“The next generation of sheet steel formed e-bikes for the daily commute”

# GRADUATION REPORT

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MOKU MONO

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*Thanks for the support on all different levels during my graduation project, it has been greatly appreciated.*

# GLOSSARY

## Frequently used terms

**E-bike**
A bicycle with an electric motor, an e-bike or pedelec can only assist the rider while pedalling, therefore, no special license is required.

**Sheet metal forming**
The collective name of production processes that use metal and form it through deformation, without adding extra material.

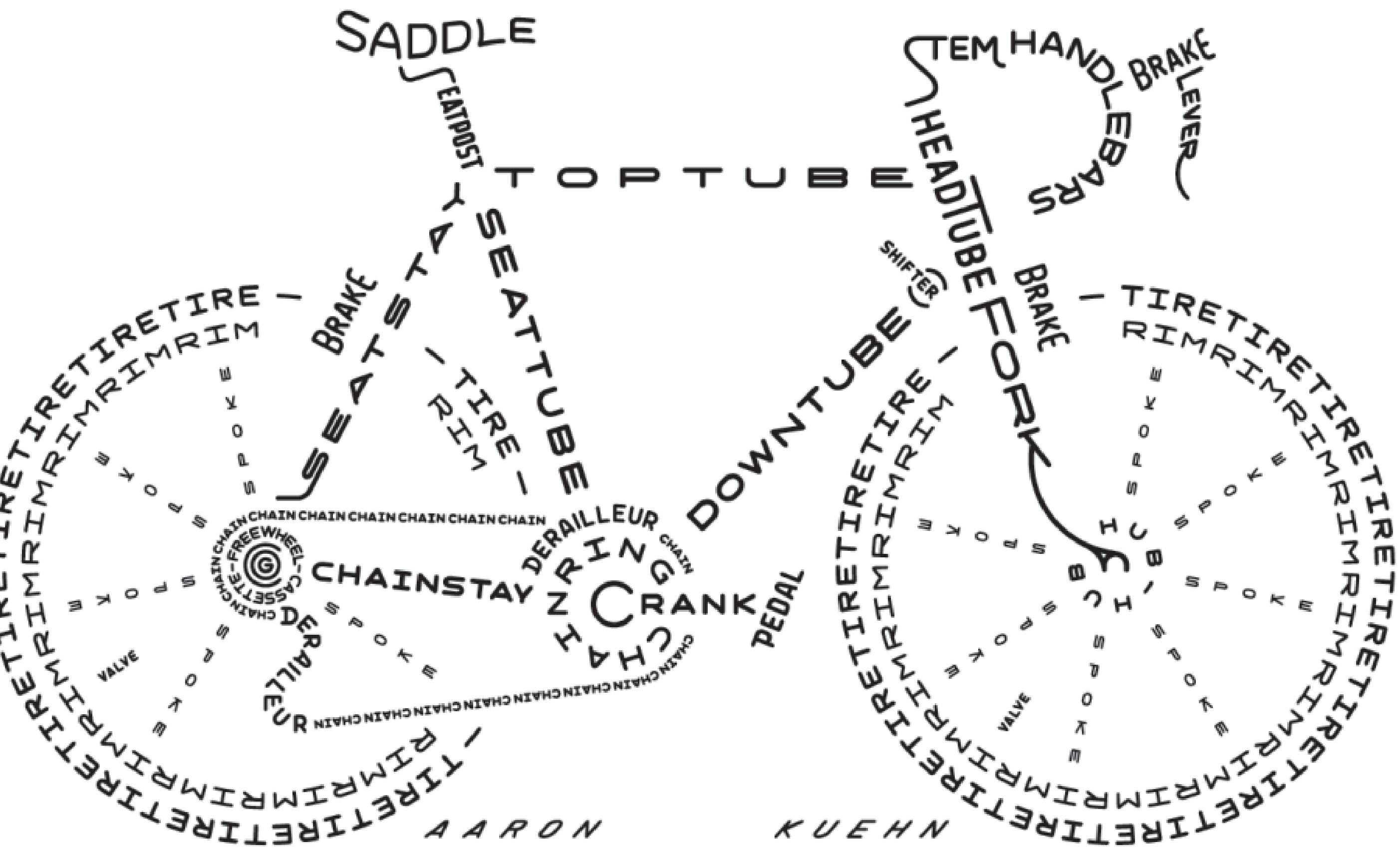


*Image 1: Terminoligy of a bicycle (Kuehn)*

# Bicycle related terms

**Headtube**
The bicycle frame part within which the front fork steering tube is mounted.

**Headset**
The bearing system in the head tube within which the handlebars rotate.

**Seatstay**
Connects the top of the seat tube to the rear fork dropouts.

**Seattube**
Contains the seatpost, on which the saddle is mounted.

**Chainstay**
One of the two frame tubes that run horizontally from the bottom bracket shell back to the rear dropouts.

**Bottom bracket**
The bearing assembly which allows the crank to rotate relative to the frame. May or may not include the spindle which connects the two arms, depending on the standard to which it was designed.

**Downtube**
Connects the head tube to the bottom bracket.

**Gearhub**
The gear ratio changing system in bicycles. Located in the rear wheel axle, connected to shifters.

**Dropout**
The slot, of various sizes and orientations, in the frame that the axles of the wheels attach to.

**Fork**
Part of the frameset that holds the front wheel.

**Rear fork**
The part of the frame where the rear wheel is placed in between the dropouts.

**Frame interior**
The inside of the sheet metal pressed frame.

**Derailleur**
A device used to change gears, activated by shifters.

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# EXECUTIVE SUMMARY

Mokumono is a small company ran by twin brothers Bob and Tom Schiller. The company started in 2016, after Bob designed the Mokumono Delta as a graduation project from the Design Academy in Eindhoven. Since Mokumono is a very small company, they have funded their project through Kickstarter, which has been relatively successful for them.

What makes Mokumono different from other bicycle companies is the production method of their bicycles. Instead of the regular method of welding tubes together, Mokumono used sheet metal pressed shells to create a frame. Nowadays, almost all utility bicycle frames are produced in the Far East, because the welding of tubes is still mostly done by hand, and comes with large production costs. By utilising sheet metal formed parts and laser welding, Mokumono can automate the process and produce locally, instead of in the Far East.

The current manufacturing process of the Mokumono Delta contains a few areas that need improvement. The greatest of these areas is the welding of the materials.Aluminium is used in the Mokumono Delta, which is hard to weld. The main goal of this project has been to look into the production method, and design a frame that fully exploits this production method, while still having a functionally sound and reasonably priced e-bike that fits the target group and brand image of Mokumono.

The e-bike market is rapidly growing around the world. With better batteries and lighter e-bikes, the e-bike is gaining a core foothold in the bicycle market. For Mokumono, the e-bike market is very interesting, since their shell design gives plenty of room for the electrical components to be integrated into the frame.

There is a great opportunity for the e-bike to replace the car and bicycle in the daily home to work commute. These advantages include lower costs, not being bothered by busy traffic and lack of parking space. It is also seen that commuting on an e-bike is more accessible than a regular bicycle, because even when commuting longer distances, the user will not get tired and sweaty, and they will arrive at work being activated by a casual workout in the morning. It is seen that this shift towards e-mobility is already occurring today, and it would be highly beneficial to aim their e-bike at this target audience. The aim of this new product is to target this audience, and still maintain the high-end value of the Mokumono bicycles.

Even though the current Mokumono frames are successful, there are still areas that need improvement. In this project, new insights are gained into the production method, and new opportunities are suggested for improving the current manufacturing process. Besides this, the main material of the designed bicycle is steel instead of the currently used aluminium. This choice has been made by Mokumono, because they want more insight in the use of steel alloys. With the current grades of steel, a strong and stiff frame can be produced with thinner sheets. This will eventually lead to a very strong frame without much extra weight.

The current manufacturing process of the Mokumono Delta is analysed and points of improvement are identified. A main area of improvement is the rear fork of the bicycle frame, since there is a left and right half of the frame, there must be an extra plate that is welded into the rear fork to close it off. This is a costly step in the current process and Mokumono could greatly benefit from this step being eliminated. Moreover, an issue is found in the laser welding. Because of the thin shells, the welding causes warping in the material because of the high temperatures. The welding also causes large post-processing costs in grinding down the welds for a refined finish of the frame.

To solve the issues currently present in the Mokumono frames, a new division of shells has been designed. Where the current frames are produced by two shells, the new design is produced by four shells, which can later be bonded together to create the frame.

For the bonding of shells, a different method is analysed. Instead of welding the thin sheet steel parts, brazing is chosen for joining the shells together. While welding melts the base material together to form a bond, brazing uses a filler material to be melted between the base parts. This filler material melts at a lower temperature than the base material, which leads to no warping in the material. A brazed connection does not have to be post processed, since the joint has a high aesthetic value directly after the brazing is done.

It is seen that this new method will reduce the overall production costs of a frame significantly. This is mainly due to the absence of post-processing costs, which are currently done by hand. The new frame construction is more viable for automation as well, which can further reduce the costs in large batch manufacturing.

While the new frame design is very different than the current Mokumono Delta design, it is designed to still be fitting in the Mokumono simplistic aesthetic style and brand identity. Combining this with the improved production method and upcoming e-bike trend, I believe that the final product, the Mokumono Dune, provides a good opportunity for Mokumono to further explore.

# PROJECT INTRODUCTION

## Introduction

The bicycle is a Dutch landmark on its own. The bicycle has been a truly loyal companion of the Dutch for many years now. During those years, the shape of the bicycle has not changed all that much. However, the way that bicycles are produced has changed drastically over time. Nowadays, bicycle frames are not produced in the Netherlands anymore. Almost all of the bicycle frames are produced in the Far East, because of the economically beneficial aspects. Using new production methods, the frames could potentially be produced locally again. This will reduce the costs of bicycles by cutting out transportation around the world. In the research of this project, the choice of this production method and the benefits will be further analysed. From the research, I will see if this is actually the most beneficial way of production for Mokumono.

Mokumono designed a new type of bicycle frame back in 2016. This new bicycle frame is much more tailored to be manufactured locally, which is something valued by the company. Mokumono focuses on designing and producing properly made bicycles with premium materials and components. There is no need to make the bicycles ‘smart’, just well made and thought through. It is important that the outcome of this project will hold on to the values that Mokumono believes in.

By using rubber pressing, two sheet metal shells are made. These two shells are welded together by a laser welding robot. Because of this very easily automated process, prices can be set competitively with those of the bicycle frames produced in the Far East.

With the upcoming trend of more and more e-bikes, it is a logical step for Mokumono to get in on this market. Since the bicycle frame designed by Mokumono has a lot of extra potential free volume in the frame, there is an opportunity to completely hide all of the electronics inside the frame. Also, you would want to have a removable battery inside of the bicycle, so the customer can recharge the battery inside of their home and the battery will be less exposed to weather conditions.

The goal of this project is to fully exploit the production method, while still having a functionally sound and reasonably priced e-bike frame which fits the target group and the brand image of Mokumono.

# Problem definition

### Production

If these bicycles were to be mass produced, some changes need to be made. The production currently includes a few expensive steps that might become unnecessary with a new product geometry. The possibilities of the given production methods will be researched and fully utilized in the following design. (Rubber pressing, two-mold pressing, hydropressing). The geometry of the frame will lead to increased stiffness where it is needed, while the frame still can be optimally produced.

### Material and weight.

Since this bicycle is going to be an e-bike, weight is less of an issue than it is with regular bicycles or road cycling bicycles. However, the frame will still need to be optimized for as less weight as possible, since all of the electronic components will add extra weight as well. The choice has already been made that the frame will be made of steel instead of aluminum. The possibilities within this material will be researched and the frame geometry will be designed fittingly.

### Integration

The electronics that make this bicycle an e-bike will probably be placed inside of the frame. This is because of the space available inside of the frame with this production method. A good integration in the shape of the frame is necessary. Also, a design challenge will be the battery. The battery will need to be removable from the frame for charging, this means that there will be a hole in the frame somewhere, compromising the overall strength of the frame.

### Aesthetics

With the upcoming trend of e-bikes, it is important to look into a good target group for Mokumono's e-bike. It is important that the bicycle's new aesthetics fit the target group. the chosen production method and Mokumono's brand image well.

# Assignment

*"Designing a new sheet steel formed utility e-bike frame with integrated electronics to fit the desired target group and express the values of Mokumono."*

For this assignment, a few variables are already given. First of all, it is certain that the bicycle frame designed is going to be an electrically aided bicycle. A target group will be defined according to the trends within this segment of the bicycle market, a new aesthetic language will be developed to fit this new group, while still holding on to the strong brand image of Mokumono.

The electronics needed for the bicycle will need to be fully integrated into the frame of the bicycle. This will present some extra design challenges for the geometry of the frame itself.

The material of choice is going to be some kind of steel. Which type of steel this is is still to be determined. There will be research into different (upcoming) steel types and their benefits towards the frame and the production method involved.

The bicycle frame that will be designed will be aimed at exploiting the positives of the chosen production method, while still holding on the visions and values Mokumono believes in.

# PROBLEM STATEMENT

With the project brief and insight gained in the project, a project statement is constructed. For this, the key points of this project have been identified. With these key points a problem statement has been defined.

## Key points project

- Bicycle frame
- Sheet steel
- Integration
- Mokumono
- Commute
- Sustainable
- Electric
- Manufacturing
- High-end

*"How can we create a comfortable electrically aided bicycle that is aesthetically desirable, practical, sustainable and produced by sheet steel 3D forming to be usable for the daily commute while holding on the brand values of Mokumono?"*

# REPORT STRUCTURE

Part 1

**ANALYSIS**

Part 2

**DESIGN VISION**

Part 3

**DESIGN**

Part 4

**EVALUATION**

Part 5

**RECOMMEN-DATIONS**

Part 6

**REFLECTION**

# PART 1: ANALYSIS

# MOKUMONO

## Short History

The company Mokumono is founded and run by the twin brothers Bob and Tom Schiller. The company started after Bob graduated from the Design Academy in Eindhoven with his project, the Mokumono. Tom graduated from the Vrije University of Amsterdam in Environmental and Resources Management. Within the company, Bob is the head of design, while Tom oversees production and the supply chain. The name Mokumono consists of two parts; Mokum (which is a term for Amsterdam) and Mono (which is short for Monocoque, which is a structural system in which loads are supported through the skin of a product).

When the company started in 2016, Bob and Tom wanted to shake up the bicycle industry, showing a well established market that there are other possibilities for the production of bicycle frames. Since the company started, they have crowdfunded their project to make the Mokumono a reality. There has been a lot of attention towards Mokumono within the industry.

*Image 2: Bob and Tom Schiller*

# Mokumono Delta

The current product of Mokumono, the Mokumono Delta, is a high segment city bicycle. (€2000 - €3300) While the product mainly has been kept the same over the last years, Bob and Tom constantly try to improve on the bicycle design. The Mokumono Delta frame already had a few different iterations to increase the ease of production. These iterations resulted from the insights gained from the first few produced series of the frame and recommendations by the manufacturing parties.

In the current stage, there are a few areas of production that could use extra attention. New possibilities within these areas have been explored while still utilising the production method used by Mokumono.

The main problems in production lie within the welding of the different parts. Since it is such a thin walled product (1,5mm. aluminum), the welded areas require a large portion of post-processing. This post-processing is an expensive step, and the production costs will be greatly reduces if this step can be eliminated.

Besides this, the rear fork is an issue, as can be seen in the image below (Schiller, 2016), there is a third part that is welded on the inside of the rear fork (the yellow part). This is a difficult step in production, but mostly the welding for this part is what forms a challenge.

Furthermore, the connection of the three shells with the extraparts (bottom bracket, dropouts and head tube) is sometimes difficult due to tolerances of the formed parts and again the welding and accompanying after-care.

These are the main areas where the production method can be improved. When these areas are exlored and improved, Mokumono gains value from this project for any future products.

