Above it can be seen that Aquax need to sell 153 units, in order to cover all the expenses. The Fixed Cost in the calculation is the loan taken. The calculation of the loan can be seen in Appendix L - Budget.
In the second year, it estimated that Aquax will sell 100 units and in the third year sell 200 units. This means that Amphitrite will break even after two years and a quarter.
This graph can be seen on Ill. 1.93.

## Return of investment for the golf clubs

Based on the information from the stakeholders the average cost for golf clubs is around 18,000 DKK to have a contractor maintain a single lake. When calculating the ROI it will depends on how many lakes the golf clubs have. The golf clubs that were visited during the research had around nine lakes. With nine lakes, it will cost the golf clubs around 162,000 DKK to get them maintained once a year. The sales price for Amphitrite is 32,000 DKK.

ROI = (Gain from the investment - Cost of investment) / Cost of investment

Gain from investment = 162,000-32,000 = 130,000

ROI = (130,000 - 32,000) / 32,000 = 306 %

A golf club with nine lakes can therefore expect in one year to have a ROI on 306%, which mean the investment have paid off after a third of a year.

# Epilogue

# CONCLUSION

The project resulted in an amphibious robotic lake mower, which is targeted towards golf clubs to make the job of maintaining lakes easier for the greenkeepers.

One of the immediate observations made on the first visit to a golf club, was that it pains the greenkeepers that they do not have the time to maintain the lakes as well as the rest of the course. The purpose of the lake on a golf course is to make holes more challenging. Even though, the aesthetic of the lakes are very important, due to that the lakes have a great impact on how golf players rate the quality of the course.
Amphitrite solves the issue of making time for lake maintenance, by working automatically without observation. Though it requires time to deploy the robotic lake mower, it does the rest of the work on its own.

Instead of the time consuming weekly management of the lakes, the clubs use contractors with large machinery every one or two years. This is expensive as the cost is around 10,000 DKK per lake. Besides the cost, the large machinery have a tendency of tearing up the course and leaving much reconstructing work for the greenkeeper.
Amphitrite will be a one time investment, and depending on the amount of lakes, it will be a good investment from the first year.

Even though the product will take time daily for the greenkeeper, the lakes will transform from untamed wilderness to well maintained lakes. For the golf players this will make the experience of playing golf more aesthetically pleasing. Well maintained lakes also have influence on the game, where it becomes an active choice from the golf club on how difficult the hazards around a lake have to be.

# REFLECTION

The process of developing the amphibious robotic lake mower has not been straight forward. The project started with a different scope: Maintaining streams.

The development of the product designed for cutting water weeds in streams, was well on its way in solving the different user needs. When the solution was presented for the involved stakeholders it was stated that the solution was too complex for the context. What was pointed out as being too complex was the solution that allowed the product to cut close to the bottom, which was one of the central demands in the solution. This function relayed on multiple sensors, actuators and moving parts. The reason why the function had so many components, was in order to replace the human influence that made the simple motor scythe able to cut close to the bottom.
The demand to have a robust solution designed to have parts that can be replaced in the field, had not been part of the design criteria when developing the concept, which strongly would have effected the solution. This demand could also have been a strong parameter in the paradox mapping, where the Weed management drown would have scored poorly.
The stream workers could also have been involved earlier in the concept development, as statements from Peter Munk was part of choosing direction. Input from the actual person that needs to use the product daily, could have been more beneficial. Nevertheless, the stream workers could see potential in the purposed solution just in another context, golf lakes.

It was chosen to reframe to this context, because it was obvious that maintaining golf lakes is a problem for many golf clubs. The problem is more simple to define, as a golf lake is a closed system opposed to a natural lake. The market for creating a solution for the golf industry, was also more appealing than for stream workers, as Denmark is the only country to maintain lakes manually on a national scale.
The reframing was a crossroad for the team. It would have to be decided if there was time to go through all the phases again. The new direction was proposed when there was about a month to hand in the project. The main reason for the decision was the bigger market potential and thereby a more “realistic” product.

The solution developed for the golf clubs is an amphibious robotic lake mower. The solution solves most of the problems described in the report. More time and energy could have been used in predicting different user scenarios, both for charging the product, but also in how to move it from lake to lake.

The setup of the product has only been described briefly in an early user scenario, this is also one of the areas where more energy could have been used to describe the interaction more thoroughly. Though, when implementing a product that is meant to work almost autonomously into the real world, many unforeseen issues will present themselves.

The aesthetic design of the product has been through multiple iterations, first on sketches and later in CAD software. Inspiration has been drawn from the form analysis of the other professional garden related equipment from Stihl and Husqvarna. Inspiration has also been drawn from robotic lawn mowers, but the team wanted to do something different as the product is a new product type.
The design revolves around the big paddle wheels. The shape of the shell gives the product direction ,and rugged details give the product a tough expression. Many of the aesthetic decisions had been made when drawing the product into the CAD software. Therefore, another iteration could have been useful, where prototype would  help dimensioning the product’s proportions.

Construction and detailing of the product has not been as thorough as the team had strived for. Most of the functions are developed to a point where the team believes they will work, but another ideation round is needed to specify more details and the exact way to connect the different items.
An area where testing is crucial is the dimensioning of wheels, motors and battery. It is expected that the motor chosen for the product is overly powerful, and a smaller lighter motors would be adequate for the propulsion of the product. The dimensioning of the battery is based on a worst case scenario, as it has been difficult for the team to determine how much energy the product will use when sailing in water.

Throughout every step of the process models and testing has been a natural part of the development. It has been pursued to make tests before settling on any solution. This has been done to verify that the principles work in real life and not just on paper. Each test has derived new knowledge about the solution, and given new ideas of how to solve the issue in a better way.

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# Appendix

# APPENDIX A

## Watercourse law

Back in year 1982 the watercourse law concerning Danish streams were radical revised. In this section the most important parts of the law will be described.

## Law and regulations

The water stream law consist of 89 sections that among other things include whom is responsible for maintaining the streams, claim for compensation and environmental harm.

In section one sub-section two the law clearly state that the diversion of water must be done in consideration of nature and environmental interests. The law does not concretely describe how this environmental maintenance need to be carried out into practice. The environmental concerns are accommodated by a number of recommendations from environmental originations and experienced stream workers about weed cutting and maintenance of streams. The law do not include which kind of tool that need to be used in the process. In section 27 sub-section two it is described that the weed in the stream can be minimised with mechanical weed cutting tools. In sub-section three it is described that the cut off must be removed from the stream, unless the weed is not to the detriment of the stream or the wetlands. (Retsinformation, 2016)

## Regulations

For each stream in Denmark a regulation is worked out. The regulation consist of all the provisions that apply to the administration and management of the streams. The regulation include among other things how the stream must be maintained, which tools that are allowed for the stream workers to use, which time of the year the weed cutting process take place, and general information about the stream.

The watercourse authority compose the regulation for the streams. The proposal is sent out to the public, whereupon the public have eight weeks to come up with objection and other proposals. The watercourse authorities evaluate the comments and make the regulation ready. If the stream is a old county watercourse the regulation also need to be approved by Naturstyrelsen. Afterward, the public have four weeks to complain. The complaint will be processed by Natur- og Miljøklagenævnet. (Ringgard, 2017)

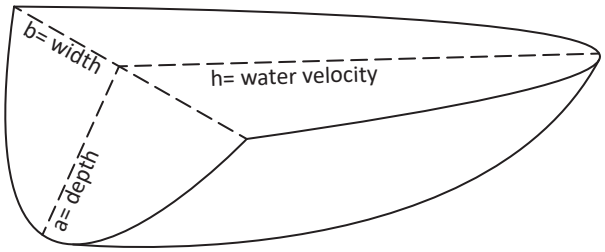
# APPENDIX B

## Hydraulic resistance in streams

To fully understand the effect of weed cutting in relation to the flood water conveyance, a mathematical representation is applied.
When making this mathematical representation many approximations will be made so the result will only be an representation of the effect of hydraulic resistance in the shape of an generalised stream.

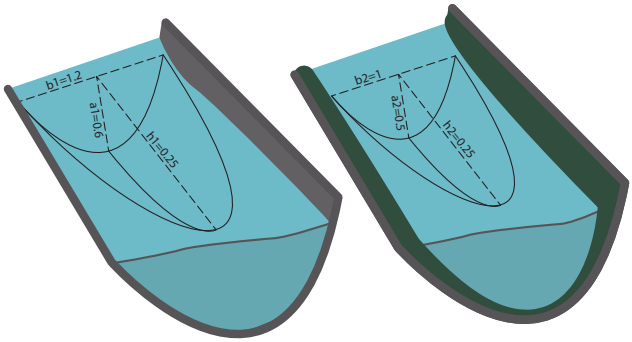
## Calculation of change in flood water conveyance

To calculate the water velocity it is assumed that the water velocity profile takes the shape of a quarter of an ellipsoid, as can be seen on Ill. 1.8.




*Ill. 1.102. Water velocity profile*

A scenario with a smaller stream with a width of around two metre, with or without water weeds will show the approximated difference in flood water conveyance. The flood water conveyance is calculated by finding the volume of an ellipsoid and dividing by four, the water velocity profile can be seen on Ill. 2.8.



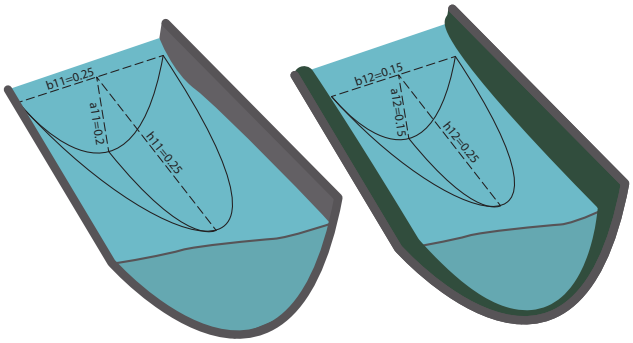

*Ill. 2.102. Water velocity profile with and without water weeds*

$$V1 := \frac{0.188 \cdot a1 \cdot b1 \cdot h1}{4} \qquad V2 := \frac{\frac{4}{3}\pi \cdot a2 \cdot b2 \cdot h2}{4}$$

$$V1 = 0.0235\ m^3/s \qquad V2 = 0.0327\ m^3/s$$

The two volumes V1 and V2 are showing a loss in flood water conveyance of 31 %, by having 0.2m of plants on the edges and 0.1m on the bottom of the stream profile.

The calculations has also been made on a smaller stream with a width of around a 0.5m to see the effects of weeds on the flood water conveyance.




*Ill. 3.102. Water velocity profile with and without water weeds*

$$V11 := 0.0196\ m^3/s \qquad V12 := 0.0039\ m^3/s$$

The difference of 80% on the result and shows that the more extreme effect on the flood water conveyance by having 0.2m of plants on the sides and 0.1m of plants in the bottom.

## Assumptions in the calculation

The calculations are based on several assumptions and approximations on how streams behave. These include:

- The water velocity is the highest at the surface of the water
- The roughness of the water plants will block the water flow completely
- The streams takes the shape of an half ellipse
- The effect on the maximum water velocity in relation to the narrowing of the stream because of water plants

# APPENDIX C

## Methods for weed cutting

There are multiple ways of maintaining streams. When choosing the method it depends on the conditions of the stream and how the regulation states the stream needs to be maintained. Other factors can be what equipment is available and what methods the municipality and contractors prefer to be working with.

The most used way of cutting is the thalweg cutting. There are multiple different ways of making thalweg cutting, but they rely on the same basic principles. The water weeds are cut in a curved path where the water current velocity is the highest, a rule of thumb is that the distance between the curves should be 5-7 times the width of the stream. By cutting the water weeds where the water velocity naturally is the greatest the flood water conveyance is greatly increased while still keeping enough plants to sustain the natural fauna and create good conditions for fish. An illustration of how natural plants could grow can be seen on Ill. 1.103

## Normal thalweg cutting

Studies show that original thalweg cutting Ill. 2.103., can develop man made canals into streams with diversity in fauna and plant life.

One of the negative effects of the normal thalweg cutting is that the continuous cutting in the same path makes it impossible for most plants life to survive, which often results in monoculture of one dominant plant. (Bach, et al., 2016) (Moeslund, 2007)