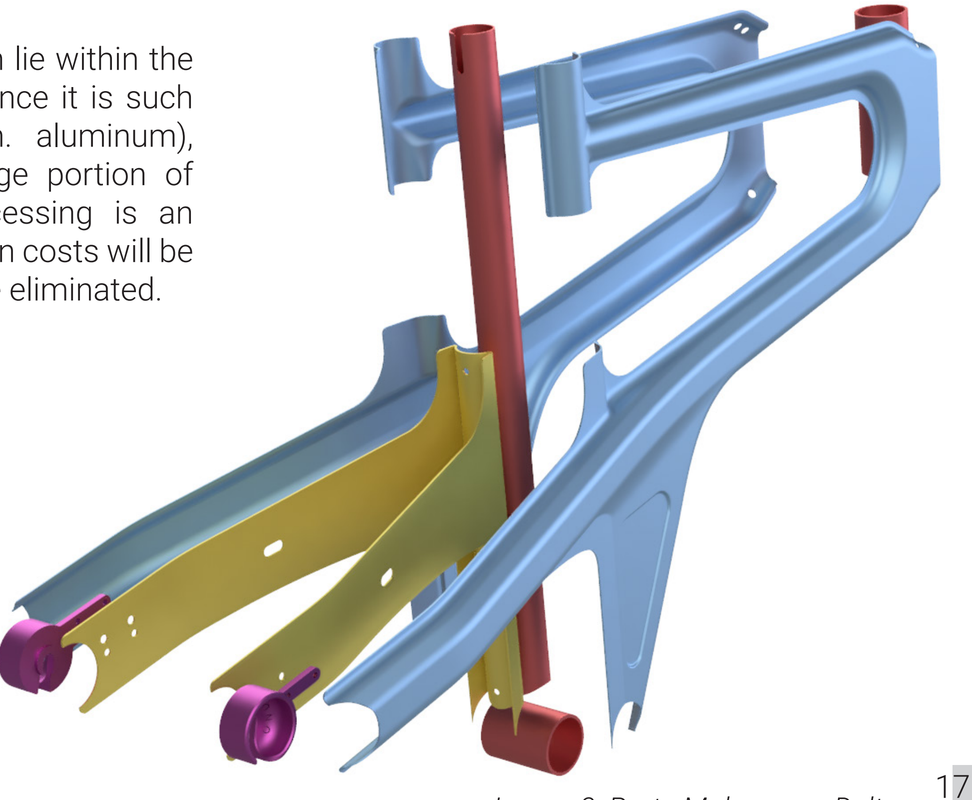


*Image 3: Parts Mokumono Delta*

# Brand personality

Initially, some keywords around Mokumono have been found in cooperation with Bob and Tom. These are keywords they consider the main aspects of their brand, Mokumono. However, these values are quite vague. Most of these values, when explained correctly, can be applied to almost any given company brand. That is why after this, another brand identity analysis has been executed.

Innovative State of the art Memorable

High Quality Dutch

**MOKUMONO**

Unique Sustainable Monocoque

Low maintenance Local production

To identify which values are important for Mokumono in a more grounded way, the brand dimensions model by Jennifer Aaker is used. With this model, a brand can be described using traits you would normallyused to describe a human being. By using human personality traits, it is easier for people to describe their brand accurately. This model uses five main dimensions in which the brand traits are divided. These five main dimensions are Sincerity, Excitement, Competence, Sophistication and Ruggedness. (Aaker, 1997) All of these dimensions have two to four personality trait, as can be seen in the image below. These traits will be ranked from 1 to 5, 1 being not applicable and 5 being very applicable.

Brand Personality Traits

| Sophistication | Sincerity | Ruggedness | Competence | Excitement |
|---|---|---|---|---|
| Charming<br>Sophistication | Cheerful<br>Sincerity | Tough<br>Ruggedness | Reliable<br>Competence | Daring<br>Excitement |
| Upper class<br>Sophistication | Down-to-earth<br>Sincerity | Outdoorsy<br>Ruggedness | Sucessful<br>Competence | Imaginative<br>Excitement |
| | Wholesome<br>Sincerity | | Intelligent<br>Competence | Up-to-date<br>Excitement |
| | Honest<br>Sincerity | | | Spirited<br>Excitement |

## Current brand identity

The current brand personality of Mokumono is visualised using the brand personality tool as described above. The most important characteristics of the brand were identified through an interview with Bob and Tom.

Mokumono current brand identity

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| | Wholesome (Sincerity) | Down-to-earth (Sincerity) | Daring (Excitement) | |
| | Charming (Sophistication) | Intelligent (Competence) | Imaginative (Excitement) | |
| | Cheerful (Sincerity) | Reliable (Competence) | Up-to-date (Excitement) | |
| | Tough (Ruggedness) | | Upper class (Sophistication) | |
| | Sucessful (Competence) | | Honest (Sincerity) | |
| | | | Spirited (Excitement) | |

**Successful**

In the current state, Bob en Tom think Mokumono is not yet really successful as a company, this is mainly because they have had problems with production and did not yet sell many bicycles. However, as a brand, they are very successful in getting attention for their product, they have won a few prices and gained a lot of media attention. The success of their actual product (the Mokumono Delta) is a large area they want to grow in.

**Upper class**

Mokumono is currently defined to be very upper class. This is because their current bicycle is quite expensive for a city bicycle (between €2100 - €3300). This is something they would like to change going into the future. They want to make their bicycles more accessible to a larger market, while still holding on to a great building quality of the bicycle and its components.

**Imaginative**

As a brand, Mokumono can be seen as very imaginative. The production method used is not common in the bicycle industry, and because of this they can be seen as an imaginative brand. Mokumono does not have a target group as wide as other big e-bike brands in the market, but the fact that they are so different makes them stand out from the crowd.

**Honest**

Honesty is an important factor for Mokumono. They try to be as honest as possible by giving their customers full insight into where the parts of their bicycle are coming from, and how their bicycles are made.

# Future brand identity

When we were done looking into the current brand identity for Mokumono, we started to think about where Mokumono is heading in the future. There already are some obvious differences in the brand personality tools in this section when comparing it to the current brand identity.


Mokumono is a relatively unknown brand. It has been in the spotlight for some prizes and awards, but the bicycles are not yet selling the way they want to. This is to be expected by such a small and young company, but this is one of the main areas Mokumono wants to develop in. They want to become a successful bicycle brand. They want to rech this by following two different paths. Firstly, they want to keep designing and producing their own products. Besides this, they also want to help other companies in the design of their bicycles, so they can be produced by 3d sheet metal forming as well.

To obtain the ultimate goal of becoming a successful bicycle brand, they want to stay on the high-end segment of the market. By constantly staying up to date in terms of production, technology and design, they want to stay relevant for many years to come. Mokumono wants to become more daring as well, this manifests in expanding on their product portfolio, with a wider range of products utilising their manufacturing knowledge. This can also be seen in the fact that they do not want to produce “regular” bicycles. They want to stay in the designer bicycle segment while still bringing the prices down, at least with their own produced bicycles.

## Conclusion

The future brand personality of Mokumono can be described by the words;

*Successful, Daring, Up-to-date, Spirited, Honest and Intelligent*

These words will help Mokumono to define their future brand identity further. This is needed when they want to become more known in the bicycle industry. Some visuals are displayed to further elaborate on what these values contain.

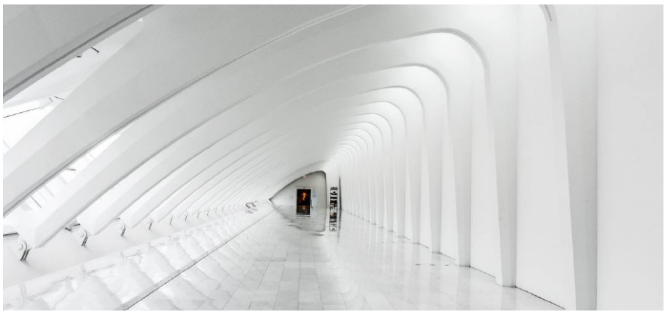
***Successful***

***Spirited***

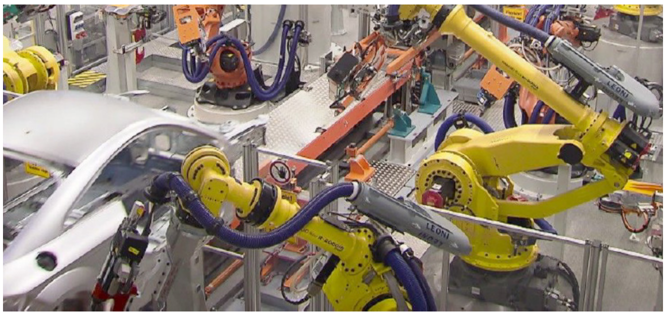
***Daring***

***Honest***

***Up-to-date***



***Intelligent***



## Moodboard

For the design of the frame, a moodboard is created. This moodboard envisions the forms on which the design will be based. The examples in the moodboard are collected to fit the image of Mokumono, while still giving enough room to create a new and refreshing design.


*Image 4: Form language moodboard*

# E-BIKE

## Short history

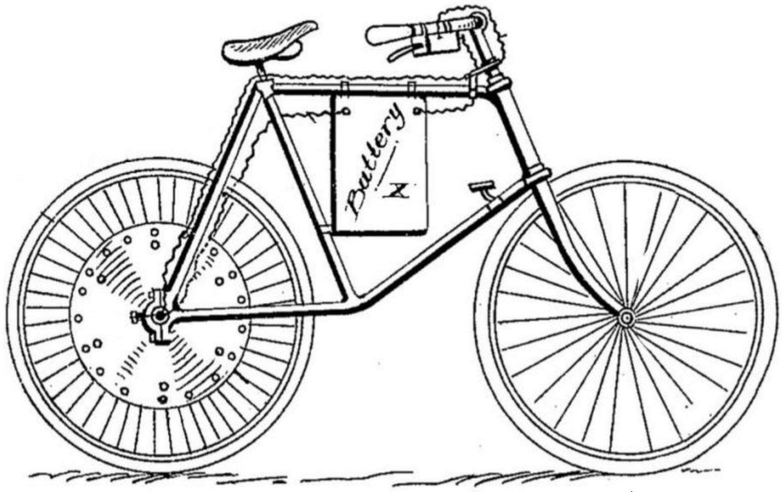



*Image 5: 1890 E-bike patent (Bolton, 1895)*

The electric bicycle, a means of transportation that is already well-established within our society. While we often tend to think that the e-bike is an upcoming new technique, the electric bicycle (or e-bike) has been around for quite some years now.

It all started in the 1890s. During this period there were a few patents that dealt with electric motors and bicycles, mostly from the United States. After this initial interest in electrically aided bicycles, there was a German company called Heinzmann that started to mass produce electric motors for bicycles in 1920. These motors were mainly used for mail delivery services. Later, in 1930 there was a company based in the United States that started to produce electric bicycles with a Ford T generator mounted to the read wheel. In the 1940s there was an increase in demand for the electric bicycles. Because of the Second World War there was a shortage of large motorized vehicles because they were mostly used for the war effort. During this period there were a lot of patents for electric bicycles granted. However, due to the increase in demand for research in motorized vehicles during the war, the development of electric bicycles was halted. After the war ended, a lot of countries dove into the development of motorcycles, and in the background, the development of electric bicycles benefited a lot from them. This went on to 1973 when the first oil crisis took place. Around this time the use of electric bicycles was being promoted, although this was not too successful (Hung & Lim, 2020).

*Image 6: Yamaha e-bike, 1993*

There were a few more e-bikes in the following years, but the first really successful e-bike was produced by Yamaha in 1993 (see image 6). This e-bike was the first one with a pedal assist system. This system gradually was being used by other e-bike brands as well. In the late 1990s, a lot of improvements were made on the e-bike. This was mainly due to the development or torque sensors and more durable batteries. While in this period the electric bicycle was on the rise, the sales of electric bicycles dropped drastically in the year 2000. When the lithium battery was developed in 2005, the electric bicycle was on the rise again. This was paired with a significant weight reduction, because the electrodes of a lithium battery are made of lightweight lithium and carbon. A lot of relatively lightweight electric bicycles (around 19 kg.) were produced by the big bicycle companies around this time. The electric bicycle market was further revived with the Lithium-ion battery. From then on, the electric bicycle has had a steadily growing market share in the bicycle industry.

# The bicycle

The bicycle is a very common product nowadays, many people use bicycles everyday to get around. However, what makes a bicycle a bicycle? This is explained in the following section, so that we can identify what makes an e-bike different from a regular bicycle. These aspects of the bicycle will be translated toward the program of requirements further on in this report.

The bicycle needs to consist of two wheels held in a frame, one wheel has to be behind the other. The vehicle is propelled by pedals, which are actuated with the feet of the user. The vehicle is steered by handlebars that are attached to the front wheel. The bicycle also needs to have a seat for the user to comfortably sit on while bicycling. Besides the actuation of the vehicle, there also has to be a braking system in place, so the vehicle can safely stop when needed. The rear wheel of the bicycle is mostly connected to the pedals and crank by a chain or similar item.

Many bicycles have some sort of lighting system to be used in dark environments. Bicycles are also used to transport items or even persons from one area to another. This can be facilitated by a luggage carrier, which is often present in a bicycle.

There are also bicycles that have a gearing system integrated. This means that the user can change the resistance and the gear ratio to finetune the ride to his or her personal needs.
The frame gives the bicycle strength, and creates opportunity to attach all the different components of the bicycle. Cycling uses less energy per kilometer than any other human mode of transport (Jordan, 2013).

*Image 7: Dutch cycling culture*

# The e-bike

Many aspects of the e-bike are the same or similar to the regular bicycle. Besides the most obvious difference, the electric motor and battery, there are also other more subtle differences in the use of an e-bike. First of all, the e-bike uses some sort of electrical propulsion system, to individually propel the bicycle, or to assist the user in their pedalling.

Besides regular cycling, the user of an e-bike is also busy with controlling the power source. In many cases this can be done with a display and different energy settings.

## E-bike types

When looking at e-bikes, there are three main categories.

**Class 1 : Pedal assist / Pedelec**

This is the most common type of electric bicycle. The user still uses the bicycle in the same way as a regular bicycle. The electric motor provides the user with passive assistance, which increases the power transferred to the rear wheel. Most often there are settings to change the degree of resistance with these bicycles as well. In most of Europe, there are regulations that limit the pedelec to give assistance over 25 kilometres per hour. These kinds of e-bikes do not require specific licensing and are allowed on every road a regular bicycle is allowed on.

**Class 2 : Throttle**

These types of e-bikes operate with a throttle to propel the bicycle forward. This is more in line with the way motorcycles or scooters operate. The user is not required to pedal in this case. These types of e-bikes are a lot less common than pedal assisted types, and there are many countries that have laws that prohibit the use of throttle operated e-bikes completely. For example, in Europe, e-bikes are only allowed to provide power when the bicycle pedals are moving forward. These kind of e-bikes are more common in the United States or in China, where these laws do not exist.

**Class 3 : Speed Pedelec**

Speed pedelec bicycles are mostly the same as the regular pedal assist/ pedelec bicycles. However, these types of e-bikes have stronger motors and larger batteries, which makes the top speed a lot higher than regular pedelecs. Speed pedelecs can have a top speed of 45 kilometres per hour. This is why speed pedelecs are considered motor vehicles in many regions, so it requires the user to be licensed.

# Configurations

The motor is one of the main components of an e-bike. The motor can be placed in a few different positions, in the rear wheel, in the front wheel or in the middle of the bycicle, at the bottom bracket.

**Rear motor**

In this case, the motor is directly connected to the drivetrain. Since the motor is behind the user, the motor will give a pushing sensation to the user, nut feels quite similar to regular bicycles. The direct connection to the drivetrain will make the ride very responsive for the user.

The rear wheel motors are generally more powerful than the other types of motors as well. The placement of the motor in the rear wheel will lead to a different balancing in the bicycle, which might feel uncomfortable for the user.

**Front motor**

The front motor is installed in the middle of the front wheel. The wiring of the front wheel motor to the battery is generally easier than with rear wheel motors. This is due to the fact that there are mostly no gear systems in front motor e-bikes.

Because of the placement in the frontal wheel, the user can experience some discomfort with steering sharp corners. However, the overall balance of the bicycle is usually better than with rear motors.

**Middle motor**

With the middle motor, or hub-motor variant, the motor is placed at the drivetrain of the bicycle. Because the motor is placed at the bottom bracket, there is usually an integrated torque sensor which senses if the user is pedalling. The overall performance of the middle motor is usually better than front or rear motors. The motor drives the crank instead of the wheel, which is better suited for this task.

The location of the motor is the most easily integrated in the frame itself and is more protected from the environment, resulting in fewer maintenance needed to the motor.