## Network cutting

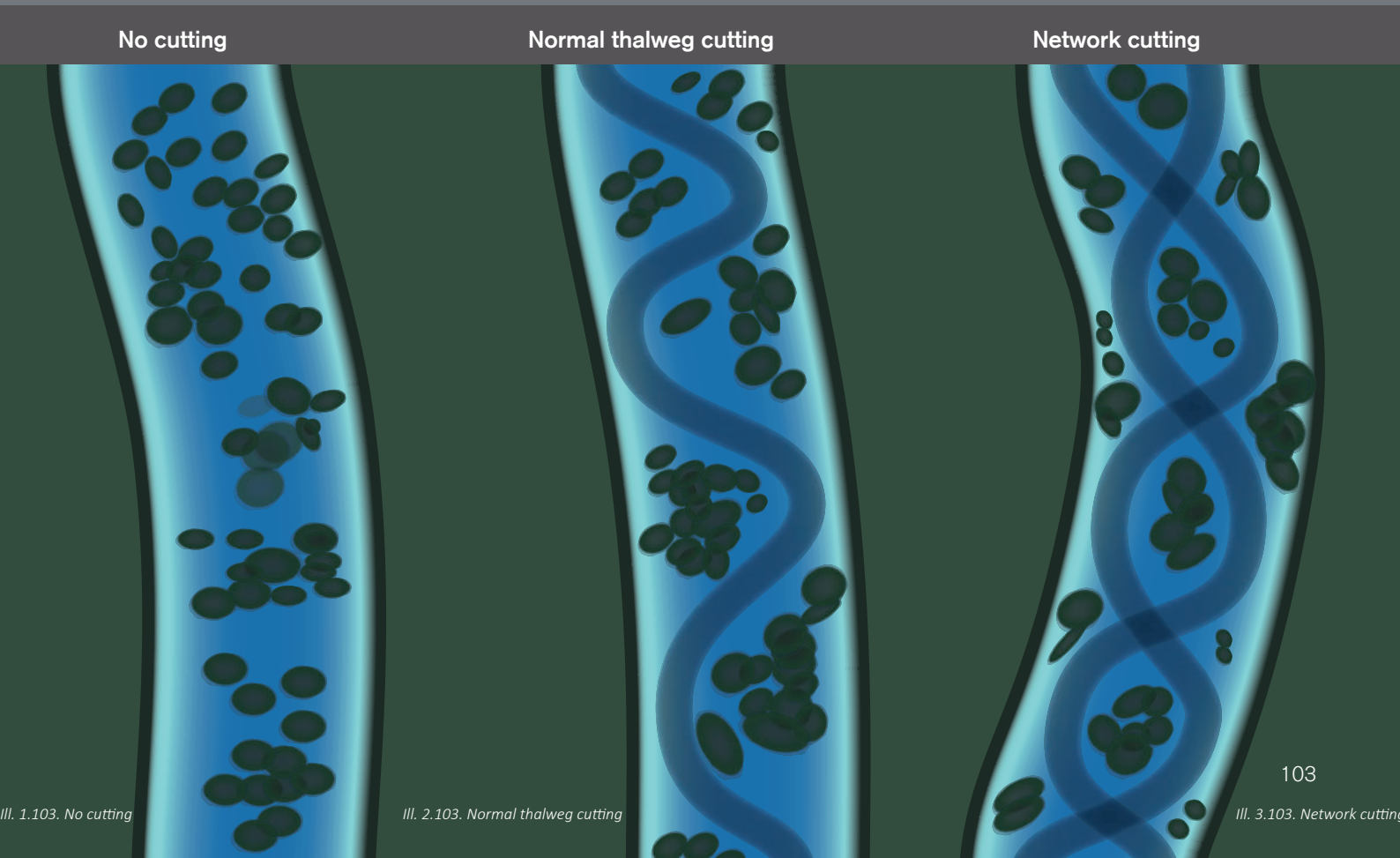
Network cutting is a more advanced version of the normal thalweg cutting, two or more curved paths are cut, Ill. 3.103. When using network cutting and leaving an uncut part of water weeds in the middle they have a chance of developing naturally. Compared to the normal thalweg cutting the environmental conditions are better for plants and fauna with the network cutting.

Some of the problems related to network cutting is that the channels does not follow the complex natural flow of the stream. Another issue is when cutting the water weeds it can be difficult to make the cuttings flow downstream without getting caught in the middle lane. (Bach, et al., 2016) (Moeslund, 2007)

## Combined thalweg cutting

The combined thalweg cutting is a combination of the normal thalweg cutting and the network cutting, Ill. 3.13. The pros of using this method is that it is better adapted to the natural flow of a stream. In the corners the weeds are cut to allow the water velocity to be high in one path. Between the corners small patches of plants are left and network cutting allows small patches of rocky bottom to form in the middle of the stream to create a optimal habitat for small fish.

This method requires experience and comprehensive understanding of all the different environmental concerns. (Bach, et al., 2016) (Moeslund, 2007)




*Ill. 1.103. No cutting*

*Ill. 2.103. Normal thalweg cutting*

*Ill. 3.103. Network cutting*

## Full cutting

Full cutting is used to give the best flood water conveyance by eliminating the hydraulic resistance of plants, Ill. 2.104. This method of cutting is damaging on the environment, only the most resistant plants will regrow, which will lead to monoculture. The full cutting will eliminate the habitat for the fauna and small fish. (Bach, et al., 2016) (Moeslund, 2007)

## The Aalborg method

The method were initially developed to lower the frequency of weed cutting. Before the Aalborg method, it was common to make normal thalweg cuttings up to nine times a year to keep the often dominating reed sparganium down.
The Aalborg method is relying on the different thalweg cutting methods but stands out by cutting as close as possible with the weed cutting boat or dredging bucket, this is time consuming and damage the equipment. When this deep and hard cutting has been preformed several times in the same path, the reed sparganium has a hard time regrowing and the fine sediment is washed away to reveal gravel and rocks. The reed sparganium naturally grows in the soft part of the bottom so other slower growing water plants, which natural habitat is a rocky bottom now has better conditions for growing. The frequency of weed cutting can then be decreased from 8-9 times to 4 times a year, because of the change in environment in favour of the slower growing water plants. (Bach, et al., 2016) (Moeslund, 2007)

## Riparian cutting

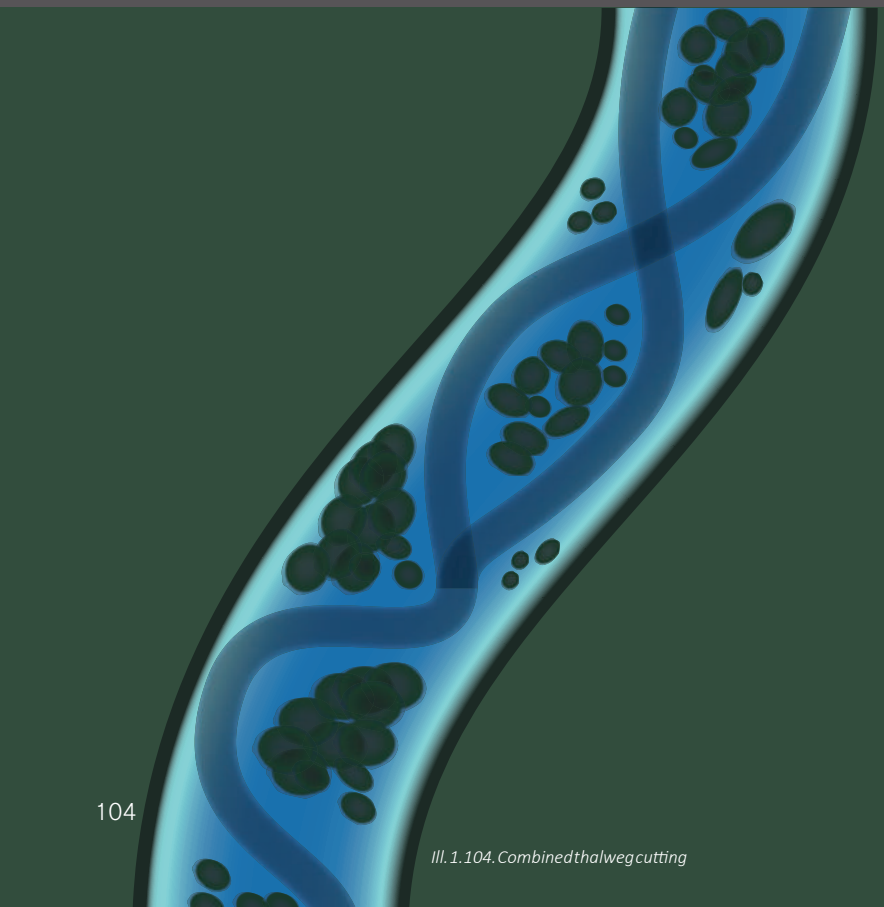
Weed cutting on the riparian can in some cases be more important for the flood water conveyance than cutting of the water plants. On streams that is cut deep into the terrain the riparian plants can block the sunlight so no water plants can survive.
Keeping the riparian plants can be utilized as a way to limit the need for multiple cuttings for a stream, but leaving the riparian plants to block out sun light for the stream can have environmental impact on the conditions for the fauna and small fish. (Bach, et al., 2016) (Moeslund, 2007)