This type of motor is currently the most widely used setup in e-bikes, and thus provides the largest pool of possible motors to choose from.

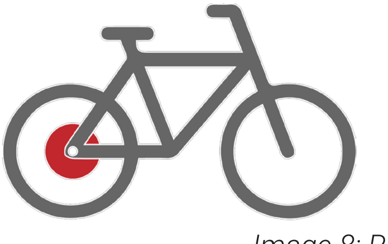


*Image 8: Rear motor*

*Image 9: Middle motor*

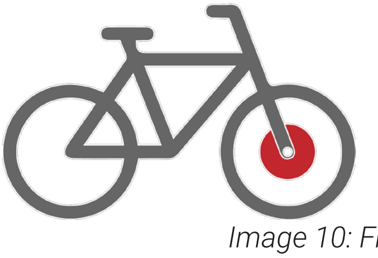


*Image 10: Front motor*

**Placement choice**

There are many good things to say for the middle motor. This setup is very well suited for the production method at hand, and offers a wide variety of different possible motors. Because of this and because of a preference by Mokumono, it is chosen to use a middle motor.

# Trends

Besides the trends specifically aimed at e-bikes, there are also a lot of relevant trends in different areas. There are social trends surrounding the bicycle industry and of course there are trends within the world of regular cycling, road cycling and mountain biking that are relevant to this project as well.

## General Trends

### Legislation around e-bikes

The rules and legislation around e-bikes is a bit confusing for people, because of the different types of bicycles, which are explained earlier in this report. There are a few requirements which the e-bike needs to meet. In the Netherlands, an e-bike or pedelec can only give assistance to the user up to 25 kilometers per hour. The motor of the e-bike can have a power up to 250 watt and can only give power when the user is actively pedalling, so there can be no independent throttle (Rijksoverheid, 2019).

### Bike sharing

Bicycle sharing is getting more and more popular in Europe. With the overall shift towards a more service and product-shared world the bicycle industry is now coming along rapidly. Nowadays there are lots of different bicycle services available, from owned bicycles to rental bicycles within cities, for example Swapfiets or Mobike (Image 11). This trend is not directly relevant for Mokumono at this stage, but if Mokumono chooses to use their knowledge to advise other bicycle frame manufacturers, the bicycle sharing market might be interesting for Mokumono to look into.


*Image 11: Mobike shared bicycle*

### Male bicycles are evolving

Looking at regular utility bicycles, the male and female archetype of the bicycle is slowly dissolving. This is most easily seen in the many different rental or shared bicycle services. The most used shareable bicycles in The Netherlands are fitted for male and female alike. The bicycle is slowly becoming a unisex product. This is also seen in the product portfolios of manifested bicycle brands. There is a lot less difference between male and female bicycles, and they are not as much advertised either.

*Image 12: Dutch OV-fiets*

### The bicycle highway

More countries are investing in so called bicycle highways. As the name suggests, these are highways specifically for bicycles. These are mainly just bicycle paths specifically aimed at long-distance traffic. These highways are light on intersections and traffic lights, besides this the paths are wide and consists of mainly slight bends in the road. In The Netherlands there are already around thirty of these bicycle highways. In Germany, a car-free bicycle highway is created that will stretch around 100 kilometers, while connecting 10 different large cities and 4 universities (see image 13). This highway is aimed to remove 50.000 cars off the road each day, when completed.


*Image 13: Bicycle highway Germany*

### Simplicity in design

The design world is more focussed on a minimalist styling than before. This also is clearly visible in the bicycle industry. Where earlier adaptations of e-bikes had clunky and often not user friendly displays, the newer models have these components more integrated in the bicycle, instead of attached to it. Also the actions needed of the user become less and less.

## E-bike trends

### Increase in e-bike popularity

Nowadays, electric bicycles are more popular than ever. This year, E-bikes already hold a larger market share in The Netherlands than conventional bicycles. This may not seem like a big deal, because of the larger costs affiliated with an e-bike. However, when you realize that this conventional bicycle market also includes road bicycles, mountain bikes and children's bikes, the growing potential of e-bikes becomes more apparent. With the introduction of the 'new' generation of E-bikes around 2012, the e-bike has been on a rise (Fishman & Cherry, 2015). However, this rise in popularity faded out a bit after the years following the initial releases. Nowadays, e-bikes have become more appealing to consumers because of better usability, added functionalities, larger battery packs and a more integrated and appealing look.

There are more reasons why e-bikes are becoming so popular. In the following section, these areas will be explored more thoroughly.

### The e-bike commute

While the image of the e-bike is improving, there is still a lot of bias involved in people's attitude towards e-bikes. The pedelecs sold were mostly for elderly people and did not seem fit for the younger generations, this is slowly changing to becoming a solution for everyone over the last years (Haustein & Møller, 2016). In these last years we have seen that the e-bike is becoming more of an alternative to the car instead of an alternative to the bicycle. Let's take a more in-depth look at how that has developed and where this is leading us (Rose, 2012).

A lot of working people have a quite serious commute to their work nowadays. Since the rent and buying prices of houses in larger cities are sky high, more and more people move toward the suburbs. This leads to extensively increasing traffic in and around big cities. This significant increase in cars on the road leads to an often more stressful commute to and from work (Plazier et al, 2017).

What we see happening is that more and more people are seeing an electrically aided bicycle as a worthy alternative to their car. Nearly harlf of the commuting trips are currently less than 7.5 km. (Rijksoverheid, 2018). These are distances easily covered by using an e-bike. Commuting with an e-bike has a few direct apparent positives when comparing to a car commute.

First of all, there is the money saved, for a lot of people an important issue. While e-bikes are generally a lot more expensive than regular bicycles, they are still a lot cheaper in use than a car. (Popovich et al., 2017) The increase in gas prices all around the world is an extra problem that can be avoided with the use of an e-bike.

Besides the saving of money, the motive of saving the environment is becoming more and more appealing to consumers as well. While there are already plans being made to make cities car-free in the future, an electrically aided bicycle might be a very good alternative. While an e-bike still contains parts that are not fully sustaionable, like the battery, it still has less impact on the environment as cummuting by car. Still it has to be said that an e-bike still is more harmful for the environment than a regular bicycle will be (Smit, 2018).

With the city centres becoming more and more crowded, parking space is often a big problem. If there is any parking space at all, it often costs a small fortune to be able to use it. With a bicycle, this is a significantly smaller problem. Even in cities where parking your bicycle is an issue, it will never be such a large issue as parking your car in the same city.

With these most apparent positives out of the way, there are a few points that still need to be addressed.

Lots of the aforementioned facts are exploitable with a conventional bicycle as well, why would an e-bike than be necessary? The answer is quite simple actually. Most people dislike bicycling for more than 30 minutes for their commute, but most people live a longer distance from their work than these 30 minutes (Rose, 2012). With the help of an electrically aided bicycle, a commute of 1 hour or more suddenly is no issue for the rider. Because you will not arrive all sweaty at work, like with a conventional bicycle. An extra effect on the consumer is that they already had some relaxed exercise before they arrive for their day at work, which will lead them to be more energized than when this time has been spent in a traffic jam (Wild & Woodward, 2019).

There is still the issue of bad weather. While strong winds is not a big issue when riding an e-bike, the rain is, as you are fully exposed to the outdoor elements while riding an e-bike. According to data, it rains 35% of the year in the Netherlands (CBS, 2015). There are still lots of people who choose to commute by bicycle and e-bike, mostly using a rain suit on the days it rains. It is seen that people stick to their chosen mean of transport throughout the year and weather factors do not influence this choice (Heinen et al., 2011).

# E-bike components

Since there are a lot of great companies that focus on e-mobility and products like electric motors and batteries, it is not needed for Mokumono to create these themselves. Most e-bikes are fitted with existing components from external companies. The frame needs to house these components, so it is necessary to gain insight in what is available at the moment. There are a few different components that make an e-bike. The main components and their functions are explained here.

## Motor

The motor can be seen as the heart of the e-bike. The motor gives the power to the bicycle and assists the user in their bicycling. As said before, the motor for this particular e-bike will be located in the middle of the bicycle, at the bottom bracket. This limits the search for an applicable motor to this specific category. The motor in an e-bike is not just an electrical motor, it also needs an electrical control system and a sensor to detect if the crank is moving. Most available motors currently are equipped with divided support levels as well, so the user can choose to which extent they will be supported.

There are a few main players in the world of e-bike motors. The most known and used are Bafang, Shimano and Bosch motors. These companies are rapidly innovating with their products to stay ahead of the market. Besides these companies, there are also smaller brands that produce very high quality e-bike motor systems.

## Battery

Besides the motor, the battery is another important component in an e-bike, since the motor gets the power from the battery, and the battery has a lot of interaction with the user. There are a few different types of batteries that are now widely used in e-bikes. These types of batteries are either NiMH, NI or Lithium-ion batteries (Li-ion). The Lithium-ion batteries are mostly used in the industry because these are lightweight and they can facilitate many charge cycles without losing potential power (Tarascon, 2010).

A lot of new research is being done into batteries. The most used batteries nowadays are Li-ion batteries. Since there is so much going on with rechargeable batteries, chemists all over the world are working on better rechargeable batteries, which can store more energy, are smaller in size and recharge quicker. The most used batteries at the moment are Li-ion cells. The modern Li-ion cells already hold more than twice as much energy by weight as the first versions of these cells sold by Sony back in 1991 and are 10 times cheaper.

However, research has been done to these kinds of cells, and most researchers think that this type of cells can gain a maximum of 30% extra power per weight, which means that Li-ion cells might not be the best option for e-bikes or e-mobility in general from 2020 (J.M. Tarascon, 2010).

It is important to note the differences in batteries and to keep this in mind while designing. Expecting that this e-bike will not be introduced before 2025, the choice of the battery may change in this period, depending on which breakthroughs there will be in the battery research going on at the moment.

This being said, it is still necessary to see what is needed for the bicycle. Because the battery needs to be integrated into the frame as well as being removable, a standard battery pack cannot be used. The shape of the standard battery packs does not connect with the final shape of the frame itself. This will be avoided by designing and creating a very own battery pack so that the shape will flow with the rest of the frame. This is a costly step in development, but it could be done with larger series or external funding.

### Lithium-Ion batteries now

The Lithium-Ion cells are the most commonly used battery cells at the moment. They are most commonly used for portable electronics and electrically powered vehicles. The most used Li-ion cell is the 18650 Li-ion cell. These cells will be used in the battery pack for the Mokumono e-bike because of the great availability, relatively low price and the small size of the individual cells (Zubi et al., 2018).

### Lithium-Ion batteries future

As mentioned before, there is a lot of research being done in the field of batteries. The main research areas are life extension, energy density, safety, cost reduction and charging speed.
With all this research being done, an assumption can be made of the state of the Lithium-Ion battery in the year 2025. Most researchers think that the Lithium-ion battery will have a 30% increase in power density by 2025. This will be taken into account while calculating the exactly needed battery to power the e-bike.

### Carbon Dioxide batteries

Another great development in the world of batteries is the Carbon Dioxide Battery. These types of batteries are still in development, but they show great potential for the future. Right now, the first prototypes are made that are fully rechargeable. What is so great about the Carbon Dioxide Battery is that the energy density of these batteries is more than seven times greater than that of a regular Lithium-Ion battery. This means that the battery packs in an e-bike can become seven times smaller than they are currently, while still providing the same coverage as current e-bike systems.

### Current batteries vs. future batteries

The current 18650 Li-ion cell has the following specifics:

18mm. cell diameter
65 mm. cell length
3.6 V

The future 18650 cells will potentially have, as mentioned before, a 30% increase in energy density. With this and the used motor, the number of needed cells will be determined. Most e-bike battery pack use a sideways orientation of the cells (see top left image). This means that the battery packs are often very wide (because the cells are already 65 mm. long). This can be done differently. Since in the future, the individual cells will be more efficient, fewer cells can be used in a battery pack than there are today.

When using an in length orientation of the cells, there is a lot more form freedom to be obtained in the shape of the battery pack since the housing is not limited to the length of the individual batteries. The optimal stacking of these cells inside the battery pack will be determined when the frame shape is decided on.

### Needed amount of batteries

With these values, the amount of needed cells has been calculated. For an estimated range of 80 km. on one battery, these calculations show that by 2025, 35 cells are needed.

# Sustainability

An often recurring problem with e-bikes is bad serviceability. For Mokumono it is important to adjust accordingly to this problem. Since Mokumono finds the sustainability aspect of their product important, there is an opportunity to exploit this. The main areas in which Mokumono can do better for the world are as described below.

### Production

Mokumono preaches that their bicycle, the Mokumono Delta, has less environmental impact than regular bicycles. The bicycles are manufactured locally instead of in the Far East, leading to reduced pressure on the environment through transportation around the world.

### Serviceability

A problem with the integration of the e-bike systems inside of the frame is that serviceability becomes more difficult. While the main components are not located inside of the steel shell, the different types of wiring will be located inside the frame for a clean external look.

For Mokumono, it might be interesting to sell their product as a flexible framework. This means that the bicycle frame will function as the basis for different e-bikes. It is beneficial for Mokumono to be able to present different types of e-bikes by changing up just the components of the bicycle, rather than the entire frame.

There are many e-bike motors that use more or less the same system for the attachment to the frame. This leads to a situation where the same bicycle frame can accommodate different classes of fitted e-bike motors. This will give the consumer a greater choice of what they want, and provides the opportunity to easily upgrade their e-bike by fitting it with different components. With a modular attachment pont for the motor, the motor brand can still be changed in later series if desired, which is beneficial for Mokumono.

Besides this, the bicycle will be more future proof. If the frame will survive for many years, this does not mean that the electrical systems in the bicycle will be around for the same length of time. The three main motor brands taken into account are Shimano, Bafang and Bosch. As these brands are the most commonly used in the e-bike world. The attachment points of the motor to the frame is very similar between these three motors. This means that the three motor brands will all be applicable to the bicycle frame with minimal adjustments to the frame (small adapter plate).

Making the frame compatible for all these motors is a good opportunity for Mokumono. It allows Mokumono to offer different classes of e-bikes, for different consumer needs with minimal adjustments. Besides, making the frame compatible for different types of motors will make the whole e-bike more future proof. The brand and type of motor can be switched when needed. In this way, the consumer can "upgrade" their e-bike without having to buy a completely new system.

For this project, the focus will lie on an e-bike system with a Shimano Steps motor. Keeping the scope of this project in mind, the e-bike is currently designed for only this motor and not completely elaborated on the other types of electrical motors. However, it is still taken into account that all these different motors still fit the frame

# Process tree

A process tree is a schematic diagram of all the actions the product encounters during its life cycle. The process tree helps to find criteria for the program of requirements and helps with gaining a deeper understanding of the steps the product in question will go through. The life of the product is divided in four main phases, originate, distribute, use and discard. The origination deals with the design and manufacturing of the product. Distribution deals with getting the product to the consumer. Use describes the product being used by the consumer and discard describes what happens to the product at the end of it's life cycle.