## Selective cutting

Selective cutting is reserved for the experienced stream workers that know, which plants to cut and which to keep to improve either the flood water conveyance and the environmental conditions. The stream worker can choose to eliminate certain unwanted plants and make the conditions better for other plants. This method is expensive but will ultimately give the best possible environmental conditions. (Bach, et al., 2016) (Moeslund, 2007)

| | |
|---|---|
| What cutting methods should the product be able to preform | ?? |

**Combined thalweg cutting**



*Ill. 1.104. Combined thalweg cutting*

**Full cutting**

*Ill. 2.104. Full cutting*

# APPENDIX D
**Injunction**

**Bilag 1: Påbud om at sikre, at arbejdet med beskæring og vedligeholdelse af vandløb udføres sikkerheds- og sundhedsmæssigt fuldt forsvarligt**

| | |
|---|---|
| **Virksomhed** | SLOTHS NATURPLEJE ApS, Ternevej 4, 8832 Skals |
| **Beskrivelse af de faktiske forhold** | Arbejdstilsynet, ved tilsynsførende Tommy Andersen og Tony Berthelsen, har besøgt Sloths Naturpleje ApS, Ternevej 4, 8832 Skals, hvor vi observerede, at medarbejdere arbejdede med beskæring og oprensning af vandløb. Arbejdstilsynet observerede at 2 medarbejdere beskar kanter og bund i et vandløb.<br><br>Under tilsynet blev der talt med: Ejer Lars Sloth, ansatte Morten Nielsen og sekretær Mia Petersen<br><br>Vi fik oplyst af ovennævnte samt konstaterede at:<br>• 2 medarbejdere typisk går i vandløbene med en motor drevet le og slår/beskærer kanter og bundvegetation. 1 går typisk med leen, mens den anden smider det afskårne grøde op på brinken (se billede). Medarbejderne var iklædt vaders af gummi.<br>• De arbejdeder ind i mellem med armene løftede fremad og opad, nogle gange op over hovedhøjde der hvor vandet er dybt. De har fat med begge hænder på skaftet på leen.<br>• De aktiverer leen med den ene hånd og har fat i et håndtag med den anden, for at styre leens bevægelser. (se billederne 1 og 2)<br>• De arbejder med foroverbøjet ryg, især når de slår bundbevoksningen i åen.<br>• Arbejdet kan være meget hårdt de steder hvor vandet er dybt og vegetationen er stor.<br>• Motorleens benzindrevne motor blev båret på ryggen på et stativ. Selve motoren (uden brændstof)vejede 10, 3 kg og skaftet med leen vejede ca. 3 kg<br>• For at tanke benzin på motoren skal de gå tilbage til bilen, de har reservedunk med sig i vandløbene til en ekstra tankfuld. En tankfuld holder ca. til en times klipning hvorefter de bytter så det ikke er samme mand der går med leen hele dagen.<br>• Medarbejderne skal være meget koncentrerede i forhold til sikkerheden i arbejdet med motor drevet le<br><br>Følgende blev også oplyst:<br>• Sæsonen for beskæring var fra ca 1. juni til 15. oktober, hvor ca. 10 ansatte arbejder fuldtid med beskæring af åer og vandløb.<br>• Ud af en dag på 8 timer arbejdes der i vandløbene med beskæring og opskovling i ca. 5,5 timer. Den øvrige tid går bl.a. med at hente brændstof til leen samt pauser o.s.v.<br>• Medarbejderne arbejder sammen 2 og 2 om vandløbene. De skal vedligeholde ca. 100 km vandløb manuelt om året. Mange af vandløbene bliver beskåret 2-3 gange pr sæson.<br>• Ved flere af vandløbene er der ikke opsamlingsmulighed, så beskærer den ene medarbejder, mens den anden skovler op med en greb (billede 1 og 2). En grebfuld vejer oftest mellem 5 og 10 kg. Den afskårne grøde skal opskovles i en højde på mellem 10 cm og 2 meter alt efter hvor høje kanterne på vandløbene er. Det opskovlede materiale må ikke ligge på kanterne. Når der skovles op, arbejdes der ligeledes med løftede arme og foroverbøjet ryg.<br>• Der er begrænset mulighed for at holde pause i arbejdet da den afskårne grøde hele tiden kommer flydende.<br>• De 2 medarbejdere i et team skiftes som regel til at beskære og opskovle.<br>• I nogle grøfter/ vandløb gik de i mudder til knæene, andre vandløb/ åer gik de |

| | |
|---|---|
| | mod en kraftig strøm. Vandet i vandløbene/ åerne variere meget i dybde.<br>• Bundforholdene i vandløb og åer gør at man skal være meget koncenteret for ikke at miste balancen, når der arbejdes med grødeskæring.<br>• Temperaturen i vandet kan være meget svingende fra meget varme sommer dage og til kolde efterårsdage. Hvis medarbejderne har for meget tøj på hæmmer det deres bevægelser og gør arbejdet meget hårdere.<br>• Der bliver holdt opsyn/ ført kontrol med grødeskæringen i vandløbene og de bliver "kasseret" hvis synsmanden ikke mener det er godt nok beskåret og så skal det ombeskæres. Det kan være ret forskelligt hvad den enkelte synsmand lægger vægt på ved en beskæring og medarbejderne beskærer heller ikke ens, så der skal foretages ombeskæring.<br>• Tilsyn/kontrol af arbejdet udføres af de enkelte Kommuner der har udbudt opgaven.<br>• Ledelsen, ved ejer Lars Sloth oplyser at arbejdet er hårdt og at han selv er slidt i bl.a. skulder og ryg efter års arbejde med grødeskæring.<br>• Desuden oplyser han, at han har tænk meget på arbejdsmiljøet ved bl.a. ikke at indføre akkordarbejde som andre i samme branche gør, samt fjerne tidspres så medarbejderne ikke skal nå en bestemt strækning hver dag, men at man når det man når og holder de pauser man har brug for.<br><br>I udbudsmaterialerne fra de forskellige kommuner er det nøje beskrevet hvilke vandløb der skal beskæres manuelt, og at det skal gøres i henhold til arbejdsmiljølovgivningen. I følge ejer Lars Sloth er det til tider meget svært, da vandløbene er meget forskellige i både tæthed af grøde, samt vanddybde og bundforhold. Sloths Naturpleje ApS har ca. 100 km vandløb årligt der skæres manuelt, og i følge Lars Sloth ville ca. 80 procent af kunne tages med maskine (mejekurv), hvis de måtte for kummunerne. Samtidig oplyser Lars Sloth, at arbejdet med mejekurv både er hurtigere og til tider mere skånsomt for både fauna og flora i vandløbene, hvis det bliver gjort rigtig. Mejekurve kan fås med forskellige størrelse skovle, hvilket gør at de kan tilpasses de enkelte vandløb (se billlede 3). |
| **Begrundelse for påbud** | Det er Arbejdstilsynets vurdering, at medarbejderne på grund af samlede fysiske belastning ved grødeskæring og vedligeholdelsen af vandløb er udsat for sundhedsskadelige belastninger. Belastningerne kan på kortere eller længere sigt resultere i nedslidningsskader på muskler, sener og led af især skulder og ryg. Dette begrundes med at arbejdet blev udført ca. 5,5 time om dagen og foregik dagligt i sæsonen fra juni til midt oktober.<br><br>Medarbejderne arbejdede gående i vand med:<br>• Foroverbøjet vredet ryg især når de beskar bundbevoksningen i vandløbene eller hvis det var små/lave vandløb. Samt når de skovlede det afskårne materiale op.<br>• Armene løftede fremad/opad, både når de beskar med leen og når de skovlede op.<br>• Tydelig kraftanvendelse når de anvendte leen i vandet idet de skulle løfte leens motor på ryggen og skaftet i hænderne, samtidig med at armene varløftet og ryggen foroverbøjet. Samt når de skovlede op, idet de løftede materiale på mellem 5 og 10 kg i en højde af mellem 10 cm og 2 meter.<br>• Mange gentagelser af ensartede bevægelser både ved beskæring og opskovling.<br><br>I vurderingen er der desuden lagt vægt på:<br>• at de samme muskelgrupper i skuldre og ryg belastes, ved arbejdet med |

| | |
|---|---|
| | beskæring og opskovling.<br>• at der blev arbejdet i et højt tempo for at kunne nå opgaven med at beskære / vedligholde de ca. 100 km vandløb.<br>• at medarbejderne skulle bruge kræfter på at gå fremad, idet der ved nogle vandløb (især åer) gik mod en ret kraftig strøm og ved andre (især grøfter) var der et tykt lag af mudder de skulle gå igennem.<br>• at temperaturen kunne være meget skiftende, fra op til 30 grader om sommeren og til frostgrader i efteråret.<br>• at der bliver ført ekstern kontrol med at arbejdet er udført godt nok og at det skal gøres om hvis ikke det er, hvilket giver en ekstra arbejdsbelastning.<br>• at arbejdet kan være psykisk belastende, idet det kan være svært at nå og overskue arbejdsopgaven, hvis fx der arbejdes i grøfter med meget mudder og arbejdet skrider meget langsom frem og er rigtig hårdt.<br><br>Det er Arbejdstilsynets vurdering, at den rotation, som foregår mellem forskellige arbejdsopgaver, ikke giver tilstrækkelig reel variation idet muskelgruppene i skuldre og ryg belastes ens ved opskovling og beskæring af grøde/planter. De nævnte arbejdsopgaver foregår gående gennem vand, kombineret med hyppig brug af skuldre og arme og foroverbøjning af overkroppen. Disse arbejdsbevægelser medfører en aktivering af musklerne i ryggen for at stabilisere rygsøjlen, samt aktivering af musklerne i skulder. Det samlede krav til kraftbrug af disse muskler i løbet af arbejdsdagen, medfører at der er risiko for muskelskeletbesvær i disse regioner.<br><br>Det er desuden Arbejdstilsynets vurdering at det samlede arbejde, med næsten konstant fysisk aktivitet, belastning af de samme muskelgrupper samt arbejde i højt tempo medfører en høj energiomsætning som kan medvirke til generel udtrætning. Samtidig vurderes det at kombinationen af mange gentagne bevægelser og uhensigtsmæssige arbejdsstillinger, samt at der skal anvendes kraft til løft af byrde (løft af leen ved beskæring og greben ved opskovling), kan medføre træthed, smerter og ømhed i de enkelte muskelgrupper i ryg og skuldre. |
| **Påbud** | Virksomheden påbydes at sikre, at arbejdet med beskæring og vedligeholdelse af vandløb, planlægges og tilrettelægges således at det i alle led kan udføres, så det er sikkerheds- og sundhedsmæssigt fuldt forsvarligt. Dette skal ske både ud fra en enkeltvis og samlet vurdering af de fysiske, ergonomiske og psykiske forhold som på kort eller lang sigt kan påvirke sundheden.<br><br>Påbuddet skal være efterkommet senest den 15. maj 2015. |
| **Hjemmel for påbud** | • §38 stk. 1 § 77, stk. 1, i lovbekendtgørelse nr. 1072 af 7. september 2010 af lov om arbejdsmiljø med senere ændringer.<br>• § 4 og §7 stk. 1, i bekendtgørelse nr. 559 af 17. juni 2004 om arbejdets udførelse med senere ændringer |
| **Vejledning** | I kan læse mere i<br><br>At-meddelse 4.05.3 om Vurdering af arbejdsstillinger og arbejdsbevægelser<br>At-vejledning D.3.4 om Aarbejdsrelateret muskel- og skeletbesvær.<br><br>Materialet findes på www.at.dk under emnet "Regler". |

# APPENDIX E

## Cutting with water pressure

In this section all the results from the water jet test can be seen. In the left column the pressure that was used can be seen. In the second column the distance between the nozzle and the leak can be seen. The way the distance was measure was with a ruler that was pasted to the water jet. The water jet was places above the leak.
Then the distance was read from above the leak to the water table. Thereby it was possible to calculate the distance between the leak and the nozzle. The hole test was filmed. In the film it could be seen that the distance between the leak and nozzle vary around 20 mm, because it was not possible to keep the water jet still during the test.

| Pressure Bar | Distance mm | Result | Notes |
|---|---|---|---|
| 200 | 0 |  | |
| 200 | 100 |  | |
| 400 | 0 |  | |

| | | | |
|---|---|---|---|
| 400 | 100 |  | |
| 400 | 150 |  | The distance vary with 5 mm. |
| 400 | 50 |  | The distance vary with 5 mm. |
| 400 | 100 |  | The distance vary with10 mm. |

# APPENDIX F

## User need mapping of concepts

The three concepts have been rated on how they preform in easy of the user need by the member of the team. The sign **+** represent that the need is fulfilled, the **o** represent that a need is either partially fulfilled or the need has not been possible to rate, the sign **-** represent a need that is not fulfilled.

| User needs |  |  |  |
|---|---|---|---|
| The product must be able to cut selective | + | + | o |
| The product needs to be able to cut close to the bottom | + | + | + |
| Solution for the exhausting task of moving in streams, especially upstream or in muddy streams | o | - | + |
| Easy transportation from car to stream The product should not apply any direct weight to the stream worker | o | o | o |
| Find cheaper cutting methods | - | o | o |
| Manual tool must be more efficient than existing solutions | o | o | o |
| The product should not apply any direct weight to the stream worker | + | + | + |
| The product should not rely on the stream worker to work with their arms extended from their body or with the back bend | + | o | + |
| The product should be able to run 5.5 hours a day | o | o | o |
| The product needs to be light and agile to access the smaller streams. | + | + | + |
| The tool must be able to cut a depths at 100-900 mm | + | + | + |

# APPENDIX G

## Weight of water jet

On recommendation by Bo from Leif M. Jensen the water jets from Den-Jet are researched, as they are some of the most robust and well build machines for providing high water pressure. As the test showed 400 bars of pressure was needed to cut the leek. A machine that fits these requirements is the CD25-400. It can provide 400 bars of pressure at 21L/m. (http://denjet.com/cd25-400)

The weight of the high pressure water jet is 350 kg. The weight can be lowered as much of the weight is added by the steel cage around the product. The footprint is the same as an EUR pallet, 1200 mm by 800 mm. Nevertheless a solution relying on using water cutting at 400 bars will be a heavy and big solution to transport around the smaller streams.