**Originate**

1. Analyse current situation
2. Analyse future situation
3. Develop product
    a. Design
    b. Prototype
    c. Test
4. Source production
    a. Source raw material
    b. Find sheet metal former
    c. Find welder/brazer
    d. Find fitter
    e. Find coater
5. Produce
    a. Sheet steel
        i. Create a blank
    b. 3D Forming
    c. After manufacturing care
    d. Assembly
    e. Welding/brazing
    f. Fit rest of bicycle
6. Quality check
7. Package
8. Store

**Distribute**

1. Set sale price
2. Advertising
3. Sell
    a. Selling by Mokumono
        i. Online
        ii. Physical store
    b. Selling by third parties
        i. Online
        ii. Physical store
4. Advise possible consumers
5. Deliver product
    a. Delivery service
    b. Pickup point
    c. Pickup at Mokumono

**Use**

1. Transport e-bike to house
    a. Transport from storage to point of distribution
    b. Quality control
    c. Packaging
    d. Transport to house/pickup point
2. Store product
    a. Lock
    b. Charge
3. Use e-bike
    a. Charge battery
        i. Disconnect battery from bicycle
        ii. Cover connector
        iii. Place battery in charger/ docking station
        iv. Charge
            1. Indication when charging
            2. Indication when charged
        v. Unplug battery
        vi. Place back into the frame
    b. Walking with bicycle
        i. Possibility for “Boost” function
    c. Cycling unassisted
        i. Disengage electric motor
        ii. Free from resistance
    d. Cycling assisted
        i. Enable motor
        ii. Automatic gearing
        iii. Change assistance mode
    e. Steering
        i. Free steering
    f. Braking
        i. Hand braking
            1. Automatic gearing
    g. Carry bag
    h. Use light
    i. Store
    j. Clean
4. Maintain e-bike
    a. Cleaning
    b. Checking parts
    c. Lubrication
    d. Change components
        i. Battery
        ii. Motor
        iii. Bicycle parts (saddle, pedals etc.)
5. Repair e-bike
    a. Self-repair
    b. External company
    c. Mokumono

**Discard**

1. Sell product
    a. Second hand
    b. Back to Mokumono
2. Trade product
    a. With Mokumono
    b. With third party
3. Reuse usable parts
    a. Parts assessment
    b. Disassemble
    c. Reuse parts
    d. Store usable parts
4. Recycle materials
    a. Disassemble
    b. Assess which materials are reusable
    c. Recycle
5. Refurbish and resell
    a. Analyse current parts
    b. Replace parts
    c. Resell

# TARGET GROUP

To have a specific foicus in the marketing of this product, a target group is chosen. This was done by looking at the upcoming trends that are relevant for this product, as well as the current and future brand image of Mokumono. Together with Mokumono a specific target group for this product is distilled. It is already said that Mokumono fits in the higher price segment of the market, which already gives some insight in the target group. Since the product will be relatively expensive  (€3500), it needs to be targeted at people with a relatively high / moderate to high income.

When considering the opportunity of the e-bike commute, we look into a young , employed audience. Here lies a large opportunity to utilise the e-bike for the daily commute, since they are not yet used to travelling in by car, making the e-bike seem more favorable. (Plazier et al., 2017) It is also seen that young professionals gravitate towards metropolitan areas, either for work or for living (MSL group, 2014). In these urban and suburban areas, an e-bike is beneficial compared to car commute.

The target audience chosen for this product include all sexes. This is quite different than the current audience of Mokumono, which is mostly aimed towards men. It can be seen that female cyclists are less hindered nowadays by the male bicycle archetype and vice versa. It will be beneficial to explore a frame that lies in between these bicycle stereotypes.

It is seen that millenials make up about 75% of the global workforce by 2025. Besides this, over half of the current world population is under 30 years old. The estimations also show that in the following years the spending power of millenials will be greater than those of the baby boomer generation. This provides an opportunity for small companies like Mokumono to market their products towards this generation (MSL group, 2014).

With this in mind, the choice has been made to accomodate a target group of young professionals between the age of 25 and 45. These people have already proven to have a greater interest in the environment and new technologies, making an e-bike an interesting product for them.

# Emotive Collage

On the right hand page, an emotive collage can be seen. To get a feeling about the emotions we want to convey with this product, an emotive collage is created. This provides a clear and communicative image to use in upcoming design meetings and as a support for the ideation phase.

What this emotive collage symbolises is the feeling the user should have when riding the designed e-bike. This is mainly focussed on the commute from home to work and vice versa. The bird symbolises the freedom experienced by the user, by having a hassle-free ride during their commute. The nature on the bottom part of the image and the urban environment symbolise the connection between these two.

When commuting with an e-bike, it is possible to explore environments that you would normally find too far away to explore, or even cannot access without a bicycle. This sense of adventure is captured in this collage, symbolised by the natural environments on the bottom half, and the layers of exploration on the horizon.

# PRODUCTION METHOD

## Sheet metal forming

Sheet metal forming is a widely used manufacturing principle. One of the most well known areas where a lot of sheet metal forming is used is the automotive industry.

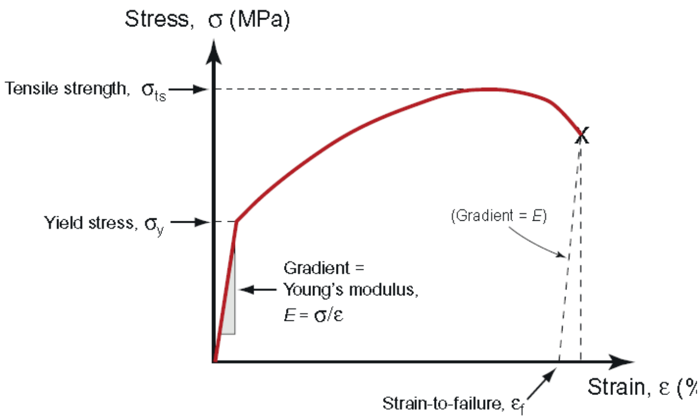
The specific process we are going to look at here is matched dye forming. There are a few important things to note when it comes to sheet metal forming in general, which will be discussed below

**Stress to strain**

For sheet metal forming, it is necessary to look into the mechanics behind the plastic deformation of metals. In image 14 (Tempelman et al., 2014) a general stress-to-strain curve can be seen. This is a schematical representation of metal behaviour. In this graph, a few important properties can be seen, specifically for sheet metal forming. These properties are: Young's modulus, yield stress, tensile strength and strain-to-failure. The specific values for these properties are different for various types of metal and alloys.

Where you normally want to keep stress levels in a product below the yiels stress, in sheet metal forming we need to get above the yiels stress to accomodate plastic deformation. In the elastic region, until the yield strength, the atoms inside of the metal spring back to their original positions, thus not deforming the overall product (Tempelman et al., 2014).

*Image 14: general stress - strain curve*




When we exceed the yield strength, the atoms inside of the material can begin to move. Inside the material there are small imperfections in the overall metal structure, called dislocations. When under enough shear stress, dislocations inside of the material will start moving. When this happens, we see plastic deformation in the product (Tempelman et al., 2014). When more and more dislocations occur, they start to hinder each other's movement, and thus the stress level needed to achieve plastic deformation rises. How much this happens is different for each distinct type of metal.

Beyon the yield point, a metal can strain permanently, which does not mean that the material becomes weaker. It actually becomes stronger when deformed. This can be countered by annealing the metal. Heating the product, to high temperatures can reduce the number of dislocation, and thus lower the yield strength and increase the strain-to-failure (Tempelman et al., 2014).

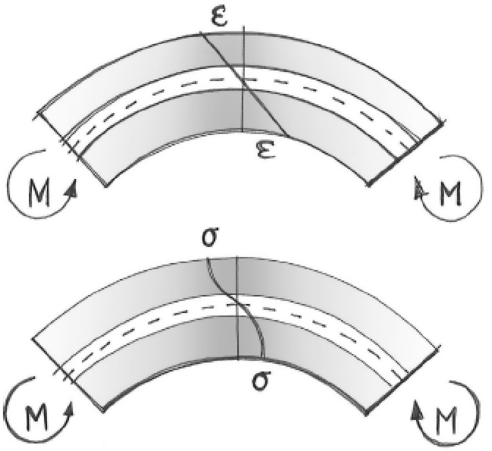



*Image 15: Internal stress during bending*

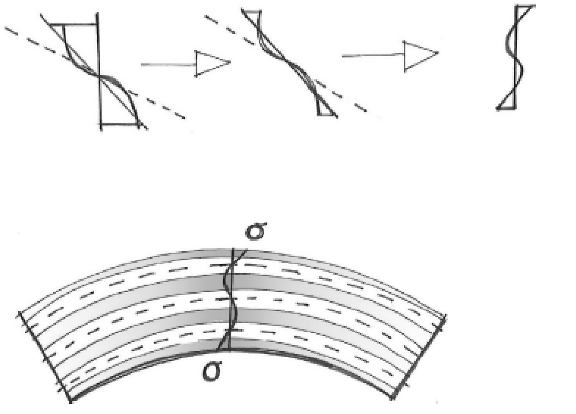



*Image 16: Residual forces after bending*

**Springback**

Another important factor about sheet metal forming is the springback. The elastic strain that occurs in the product because of the force applied to it remains in the product, until that force is removed. This is why in sheet metal forming there is elastic springback.

In certain shapes you can calculate the springback occuring in a specific area of the product, this can then be implemented in the design by adjusting it accordingly. This can be done to form the product is beyond its eventual shape, so that with the springback, the product shape returns to it's desired form (Zhang et al., 2018).

The springback also leads to internal residual stress. This stress is locaten in the cross section of the product. These forces, as can be seen in Image 15 and 16 (Tempelman et al., 2014), eventually balance each other our, since there is an equilibrium in the product.

**Form limit diagram (FLD)**

Because the design will consist of double curved parts, there will be forces in at least two directions. The forming possibilities can no longer be looked at as a 2D simplification. In these products, the applied stress has become biaxial. Because of this, we can use a forming limit diagram, or FLD, to determine the formability limits. In an FLD, the allowable strain in one vertical direction is plotted against the allowable strain in horizontal direction. (see image 17) (Tempelman et al., 2014) These FLD diagrams are different for various types of metal.

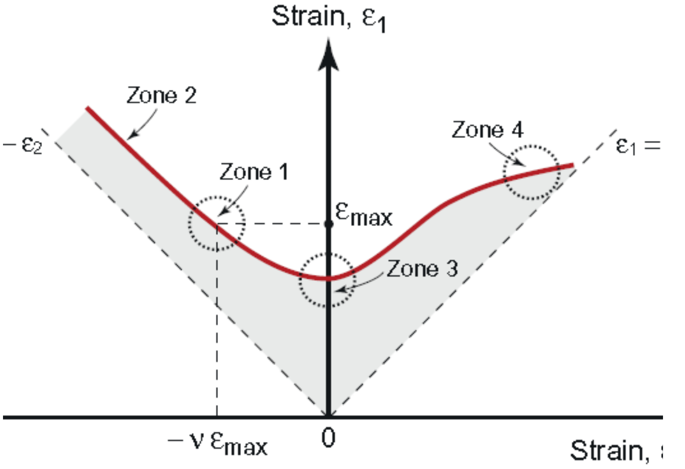



*Image 17: Form limit diagram*

The strains used in the FLD are true strains. The vertical axis contains the vertical true strain, which is in the tensile direction (e.g. along the sides of the material in the direction of force). The horizontal axis contains the true strain perpendicular to this, which may be tensile or complressive.

The diagram is limited by FLD, above of which the material will fail. The gray area in this FLD is the area that is achievable by a forming process (Tempelman et al., 2014).

# Brazing

To minimise the currently existing difficult ares in the assembly of the different formesdshells, the choice has been made to explore the possibilities of brazing. One of the greatest advantages of brazing instead of welding is the lower temperatures at which it takes place. When welding thin sheet steel, there is a large risk of deformation due to the high temperatures. The weld itself will be a strong connection, but the area around it will become weaker due to these extreme teperatures. This is different with brazing. Moreover, the weld will need to be grinded down to have an appealing aesthetical value (TRUMPF, 2019).

Brazing is a process in which materials are joined together by melting a filler metal into the joint of the seperate parts. The filler metal used has a lower melting point than the base metals, which means that overall less warping will take place. The most used filler metals for brazing steel are silver, copper and nickel (Schartz, 2003).

Because the filler metal flows into a gap in between the main parts by capillary action, there needs to be an overlap between these parts.

There are different ways to enable a good bond between parts with brazing. The main examples of succesfully bondable joints can be seen in image 19 (Schwartz, 2003).

Using a technnique called laser brazing, the brazing process can be automised. This process is already widely used in the automotive industry, and fits the production method of Mokumono perfectly (TRUMPF, 2019).

With laser brazing, the same characteristics apply as with regular brazing. The cost effectiveness of the process itself is comparable to that of laser welding, the technique currently used by Mokumono. However, the end quality of the joint and the overall product is much higher due to minimal warpage in the base material. Furthermore, the seam will be of high aesthetic and structural quality, which means there will be less costs in the post-processing of the brazed parts. This will ultimately lead to a lower production cost per frame, since the post-processing of the welds are a large expense in the current production process.


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*Image 18: Laser brazed fillet seam (TRUMPF, 2016)*

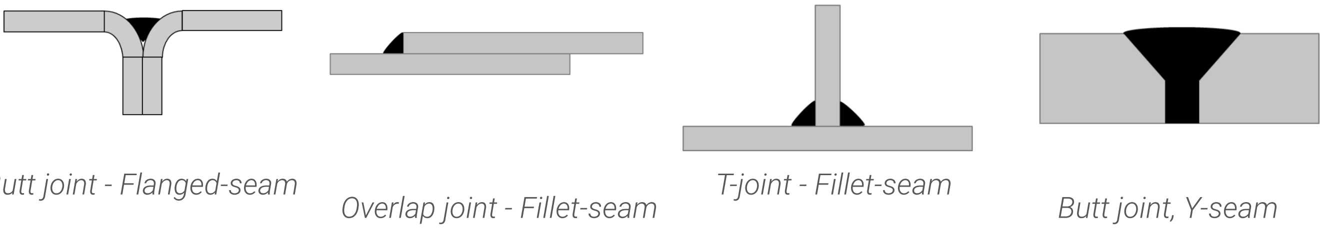



*Image 19: Different brazing joint designs (Schwartz, 2003)*

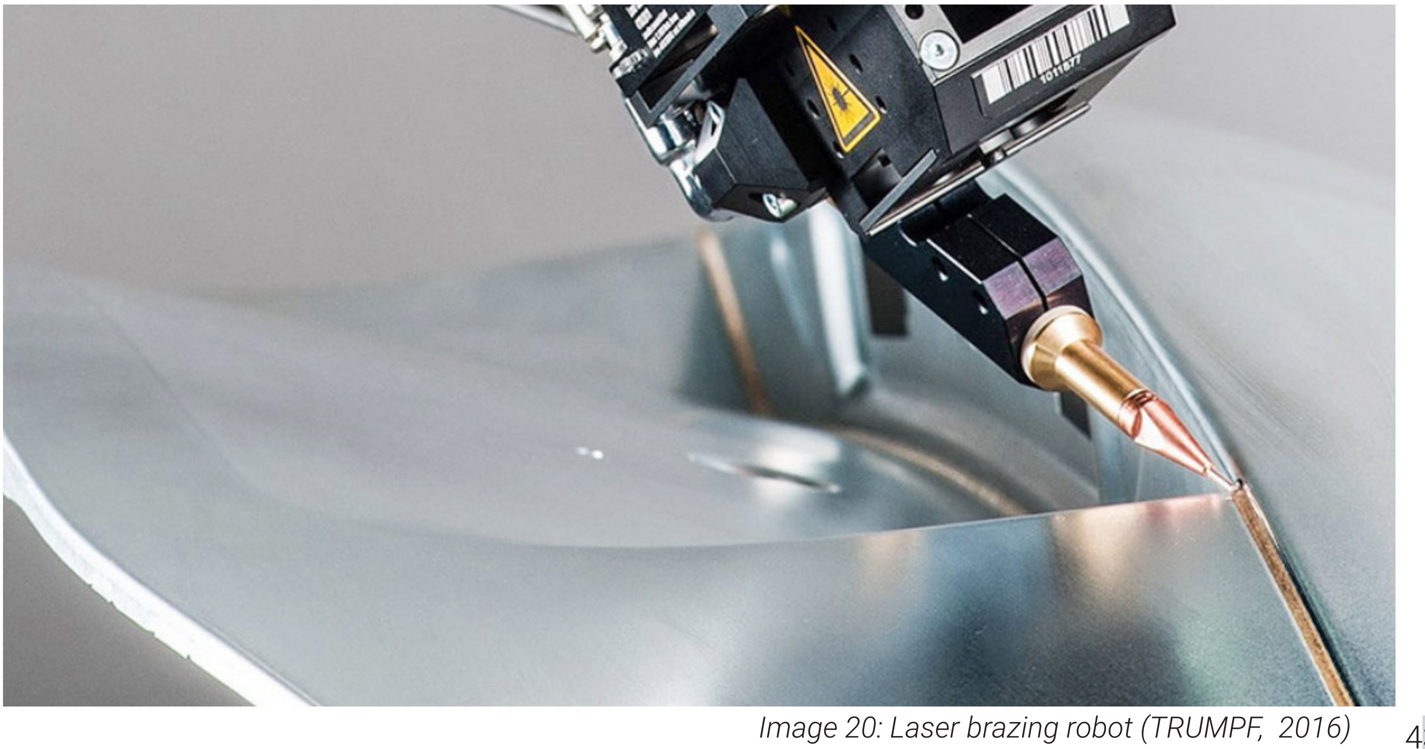


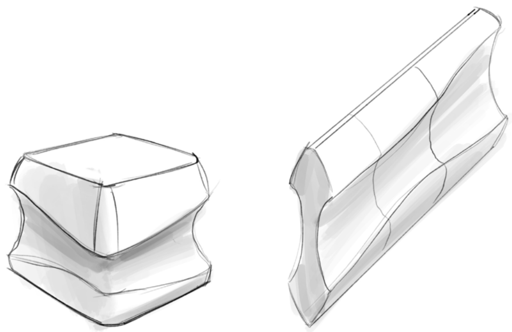
*Image 20: Laser brazing robot (TRUMPF, 2016)*

# Sheet metal strength and geometry

There are dfferent ways to ensure strength in thin walled sheet metal parts. To design a strong frame, possibilities to strengthen a product are explored. The main possibilities are displayed below.

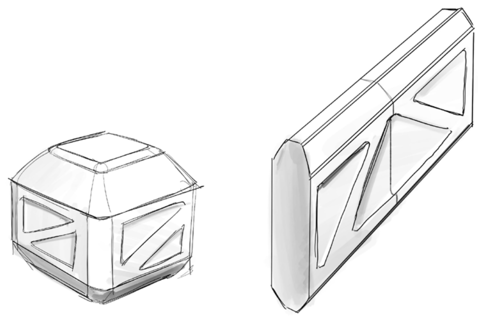
### Organic lines

By using curved, organic lines, the frame can be given extra support where needed. By changing the cross section shape through the frame, the properties of these sections of the frame can be adjusted to where it is needed.



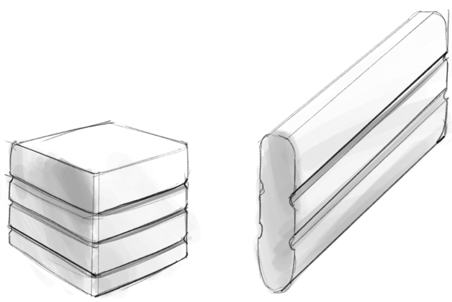
### Indentations

Another possibility is the punching of shallow shapes into the frame, this will give the frame extra strength, and fits right in with the current style of mokumono. The shapes of these indentationn can be varied for an optimal result.



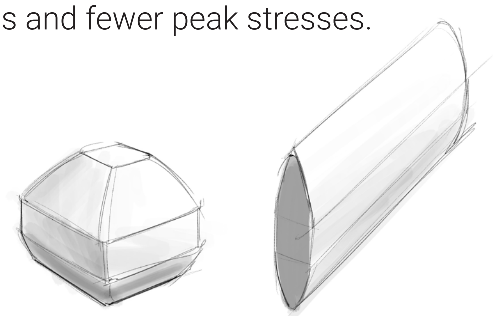
### Pressed ribs

Pressed ribs can be used to strenthen the overall shape as well. These ribs can vary in profile, depth and direction. Besides from ribs over the length of surfaces, ribs can also be pressed in the bent edges. The ribs do not have to be parallel to each other, this can be optimised further using simulations.



### The rounded chamfer

Chamfers make for a lot stronger design than rounded filleted edges. However, when the chamfer has a slight radii in it, the strength of the overall part will improve, since the stresses can more easily flow through the part. Do note that the hard edges leading to the chamfer need to be rounded off slightly for produceability reasons and fewer peak stresses.



# Production design guidelines

When designing for sheet metal forming, a few basic design guidelines need to be taken into account. In a conversation with R. Bukkems of Phoenix 3D metaal the basic guidelines of sheet metal forming have been discussed (personal communication, November 26, 2019). These guidelines are incorporated into the design of each individual frame part, to ensure good manufacturability.

However, do note that these guidelines are not guaranteeing a formable product, this is a simplification. The actual produceability highly depends on the overall geometry of the total product.

While this may not give a complete guarantee on produceability, it does give a good foundation to base the designed shapes on. When these guidelines are constantly followed, later on there will be fewer adjustments needed to ensure good production of the final frame.

1. Upper radius needs to be significant due product depth on point 2.
2. Two smaller radii will result in one big radius (see red line), otherwise it will fracture.
3. Radius can be smaller than nr. 1 (depth 1-2 is bigger than 3-2)
4. High risk area, product request material stretch on both sides. Because there the material amount is limited the stretch (and thus fracture possibility) will be significant.
5. Small radius allowed (enough stretch between point 5-9).
6. Big radius requested because there is no draft (point 5-6).
7. Small radius allowed (enough material).
8. Small radius allowed (less material stress requested).
9. Ideal product shape
10. Small radius allowed (less material stress requested).
11. Small radius allowed (less material stress requested), enough stretch between 11-13.
12. Big radius needed because due the sharp shape
13. Small radius allowed (enough material).

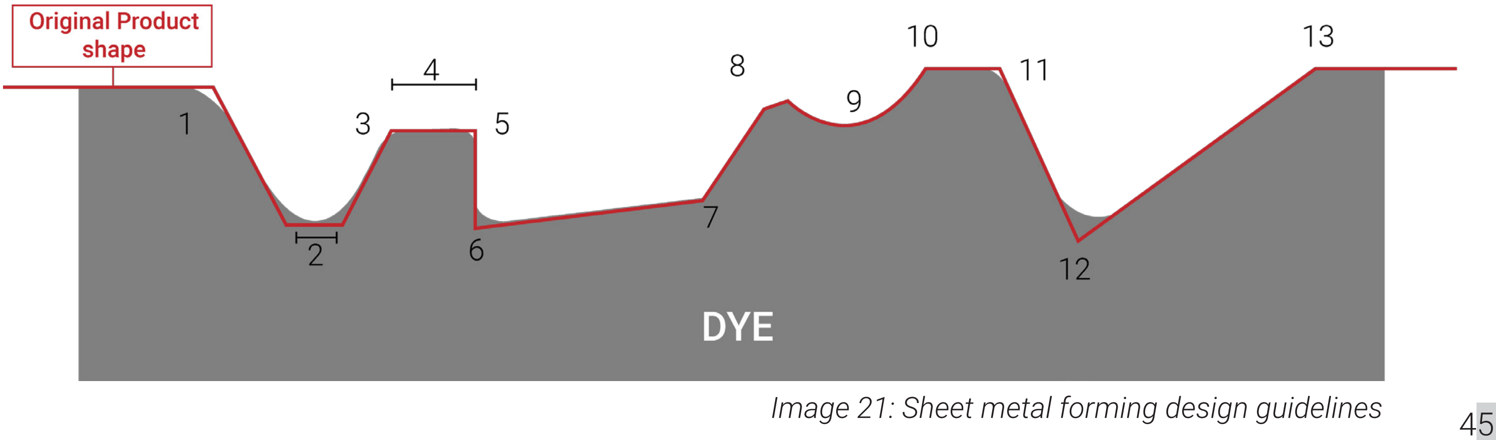



*Image 21: Sheet metal forming design guidelines*

# PART 2: DESIGN VISION

# DESIGN REQUIREMENTS

## Demands

In the following part, the guidelines for the design phase are given. With these guidelines and requirements of the final product, a boundary is set within which the design process will focus.

Apart from the requirements, some wishes will be formulated as well. These wishes are aspects of the design that are desired to be present, so these will be weighted more in the upcoming concept selection.

Not all of these requirements are weighted equally. Some requirements might be more important than others, and thus will have a larger impact on the upcoming design.

Besides forming good support for the design phase of this projects, the project of requirements also will help out in the selection phase. When a final concept will be chosen, the wishes of this list will help with selecting the best concept in an objective way.

1. **Performance** - Which main functions will the product fulfill?
   - 1.1 The e-bike motor can only assist up to 25 km/h.
   - 1.2 The e-bike motor can have a power maximum of 250 W.
   - 1.3 The e-bike motor can only assist when the user is pedalling, no individual throttle is allowed.
   - 1.4 The e-bike needs to be functional without a working motor.
   - 1.5 The e-bike needs to be able to withstand the forces that occur during normal use.
   - 1.6 The frame needs to be able to withstand the forces of an adult male during use.
   - 1.7 The e-bike must have an action radius of at least 80 km on one battery.
   - 1.8 The e-bike must be usable on the Dutch flat roads.
   - 1.9 The e-bike must be able to hold fenders.
   - 1.10 The e-bike must have integrated lighting.
   - 1.11 Electronic components need to be removable when not using the e-bike.
2. **Environment** - What environmental influences does the e-bike need to withstand during use?
   - 2.1 The e-bike must not be able to rust within 1 year of storage.
   - 2.2 The e-bike must not rust with daily use (at least 2 hours, 5 days a week).
   - 2.3 The e-bike will not lose functionality when not cleaned.
   - 2.5 Dirt and debris can not find a way inside of the frame.
   - 2.6 The frame must not fail with normal use by regular environmental factors within 10 years.
3. **Lifespan** - How intensely will the product be used and how long will it last?
   - 3.1 The e-bike must be used at least 5 times a week for commute, calculated at 80 kilometres a day at a maximum.
   - 3.2 The e-bike frame must last at least 10 years without failing. In this time external components can be changed.

4. **Maintenance** - Is maintenance possible and necessary?
    - 4.1 The standard bicycle parts must be maintainable by the user or the bicycle repair shop.
    - 4.2 The specific electrical components must be maintainable by the company or specialised e-bike repair centres.
    - 4.3 All parts attached the e-bike need to be able to be removed for maintenance.
    - 4.4 The e-bike must be able to withstand regular cleaning (water and soap),
5. **Production costs** - What is a good price for the product?
    - 5.1 The e-bike retail price must not exceed 3000 euros.
6. **Transport** - What does the product need for transport during use?
    - 6.1 The e-bike must be able to fit on all regular bicycle racks.
    - 6.2 The bicycle must be mountable of bicycle racks for vehicles.
7. **Packaging** - Is packaging needed for this product?
    - 7.1 Packaging of the product will be needed if sold online and sent to the user.
    - 7.2 Packaging will not be required if the user picks up the bicycle in the store.
8. **Quantity** - What number of products should be produced?
    - 8.1 The e-bike must be producible in a series up to 10.000 pieces.
    - 8.2 Part stocking for the e-bike needs to be possible.
9. **Production facilities** - Which production facilities can be used and do we need new production resources?
    - 9.1 The e-bike frame must be producible with 3D sheet metal forming techniques (2 mould forming, hydroforming or rubber forming).
    - 9.2 The e-bikes need to be able to be fitted in the Netherlands.
    - 9.3 The e-bike frames need to be manufactured in the Netherlands.
    - 9.4 The e-bike batteries must be installed locally.
10. **Dimensions and weight** - What are the boundaries to the size and weight of the product?
    - 10.1 The e-bike needs to be able to fit inside bicycle racks.
    - 10.2 The e-bike must not weigh more than 25 kilos in total, with all components attached.
11. **Aesthetics, finish and appearance** - Are there specific aesthetic boundaries that the consumer expects in this product?
    - 11.1 The frame must have as many components integrated into the frame shape as possible.
    - 11.2 The electrical motor must be visible.
12. **Materials** - Which materials should be used in this product?
    - 12.1 The frame of the e-bike needs to consist of a steel alloy.
13. **Product life span** - How long is this product expected to be used and produced?
    - 13.1 The product must be able to withstand at least 10 years of regular use.
    - 13.2 The e-bike must be able to be fitted with new components to extend the lifespan.
    - 13.3 The e-bike frame must be able to be produced for at least 10 years, with additional iterations during this time period.
14. **Rules and regulations** - Which rules does the product need to comply to?
    - 14.1 The e-bike must comply to norm DIN EN 15194:2009 fietsen – elektrisch aangedreven fietsen, EPAC fietsen.
    - 14.2 The e-bike must comply to norm Laagvoltage richtlijn 2006/95/EC.
    - 14.3 The e-bike must comply to norm DIN EN 14764 voor stads- en tourfietsen.
    - 14.4 The e-bike must comply to norm CEN EN 14764 - Bicycles for common use.
    - 14.5 The e-bike must comply to norm CEN EN 14782 - Luggage carriers.
    - 14.6 The e-bike must comply to norm CEN EN 15496 - Cycle locks.
15. **Ergonomics** - What are the requirements for handling this product?
    - 15.1 There need to be three different sizes of e-bikes to accommodate a large group of consumers.
    - 15.2 The e-bike must use the sizing system of the current Mokumono Delta.

**16.** **Reliability** - Which degree of failure is acceptable from this product?
- 16.1 The e-bike must never fail in regular use.
- 16.2 The battery must not be able to overheat.
- 16.3 The e-bike must not fail due to irregularities in the road.

**17.** **Storage** - What is expected of the product during long times of storage?
- 17.1 The product must be placed inside whenever possible.
- 17.2 The product must be able to withstand short storage outside (rain and sun).
- 17.3 The battery should be removed when stored.

**18.** **Testing** - Which tests need to be conducted on the product?
- 18.1 The product must be tested by Mokumono before production.
- 18.2 The electrical systems need to be tested extensively to make sure no accidents can happen.

**19.** **Safety** - Which safety precautions should be taken in this product?
- 19.1 The electrical components must not be able to overheat.
- 19.2 The electrical wiring must be out of reach for the consumer.
- 19.3 No parts on the e-bike must be able to interfere with the moving parts.
- 19.4 The frame must never break during normal use.

**20.** **Product Policy** - Are there requirements coming from the current product portfolio?
- 20.1 The bicycle must fit within the company Mokumono.

**21.** **Societal and political implications** - What are current opinions on this product?
- 21.1 The product must help overcome the current e-bike image.
- 21.2 The product must help overcome the negative attitude towards steel instead of aluminium.

**22.** **Liability** - Who will be held accountable in case of failure of the product?
- 22.1 Mokumono will be held accountable if the e-bike frame fails.
- 22.2 Mokumono will be held accountable if the battery pack fails.
- 22.3 The motor producer will be held accountable if the motor system fails.

**23.** **Installation and initiation** - What demands result from the assembly and installation of the product?
- 23.1 The user must be able to perform their own initiation of the e-bike.
- 23.2 There must be clear instructions on how to fit the bicycle to your measurements.

**24.** **Reuse and recycle** - Can the materials and components be recycled or reused?
- 24.1 The external components of the e-bike need to be detachable for re-use at end of life.
- 24.2 The frame shells should be able to be parted.
- 24.3 The electronic components need to be fully removable.
- 24.4 As many components need to be removable from the frame as possible.
- 24.5 Mokumono must facilitate a good end-of-life for their products if possible.

# Wishes

1. The e-bike should facilitate carrying a bag.
2. The e-bike should be usable by both male and female users.
3. The e-bike should have an anti-theft system.
4. The aesthetic of the bicycle should fit with the style of Mokumono.
5. The e-bike should be as light as possible.
6. The components of the e-bike should not be attached to the frame, but rather be integrated with the frame shape.
7. The e-bike design should have a minimalistic aesthetic, and fit in with other Mokumono products.
8. The bicycle should look like a modern, integrated electric bike, instead of a regular bicycle with a battery attached.
9. The frame should be strong enough to withstand normal use, but not so stiff that the riding experience will suffer from it.

# FORM LANGUAGE MOKUMONO

The current product of Mokumono, the Mokumono Delta, has a strong personality. Bob completely let go of the stereotypical bicycle frame shape we all know, the double triangle. The Mokumono Delta really stands out from the crowd.

The e-bike that is designed will needs to fit the strong visual language of the Mokumono Delta. However, we do not want to just copy the current visual language to a new bicycle frame. Because the e-bike fits a completely new product group and is aimed at a different target group, there are possibilities to change the visual style a bit. In the end the product will have a visual language of its own, while still being a typicial Mokumono frame.

To accomplish this, the current product form of the Mokumono Delta is analysed. This analysis resulted in a few aspects that are believed to be very unique for Mokumono. These aspects can be seen in image 22. These key aspects of the design will be taken into account when further designing the e-bike frame.

The key features that are identified to be essential to the Mokumono style are the line from the dropouts to the headtube, as well as the triangular shape above bottom bracket. Besides these two obvious elements, the profile of the body is also important. While in the Delta this shape is very rounded, at first Bob aimed to make these edges a lot sharper, however this proved to be difficult for pressing the shells. Where the edges will always have a radius for the formability, this radius can become much smaller if the mold of the part is less deep.