# APPENDIX H

## User ratings

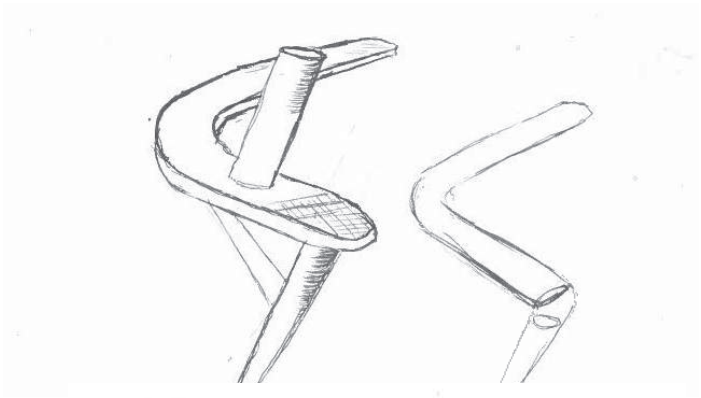
As a part of creating the house of quality, the user needs were rated by some of the involved stakeholders. The rating were made by Peter Munk from the Aalborg municipality, and by Lars and Ole from Sloth Naturpleje.
The two different stakeholders are rating most of the needs similar. The average score is calculated and transfered to the house of quality inside the process report.

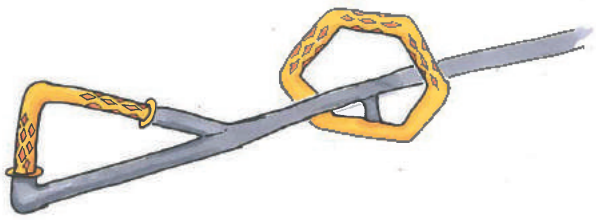
| | | Lars and Ole - Sloth Naturpleje | Peter Munk | Average |
|---|---|---|---|---|
| 1 | The product needs to be able to cut close to the bottom | 5 | 5 | 5 |
| 2 | Solution for the exhausting task of moving in streams, especially upstream or in muddy streams | 5 | 3 | 4 |
| 3 | The product should not rely on the stream worker to work with their arms extended from their body or with the back bend | 5 | 5 | 5 |
| 4 | The product should be able to run 5.5 hours a day | 2 | 5 | 3.5 |
| 5 | The product needs to be light and agile to access the smaller streams. | 3 | 5 | 4 |
| 6 | Find cheaper cutting methods | 5 | 5 | 5 |
| 7 | Manual tool must be more efficient than existing solutions | 5 | 4 | 4.5 |
| 8 | Easy transportation from car to stream | 5 | 5 | 5 |
| 9 | The tool must be able to cut a depths at 100-900 mm | 3 | 5 | 4 |
| 10 | The product must be able to remove the cut off weed | 3 | 3 | 3 |
| 11 | The product must be able to cut the riparian | 4 | 4 | 4 |
| 12 | When operating the product from the riparian it must be able to cut in streams at a width of 3m | 1 | 3 | 2 |
| 13 | The product should be functional even in muddy water with plant debris | 5 | 3 | 4 |
| 14 | The product must not be able to tip over during the operation | 5 | 1 | 3 |

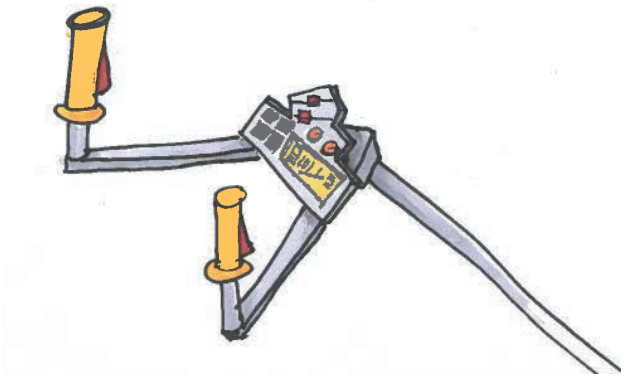
# APPENDIX I

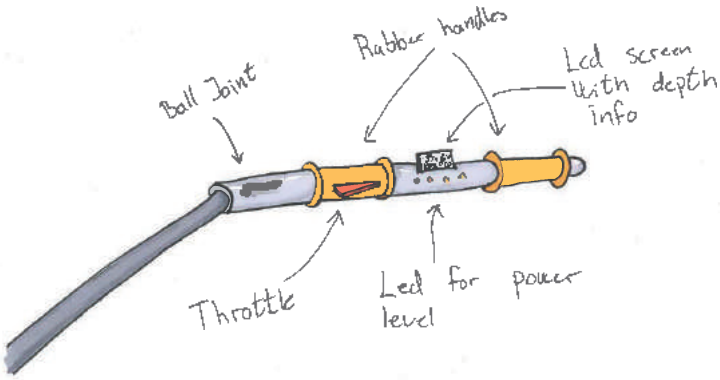
## Interaction

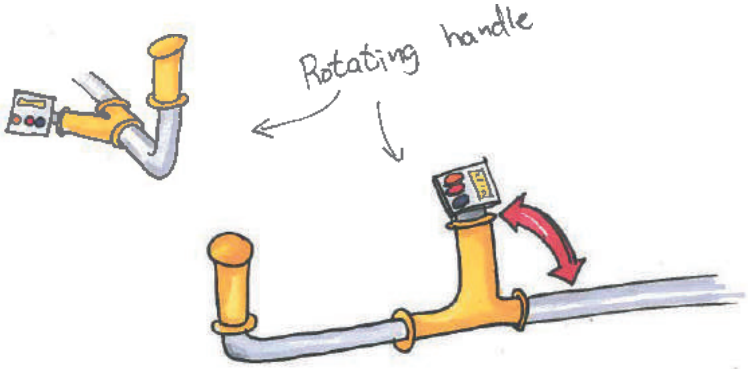
Sketches of how the handles could be styled was made. In the styling of the handles, the interaction with the product was in focus. A list of some of the different was to interacts was made to act as inspiration of different possibilities. If the handle should be high tech or more manual.

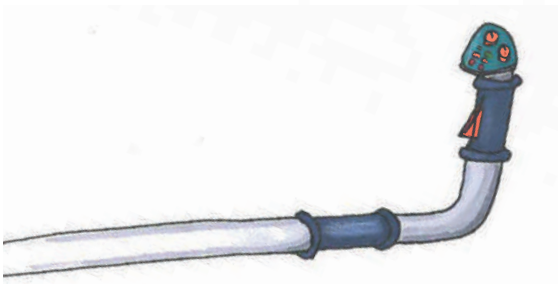


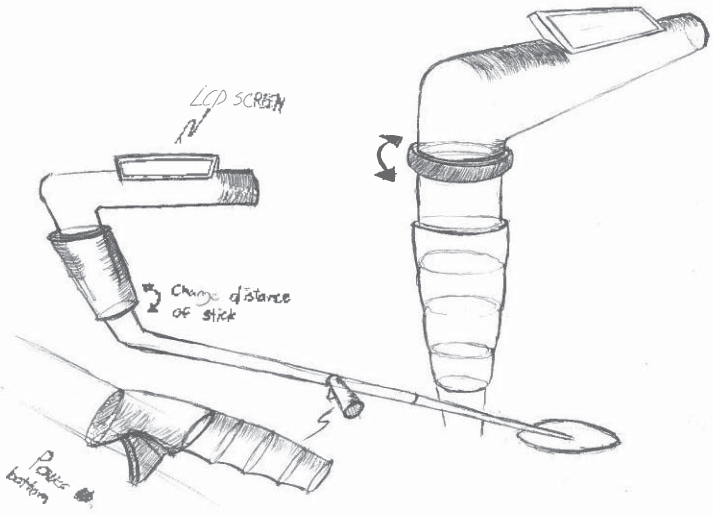









| Feed forward | |
|---|---|
| Need | Interaction face |
| Change the depth of the cutter | Rotating button, push button, slider button |
| Speed of the cutter | Rotating button, push button, slider button |
| Max power in the motors (sensitivity) | Rotating button, push button, slider button |
| Emergency stop for the cutter | Push button |
| **Feed back** | |
| Distance from bottom to cutter | Light, display, sound, vibration |
| Water depth | Light, display, sound, vibration |
| Energy left (gasoline, battery power) | Light, display, sound, vibration |
| Incoming stones | Light, display, sound, vibration |
| Cutter speed | Light, display, sound, vibration |
| Cutter or propeller stuck | Light, display, sound, vibration |

# APPENDIX J

## Redefinition of user needs

As some of the user needs from before the reframing was still relevant, instead of changing them they were redefined to fit with the new context.

| | |
|---|---|
| 1 | The product should not rely on the stream worker to work with their arms extended from their body or with the back bend |
| 2 | Easy transportation from car to stream |
| 3 | The product should be functional even in muddy water with plant debris |
| 4 | The product must not be able to tip over during the operation |

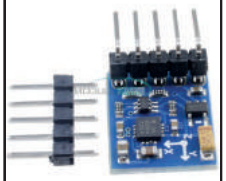
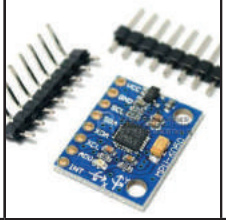
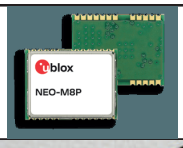
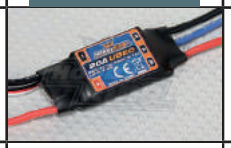
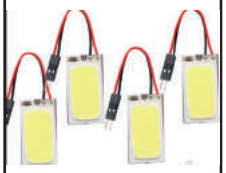
| | |
|---|---|
| 1 | The product should not rely on the greenkeeper to work with their arms extended from their body or with the back bend |
| 2 | Easy transportation from golf cart to the lake |
| 3 | The product should be functional even in muddy water with plant debris |
| 4 | The product must not be able to tip over during the operation |

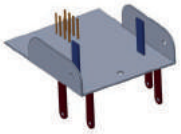
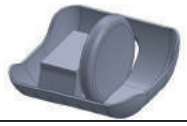
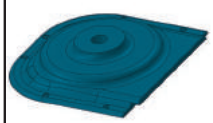
# APPENDIX K

## Components

A list of the components in Amphitrite is compiled. The weight and price of the different components is stated. There are three lists, one for general components, one for electrical components, and one for production components.

| Component list | | | | | |
|---|---|---|---|---|---|
| Component description | Picture | Data | Number of components | Weight Kilograms | Total price DKK |
| Motor for drive wheels<br><br>https://www.motion-dynamics.com.au/zd1633r-12v-100w-30-55-rpm-8-50nm-torque-left-angle.html |  | 12 v<br>50 Nm<br>55 RPM<br>100 w | 2 | 2.8*2 = 5.6 | 2*570 = 1,140 |
| Motor for trimmer<br><br>https://www.motiondynamics.com.au/90mm-60-watt-dc-motor-12-24-volt.html |  | 12 v<br>3600 RPM<br>60 w | 1 | 1.8 | 570 |
| Gear for trimmer ACP-G-5U3.6-K<br><br>http://www.anaheimautomation.com/products/gearbox/spur-gearbox-item.php?sID=301&serID=5&pt=i&tID=146&cID=31 |  | Gear ratio: 1: 10 | 1 | 1.2 | 718 |
| Battery and charger<br><br>https://www.aliexpress.com/item/350W-High-capacity-12V-60AH-lithium-battery-pack-12V-60000MAH-rechargeable-battery-with-12-6V-5A/32803151638.html?spm=2114.search0204.3.14.5d2a135dll9N-up&ws_ab_test=-searchweb0_0,search- |  | Voltage: 12<br>Capacity: 60 Ah | 1 | 4 | 1,816 |
| U-Joint<br><br>https://www.mcmaster.com/#6450K3 |  | Maximum Operating Angle: 136° | 2 | 0.7 x 2 = 1.4 | 925 x 2 = 1,850 |
| | | | Total | 14 | 6,094 |

| Electronic component list | | | | |
|---|---|---|---|---|
| Component description | Picture | Number of components | Weight Kilograms | Total price DKK |
| Raspberry Pi<br>Main control board<br><br>https://raspberrypi.dk/produkt/raspberry-pi-3-model-b-plus/ |  | 1 | Na. | 329 |
| Digital compass<br><br>https://www.ebay.com/itm/GY-271-HMC5883L-Digital-Compass-Module-3-Axis-Magnetic-Sensor-Module-For-Arduino/172421302792?hash=item-28251c4a08:g:-kwAAOSw~T9aVJi3 |  | 1 | Na. | 13 |
| Gyroscope<br><br>https://www.ebay.com/itm/MPU-6050-6DOF-3-Axis-Gyroscope-Accelerometer-Module-for-Arduino-DIY/201415045005?hash=item2ee545af-8d:g:OSwAAOSwDwtUm4WP |  | 1 | Na. | 8 |
| GNSS module<br><br>https://www.u-blox.com/en/product/neo-m8p-series |  | 2 | Na. | 790 x 2=1,580 |
| Electronic speed controller<br>165<br>https://hobbyking.com/en_us/hobby-king-20a-esc-3a-ubec.html |  | 3 | Na. | 55 x 3=165 |
| LCD Screen<br><br>https://www.ebay.com/itm/7-inch-LCD-Screen-Display-Monitor-for-Raspberry-Pi-Driver-Board-HDMI-VGA-2AV/171280831162?epid=769125039&hash=item27e12212ba:g:8sQAAOSw0GJZpTSM |  | 1 | Na. | 182 |
| LED Light<br><br>https://www.ebay.com/itm/NEW-White-48-SMD-COB-LED-T10-4W-12V-Car-Interior-Panel-Light-Dome-Lamp-Bulb/152492354478?hash=item238140abae-:g:fLkAAOSw~AVYpPzJ&vxp=mtr |  | 2 | Na. | 2x7=14 |
| Caples and miscellaneous | | | Na. | 200 |
| | | Total | ~1 | 2,,095 |