*Image 22: Mokumono Delta (Schiller, 2016)*

# EASE OF PRODUCTION

For Mokumo, the manufacturability still is the main area of their design to improve on. For Mokumono to grow, the procces of manufacturing their bicyle frames needs to be further optimized.

This project will help Mokumono in exploring different directions when it comes to manufacturing a sheet metal formed bicycle frame. If the overall process can become more efficient, they will be able to produce larger volumes of bicycles and become more established within the bicycle market.

As discussed before, the most benificial areas to improve the overall production process on is the connection between the different parts. Besides this there is the new material type, While the current Delta frames are made of aluminium, the e-bike frame will be produced in some kind of steel. This is because of the issues currently paired with the welding of aluminium. With the use of the right steel we can still obtain a great formability, making the overall frame stonger while using less material. With the current steel alloys, the overall weight of the frame does not have to increase with the use of steel instead of aluminum.

These are the parts that will be focussed on in the design phase. However different areas of improvement will be explored as well.

The aim here is to explore options different from the current status quo of Mokumono. This will potentially lead to useful insights into the production method for Mokumono to utilise in whichever project follows.

# PART 3: DESIGN

# CONCEPTS

With the insights gained from the analysis, three concept e-bike frames have been created. These three concepts will then be evaluated and a choice will be made.

## Concept 1

This concept design lies closely to the current Mokumono Delta bicycle design. For this design it is chosen that the battery is placed within the opening in the frame. This leads to a large potential battery volume, but also leads to a less optimal weight distribution within the e-bike. The weight of the battery lies quite high, which is not ideal. For an optimal cycling experience, the weight should be as close to the ground as possible.

It is already known that with this frame shape it will be possible to get a strong enough frame to withstand more than regular use. However, because the frame design is so close to the design of the current Mokumono Delta, it contains the same issues. One of these issues is the inside of the rear fork. This still needs an extra sheet to be attached inside of the rear fork, which is a difficult and therefore expensive step in the production process.

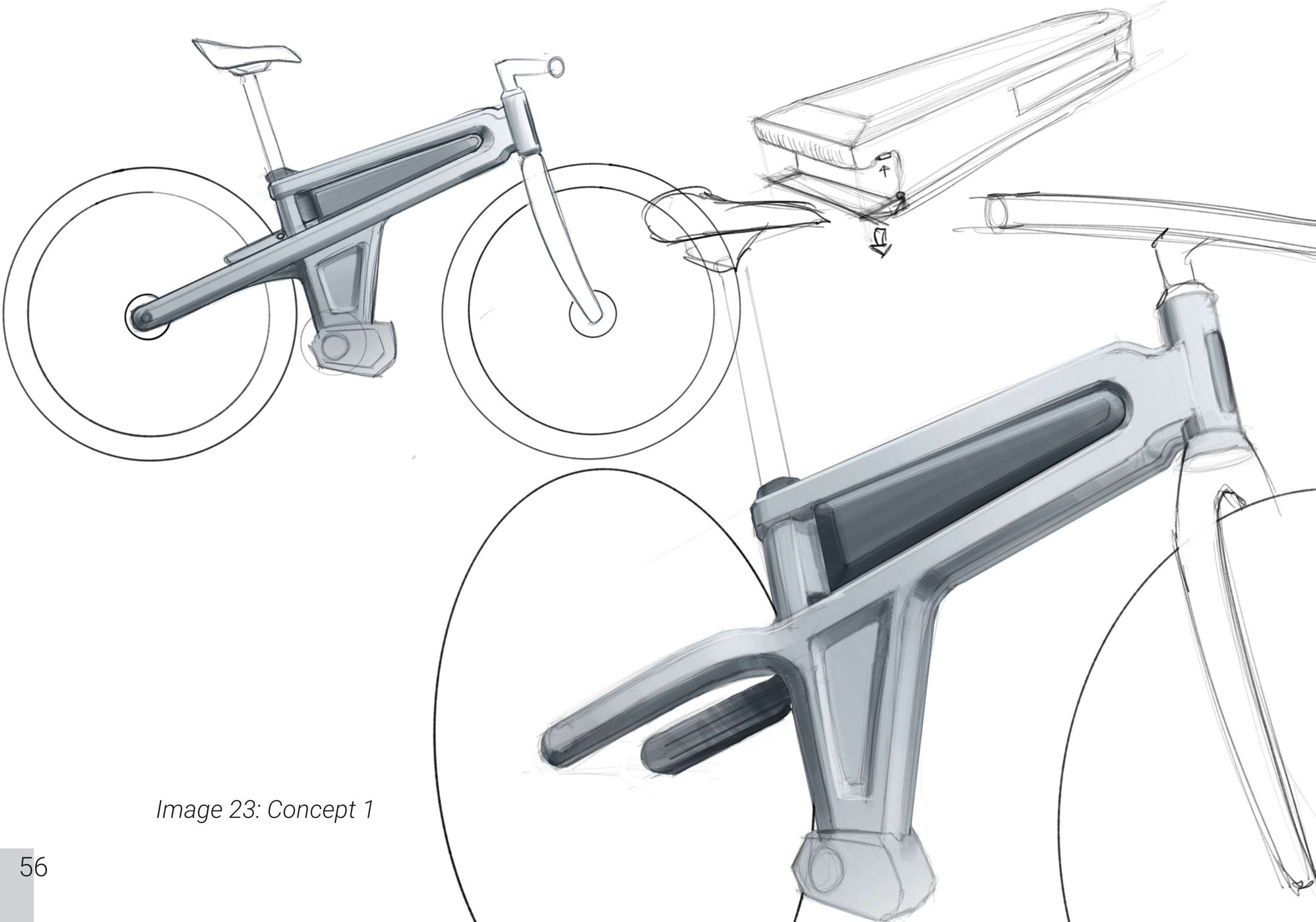


*Image 23: Concept 1*

# Concept 2

This concept is mainly aimed at accessibility. This design provides a low entry in the frame which makes is usable by male, female young and old users. Although this design is fit for an integrated battery, the overall design shape is not well fitted for strength and stiffness. Due to the low entry point in the frame, lots of internal stress will congregate at that point.

Moreover, the design is heavily inspired by traditional unisex e-bikes. This leads to a less expressive look than what fits Mokumono.

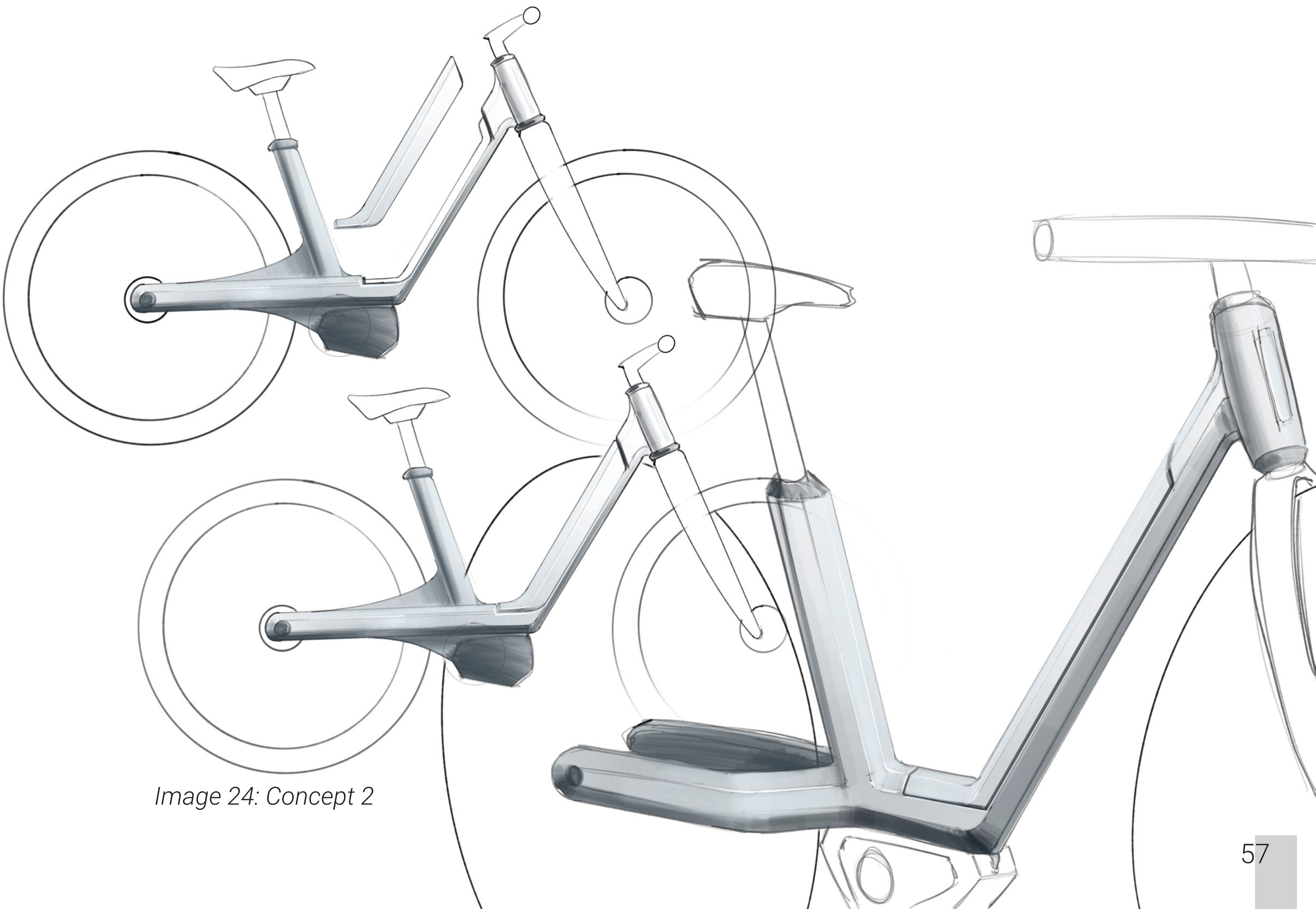


*Image 24: Concept 2*

# Concept 3

This concepts consists of a cross frame. The line from the rear wheel to the head tube, which is important for the Mokumono feel, is extra visible in this design.

Besides the minimalistic style of this concept, it is an accessible design that lies between the archetypical male and female bicycle frame.

The triangle above the engine is replaced by the battery. This makes it feel like a Mokumono, because of the triangular shape. This also makes the weight balance in the bicycle to be low, which is a preferred situation for the riding experience.

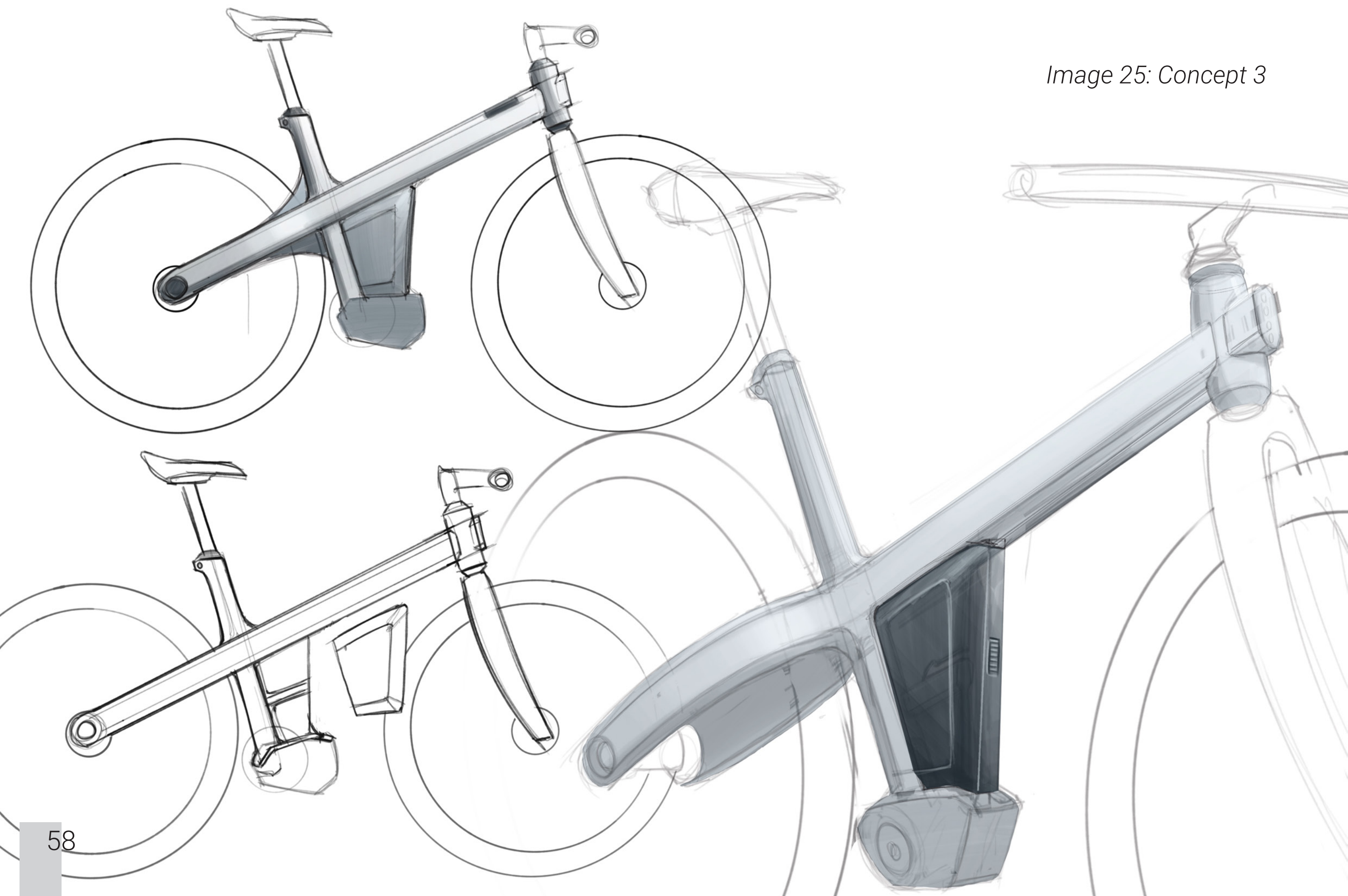


*Image 25: Concept 3*

# CONCEPT CHOICE

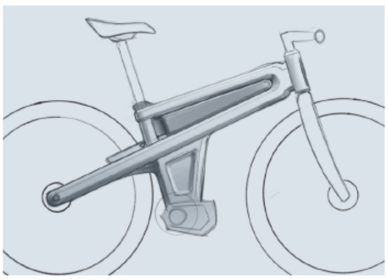
One of the above described concepts was chosen for further development. For this choice the Weighted Objectives method is used from the Delft Design Guide (Van Boeijen et al., 2014). To be able to use this model, 6 important wishes are identified. This is done through the results of the analysis and the input from Mokumono.

The used selection criteria are as follows:

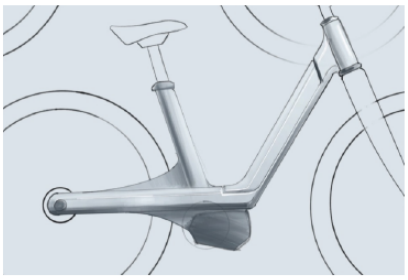
**Male and female use** - Is the e-bike usable for both male and female users?
**Mokumono style** - Does the frame design fit with the style of Mokumono?
**Innovative** - Is the frame design refreshing or old fashioned?
**Integration** - How well are the electric components integrated within the frame?
**Sustainability** - How sustainable is the frame? How much material is expected to be used and how well can repairs be executed?
**Strength** - How strong and stiff is the frame expected to be?

These criteria have a weight distributed to them according to how important the criteria is for the project. These values are determined through interviews with Bob and Tom of Mokumono.