| Production components list | | | | | |
|---|---|---|---|---|---|
| Component description | Picture | Material | Number of components | Weight Kilograms | Total price DKK |
| Top shell |  | ABS plastic | 1 | 1,161 $cm^3$ x 1.03g/$cm^3$=1.2 | 500 Based on personal insight from company |
| Bottom part |  | Expanded polypropylene (EPP) | 1 | 28,662 $cm^3$ x 0.02g/$cm^3$=0.6 | 300 |
| Construction base |  | Aluminium 5052 | 1 | 848 $cm^3$ x 2.6 g/$cm^3$=2.2 | 500 |
| Cutter |  | Steel | 1 | 131$cm^3$ x 7.9 g/$cm^3$=1 | 900 |
| Base plate cutter |  | Aluminium 5052 | | 181 $cm^3$ x 2.6 g/$cm^3$=0.5 | |
| Skies and wheels |  | Na. | 2 | 0.5x2=1 | 250x2=500 |
| Tires |  | Na. | 2 | 2x2=4 | 500x2=1,000 |
| Connection bars to cutter |  | Aluminium 5052 | 4 | 47.5 $cm^3$ x 2.6 g/$cm^3$=0,2x4=0.8 | 50x4=200 |
| Handle |  | Na. | 1 | 0.5 | 300 |
| Axel for cutter | | Steel | | 0.5 | 50 |
| Housing for cutter gear |  | Aluminium | 1 | 40.5 $cm^3$ x 2.6 g/$cm^3$=0,2x4=0.1 | 300 |
| Bolts and miscellaneous | | | | Na. | 3000 |
| | | | Total | 12.4 | 7,550 |

# APPENDIX L
## Budget

The first year will be used on further developing of Amphitrite. 200,000 will be used on prototypes and so on. A building will be rented in order to have place where prototypes will be made and tests will be carried out.

| **Cash period development** | **First year** |
|---|---|
| Development | 200.000,0 |
| Rent of building | 113.980,00 |
| **Total** | **313.980,00** |

The second year will Aquax launch the product Amphitrite. A sales person will be hired. He will be paid 300 DKK per hour, and will work daily eight hours.
The sales person job will be to drive out to golf clubs and present and sell Amphitrite. In order to that he will need a car. Aquax will lease a Polo 1.0 TSI Trendline, which the sales person can use.
50,000 DKK will be used on promotion. The money will be used advertisements in different golf magazines.

| **CASH PERIOD COST** | **Second and third year** |
|---|---|
| Salary - 1 sales man | 607.200,00 |
| Leasing a car | 35.988,00 |
| Promotion | 50.000,00 |
| Rent of building | 113.980,00 |
| **Total** | **807.168,00** |

https://www.volkswagen.dk/app/site/privatleasing/downloads/volkswagen_privatleasing_samlet_prisliste.pdf

https://www.lokaleportalen.dk/aalborg-produktion-vaerksted/aalborgoest/111215

| Depreciation | Cost price | Depreciation next five year |
|---|---|---|
| Mould for vacuum | 60.000,00 | 12.000,00 |
| Mould for foam | 500.000,00 | 100.000,00 |
| Mould for left wheel | 300.000,00 | 60.000,00 |
| Mould for right wheel | 300.000,00 | 60.000,00 |
| Mould for hub cap | 60.000,00 | 12.000,00 |
| **Total depreciation each year** | | **244.000,00** |

There need to be invested in different mould in order to produce Amphitrite. The prices for the mould are estimated. The estimation build on insights from one of the team member internship at Odder barnevognsfabrik.
All the mould will be depreciated over a period of five years.

| | Remaining loan | Instalment | Interest | Combined repayment |
|---|---|---|---|---|
| Repayment Plan [5 Years] | 2.341.148,00 | | | |
| Year 1 | 1.872.918,40 | 468.229,60 | 56.187,55 | 524.417,15 |
| Year 2 | 1.404.688,80 | 468.229,60 | 42.140,66 | 510.370,26 |
| Year 3 | 936.459,20 | 468.229,60 | 28.093,78 | 496.323,38 |
| Year 4 | 468.229,60 | 468.229,60 | 14.046,89 | 482.276,49 |
| Year 5 | 0,00 | 468.229,60 | 0,00 | 468.229,60 |
| **Paid in total** | | | | **2.481.616,88** |

In order to finance the budget a loan must be taken. The loan taken is on 2.341.148,00 DKK. The loan is calculated by addition all the mould plus the Fixed cost for the first two years, which is the Cash period cost. It is estimated that the interest will be 3% of the remaining loan each year.

| Problem | Coping strategy |
|---|---|
| **Scythe and motor scythe** | |
| Injunction from the work regulation no working with manual tool like the scythe and motor scythe | Stream workers are working in shifts and using different tool to accommodate the injunction. By using different tools they can work more days a week even though they still use many of the same muscles |
| Removal of the cut off weed is also covered by the injunction of using manual tools | The process is still being used in most cases. In the municipality affected by the injunction they have started using the dredging bucket more and more |
| Moving in the water can be hard and exhausting especially upstream | If the current is strong they only work downstream even though there are pros in working upstream like moving the cut off down stream |
| Cutting the Reed Sparganium at the roots to kill the plant and stop it from regrowing | The manual tools are hard to operate so close to the bottom and is resulting in heavy wear on the tools. The angle on the cutter on the motor scythe makes it hard to cut along the bottom, and the cutter is sensitive to small rocks that can get stuck in the moving cutter. |
| **Weed cutting boat** | |
| Making selective cutting with the weed cutting boat | With the weed cutting boat the problem is that the cutter is too wide and the boats manoeuvrability makes it difficult to spare single plants |
| Cutting the Reed Sparganium at the roots to kill the plant and stop it from regrowing | The weed cutting boat is good at cutting and killing the Reed Sparganium especially when using the Aalborg method, but this method results in much wear on the equipment resulting in more sharpening and more often replacement of the cutter. |
| Requirements to the width | The dredging bucket can not always fit in the smaller streams because of the width of the boat |
| Requirements to the depth | Depending on the weight of the boat the boat will sometimes go too deep and strand the boat. Some streams also wary much in depth from 10 cm to 3 meter in the same stream |
| **Dredging bucket** | |
| Making selective cutting with the dredging bucket | With the dredging bucket the problem is that the bucket is too wide to spare single wanted plants and the long bucket makes it hard to follow the curved shape of the stream |
| Cutting the Reed Sparganium at the roots to kill the plant and stop it from regrowing | The dredging bucket is the ideal tool for removing the Reed Sparganium but an inexperienced machine operator can destroy the bottom of a stream |
| The big excavator can not always gain access to the stream | The big excavator can not always get around especially if it is in the city |
| The dredging bucket is too big to cut narrow streams with a desired thalweg cutting of 40 cm | Using manual tools |
| **Common for every tool** | |
| Difficult to find where the current is the strongest to make a successful thalweg cutting | The solution is well educated stream workers, but the education only takes three days so most of the “good” stream work is done by passionate stream workers with years of practical experience |
| There are big maintenance cost for every tool especially when preforming the Aalborg method | Cutting higher to avoid stones and gravel at the expense of faster regrowth, or replacing expensive equipment |