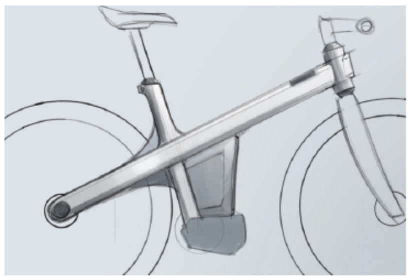
Concept 1



Concept 2



Concept 3



| | Weigth | Concept 1 Score | Concept 1 Total | Concept 2 Score | Concept 2 Total | Concept 3 Score | Concept 3 Total |
|---|---|---|---|---|---|---|---|
| Male and female use | 10 | 2 | 20 | 9 | 90 | 6 | 60 |
| Mokumono style | 20 | 9 | 180 | 6 | 120 | 8 | 160 |
| Innovative | 10 | 6 | 60 | 3 | 30 | 7 | 70 |
| Integration | 25 | 7 | 175 | 8 | 200 | 7 | 175 |
| Sustainability | 15 | 4 | 60 | 6 | 90 | 8 | 120 |
| Strength | 20 | 8 | 160 | 5 | 100 | 6 | 120 |
| *Total Score* | 100 | | 655 | | 630 | | 705 |

From this selection procedure, concept number three has been chosen to be the final concept. This frame will be further developed towards a fully functional e-bike.

# CONCEPT DEVELOPMENT

With a good concept as a base for the final design, the frame is further developed. This is done through a combination of sketching, prototyping and 3D CAD modelling. When developing the concept, it became clear that the cross, where the four areas of the frame meet, needs a lot of attention. This was adressed by creating rough prototypes and simultaneous sketches.

## Accessibility

There has been an explorative step into the acessibility of the frame shape. This is done to increase the potential accessibility of the frame. Eventually there has been a choice together with Mokumono to not pursue this path, because it is deemed to be undermining the design language of the frame. Moreover, it was concluded that the current step in of the frame is already at a low enough point to comfortably facilitate both male and female users.

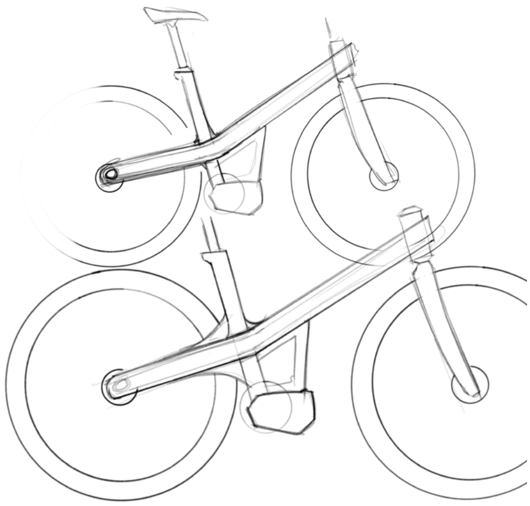


*Image 26: accessibility exploration*

## Rear fork

Initially, there has been an idea to work with a single sided rear fork. This is a logical design step because of the way the Mokumono products are constructed, with two main shells. If a single sided rear fork is used, the problem of the inside of the rear fork is eliminated. With a single sided rear fork the frame can be fully self-contained. Although this might be a good option, other options to eliminate the rear fork issue have been explored, as a single sided rear fork brings a lot of issues as well. These issues mostly concern the overall balance of the bicyle, the strength of the rear fork and the trustworthiness of the frame towards the user. In image 27 *(English, R. 2012)*, an example of a single sided rear fork can be seen, made by English cycles.

*Image 27: Project right single sided rear fork*

# Amount of shells

At first, all of the concepts have been designed with the idea of just two shells bonded together, with an extra piece of sheet metal in the rear fork, just like the Mokumono Delta.

The way the sheets are oriented in the Mokumono Delta provides some problems. Because the rear fork is essentially open, there is an extra bended part that needs to be welded inside of the rear fork, which is currently a difficult and expensive step in the production process. The seat tube is welded in between of the two shells. This provides extra strength to the frame and functions as a place for the seat and the bottom bracket to be attached to.

To counter these problems, new possibilities have been explored. The most notable has been the orientation and the amount of shells.

There is an opportunity to create the bicycle not from 2, but from 4 different shells. With this opportunity, the attachment of the different parts through brazing will be much easier than it is now, cutting the production time and difficulty of the production steps. This method of joining also makes sure that no water or debris that can enter the frame.

Looking at image 28, part 1 will be the main part of frame, most of the strength will come from this part. Instead of the current production method the Mokumono Delta, which is with a left and a right shell, this part will be manufactured with a top and bottom part, as can be seen in image 29. Because of this choice, the whole rear fork and the tube that leads from the cross to the head tube can be produced out of two shells. This makes the extra process of filling in the rear fork unnecessary.

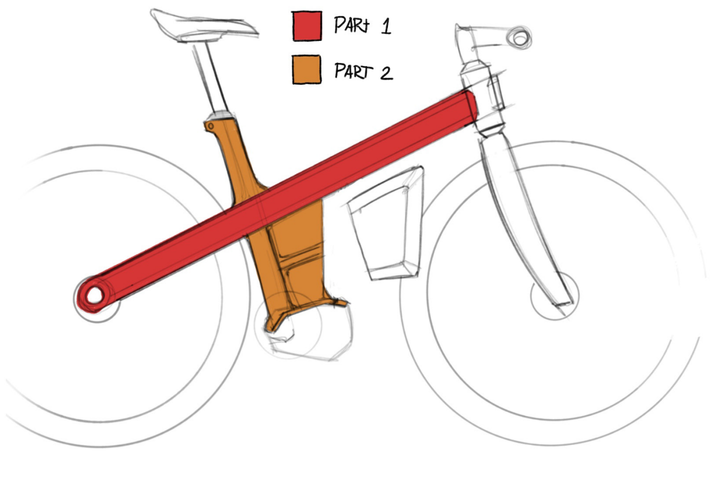



*Image 28: Overall part division*

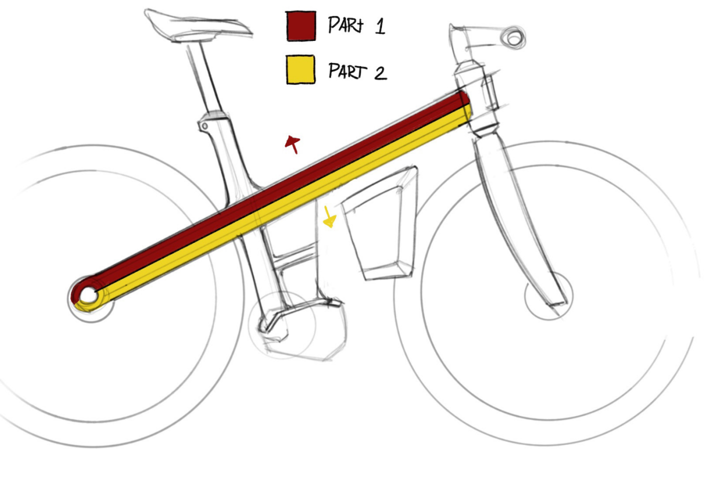



*Image 29: Main part division*

# Battery attachment

The triangular shape above the motor is designed to follow the form language of the Mokumono Delta, which has a very iconic triangle towards the bottom bracket. However, as this is the area where we want to attach the battery, we want to minimise this surface. Currently, the attachment point for the battery is a lot of extra material that is not needed. This will also mean that the battery will be essentially cut in half by the frame, so that the battery wraps around it. This makes the orientation of the different cells inside the battery pack more difficult.

This triangular area needs to be minimised, but not totally deleted, because there is another use for this part. Since the frame contains no closed off shapes, locking the bicycle is becoming a problem. The triangular area is a perfect location for a hole through the frame, through which the user can lock their e-bike with a regular chain lock. Because of the hole, the battery will also be locked to the frame, while still being able to lock the e-bike without the battery attached.

The battery attachment is redesigned to be less intrusive and material heavy, while still maintaining functionality.

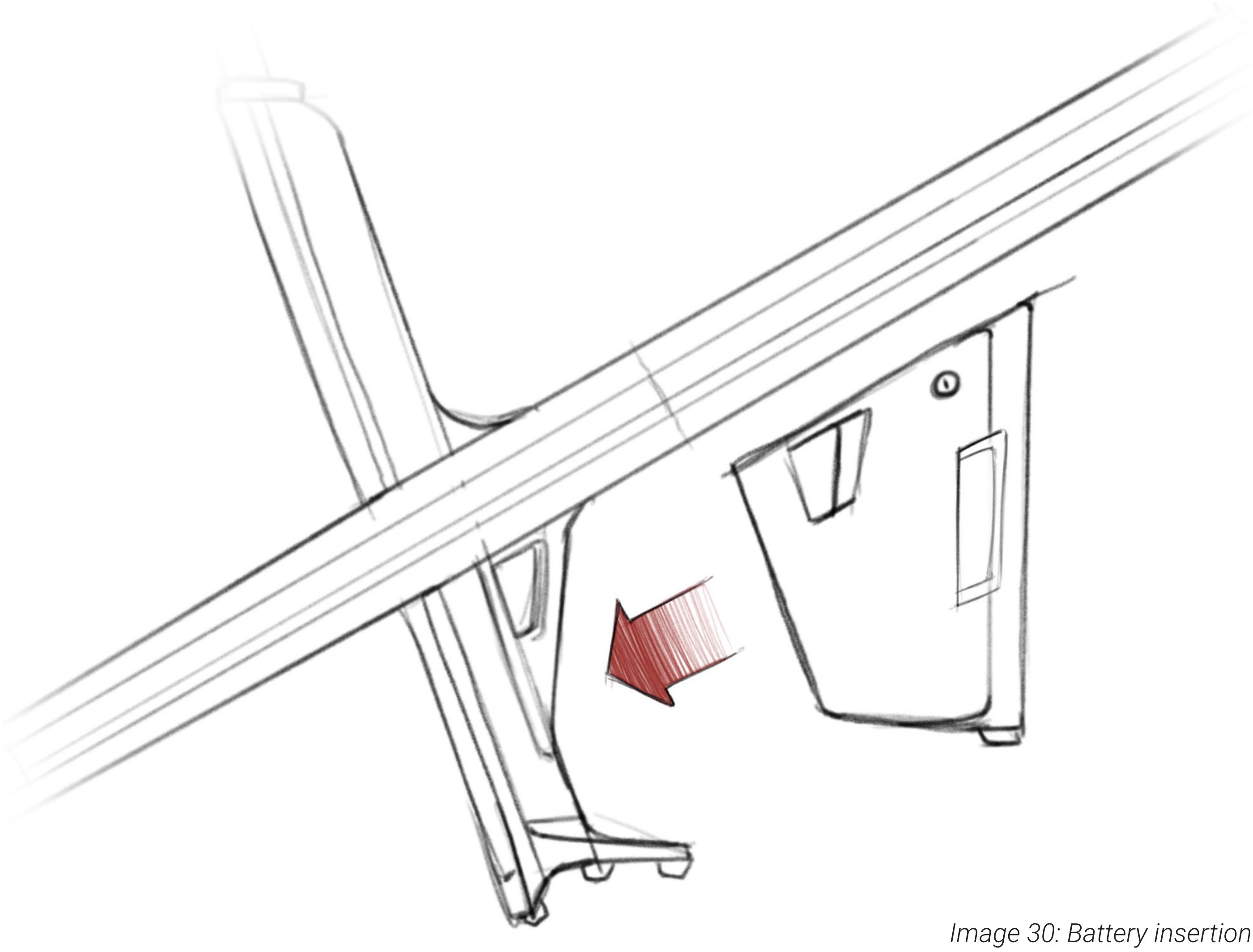


*Image 30: Battery insertion*

# Connection of parts

One of the main challenges has been to find a good solution to join the two main parts together. Different possibilities have been explored. For the proposed solutions, the joint has been designed in such a way that it can be brazed easily. For this, at least 10 millimeters of overlap between the two parts is needed.

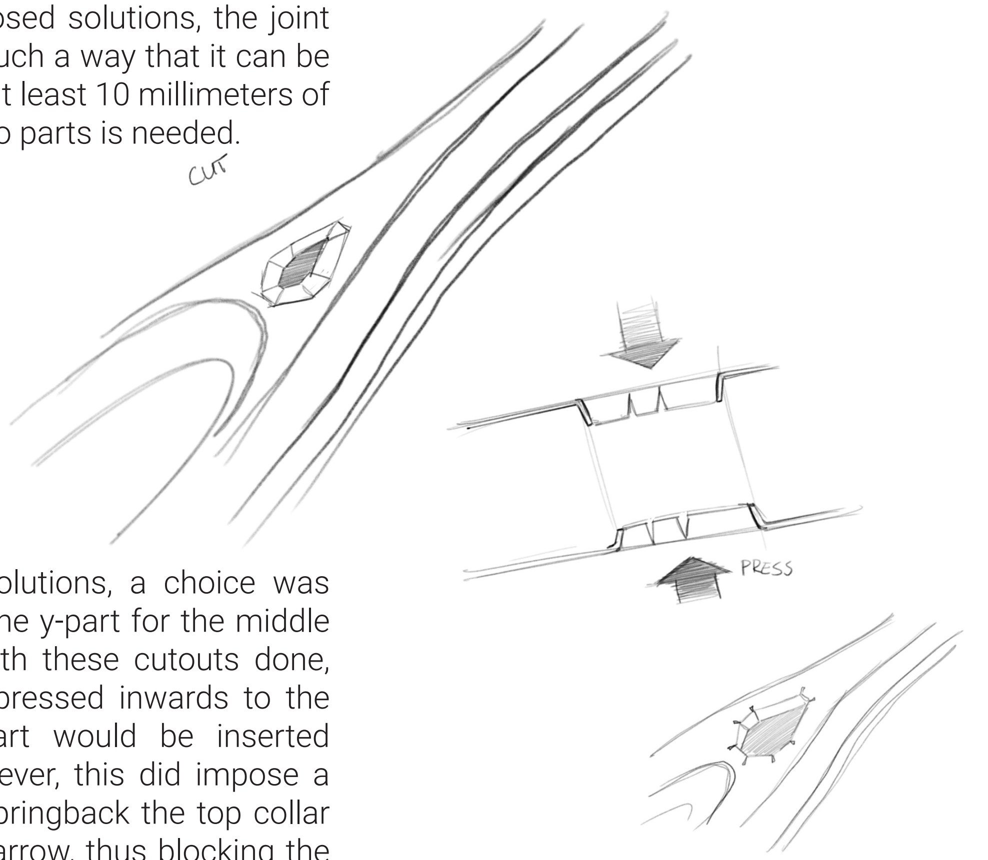



Image 31: Extra pressing step

After initial possible solutions, a choice was made to cut a hole in the y-part for the middle part to go through. With these cutouts done, the falnges would be pressed inwards to the y-part. The middle part would be inserted from the bottom. However, this did impose a problem. Because of springback the top collar would become more narrow, thus blocking the middle part from going through. Moreover, the transition between the two parts would not be aesthetically pleasing.

To improve upon this, a new solution for the joint between the two parts is designed. This solution consists of a self seeking form when inserted from below the y-part. There are two collars, which are pressed in the two y-part shells. These collars give a good surface for brazing of the two parts.

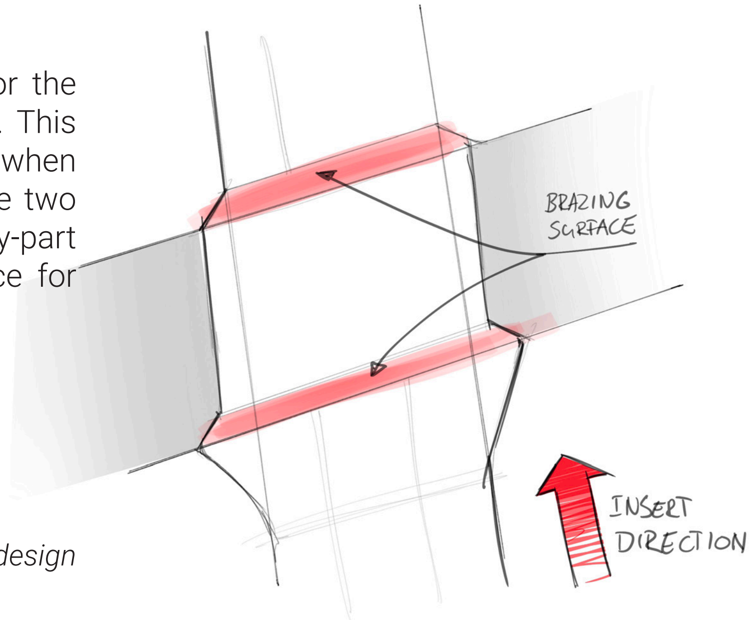



Image 32: Double collared design

# THE FINAL DESIGN

## The Mokumono Dune

The e-bike has been named in the same line as the other Mokumono products. Mokumono always uses typical dutch names for their bicycles, the Mokumono Dam and the Mokumono Delta. The Delta refers to the dutch landscape, the river delta. The dutch river delta is the region in which the three main rivers congregate into a delta that leads to the North Sea. The dutch river delta is characterized by mainly flat lands. The dam is named after the Dam in Amsterdam, as well as the dutch dams, being protection from the water.

The e-bike has been named the Mokumono Dune, The dutch dune landscape had a lot more elevation than the river delta, which corresponds to the extra power an e-bike gives the user. It also fits in with the rest of the Mokumono product names, and starts with the letter D as well, to maintain unity between the different Mokumono products.

*Image 33: Mokumono Dune*

## Shell connection

As mentioned before, the frame consists of four main shells, these are brazed together as can be seen in the exploded view on page 68. All these shells have a release angle of 2 degrees, which is deemed to be sufficient by Rene Bukkems of Phoenix 3D metaal (personal communication, November 26, 2019).

Because all the parts have this release angle, the connection between the shells has a gap of 4 degrees, as can be seen in image 34 and 35. This angle allows the brazing filler metal to flow between the shells by capillary effect, ensuring a good bond between the shells.

The shells are designed in such a way, that in the assembly and the brazing process, there is only one way they can fit together. This makes the bonding process easier and more appropriate for automatisation.

The edges are relatively sharp, but still contain a radius of approximately 6mm., this is needed to ensure good manufacturability. These edges are sharper than the current Mokumono Delta, because the frame shells are not as deep in the pressing mold as the current shells of the Mokumono Delta.

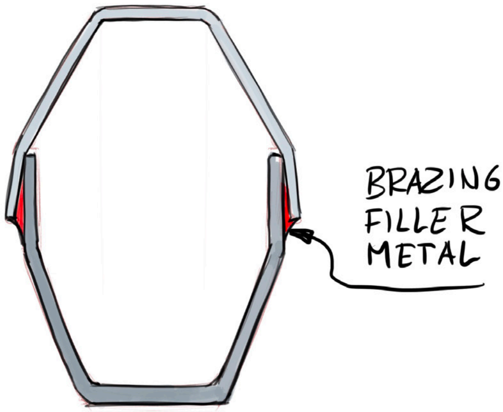



*Image 34: Brazing connection Y-shape*

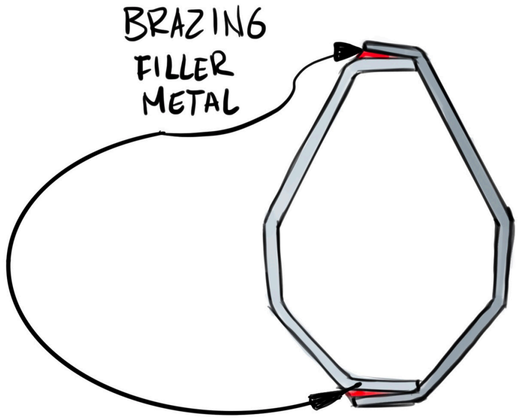



*Image 35: Brazing connection middle part*

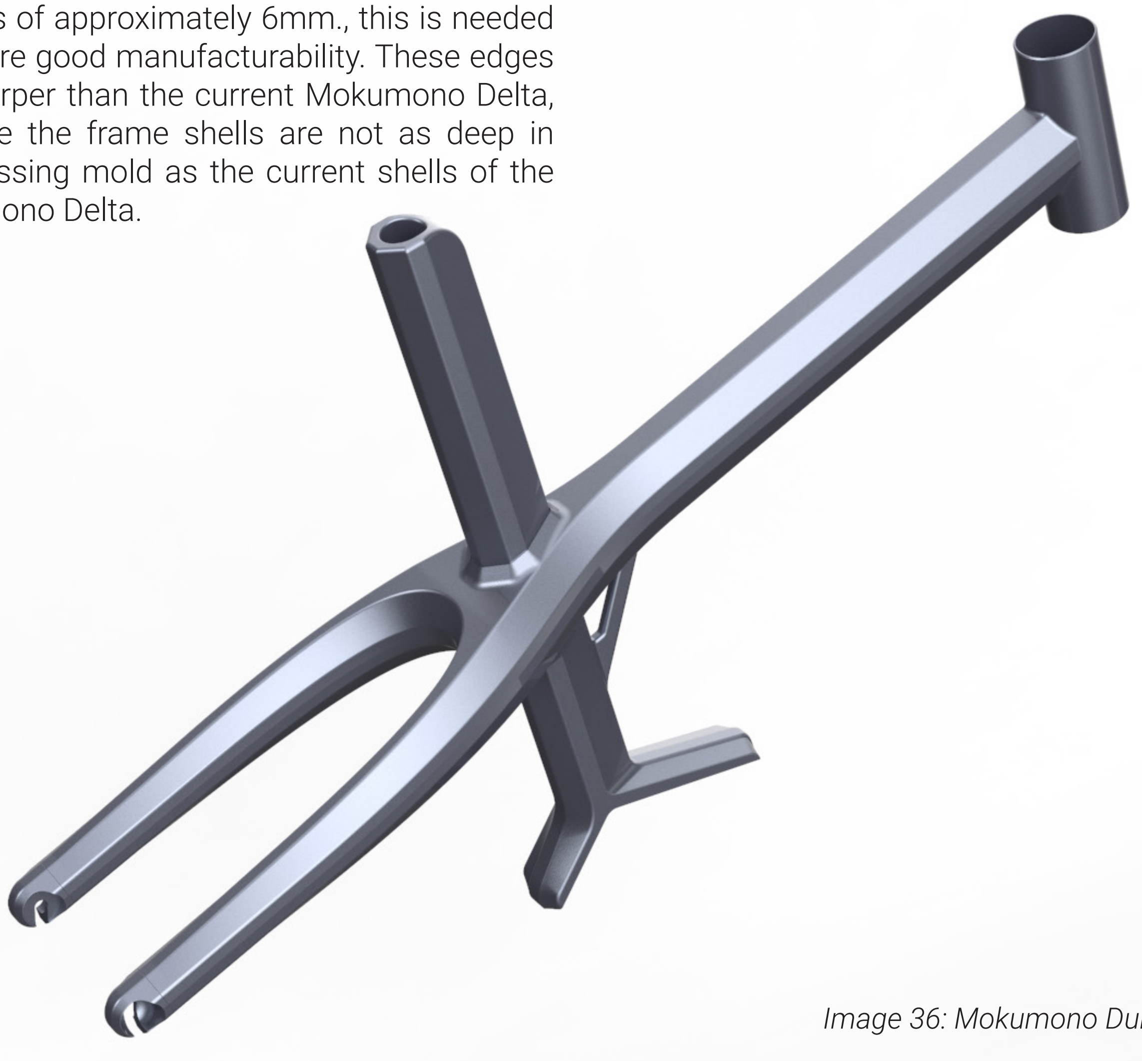


*Image 36: Mokumono Dune frame*

# Exploded view

## Total frame

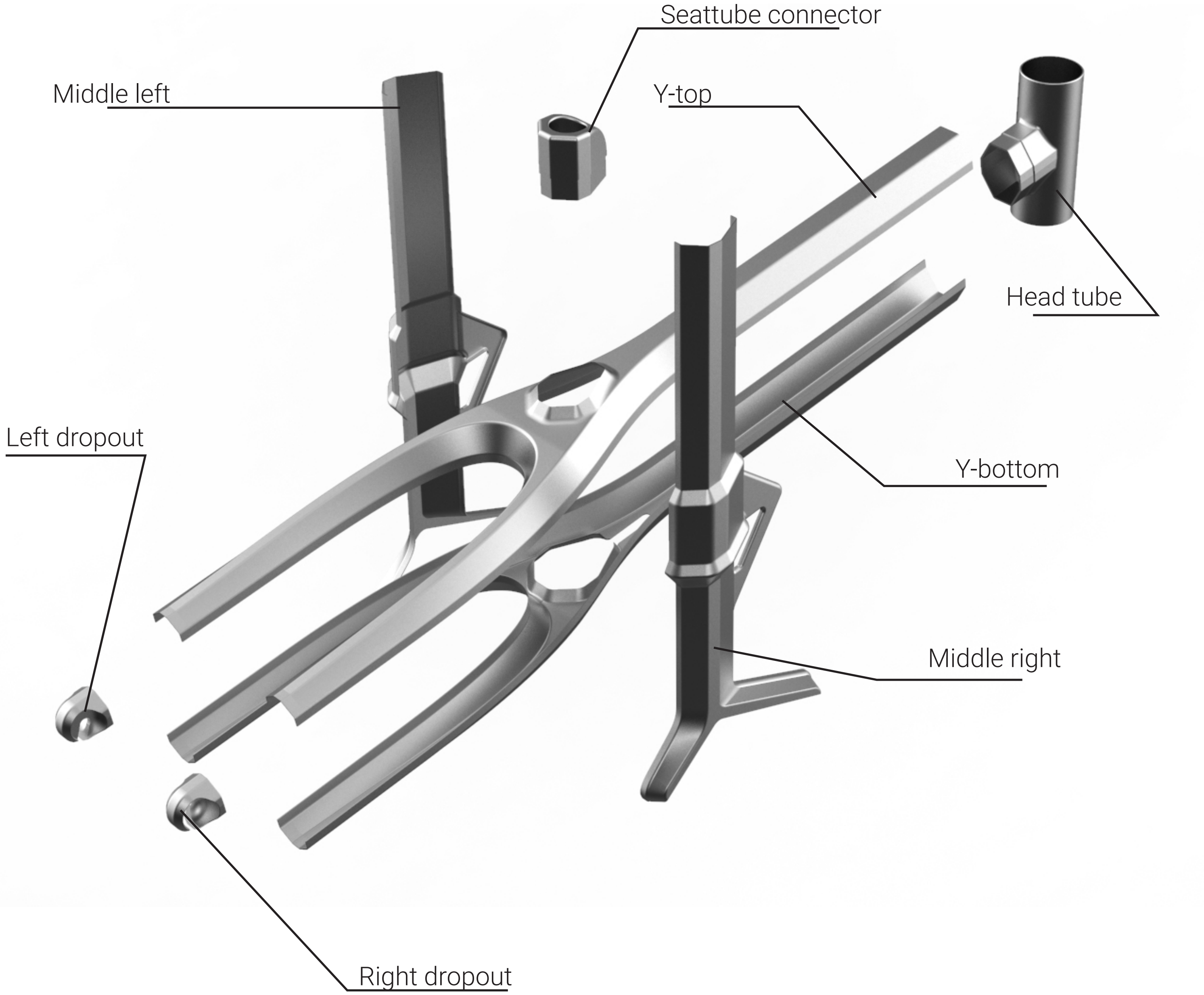



*Image 37: Total exploded view*

## Y-shape

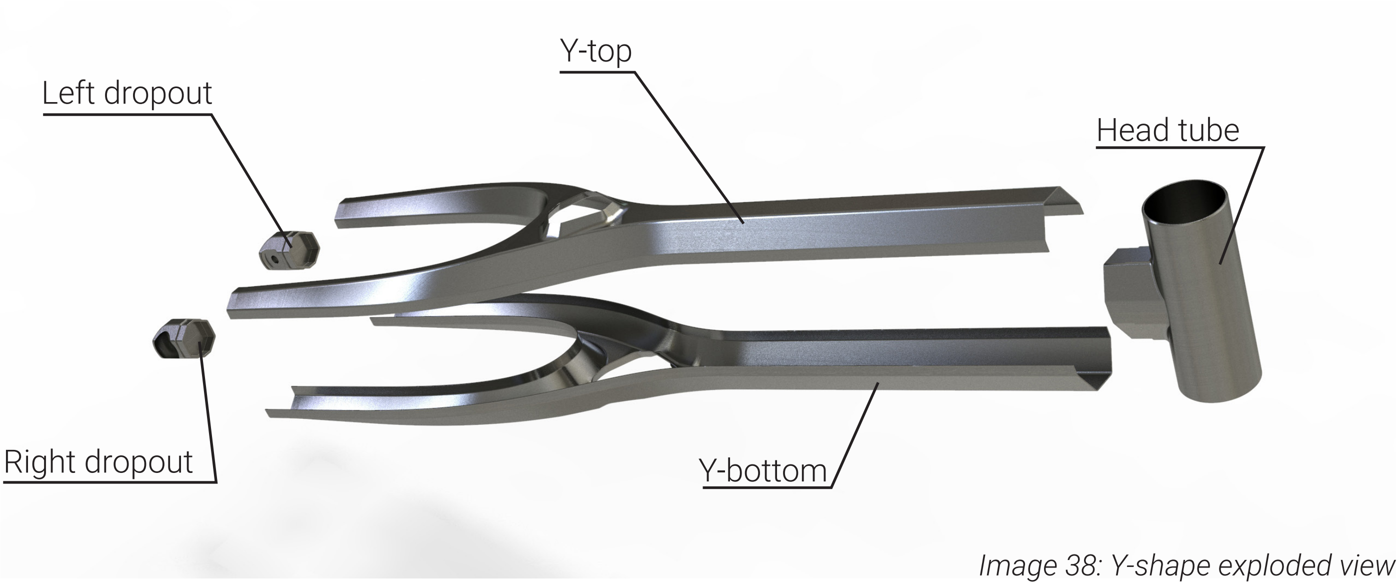



*Image 38: Y-shape exploded view*

The Y-shape, which can be seen in image 38, connects the headtube and the rear wheel. This is the most difficult part for pressing, because of the length of the part. The two shells will first be brazed together before joining the middle part to the frame.

These shells will most probably be pressed in one mold, as can be seen in 39. This is because the standard mold dimensionsare usually wider than the width of this product, so the overall production can be executed faster.

*Image 39: Single mold nesting*

## Middle part

The middle part, as shown in image 40, connects the motor, the saddle and the battery to the frame. This part is inserted into the y-shape from below. Because this part is continuous throughout the frame, it acts in the same way as the seat tube does in the Mokumono Delta, giving strength to the overall frame.

The two shells will be brazed together before insertion into the y-shape, to ensure an easy assembly.

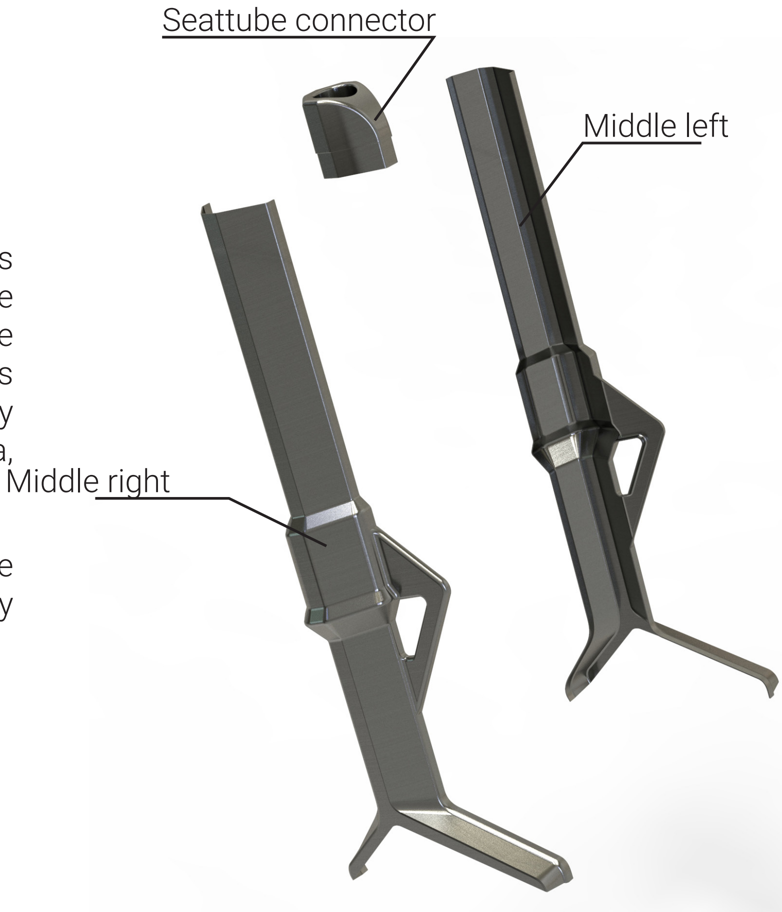
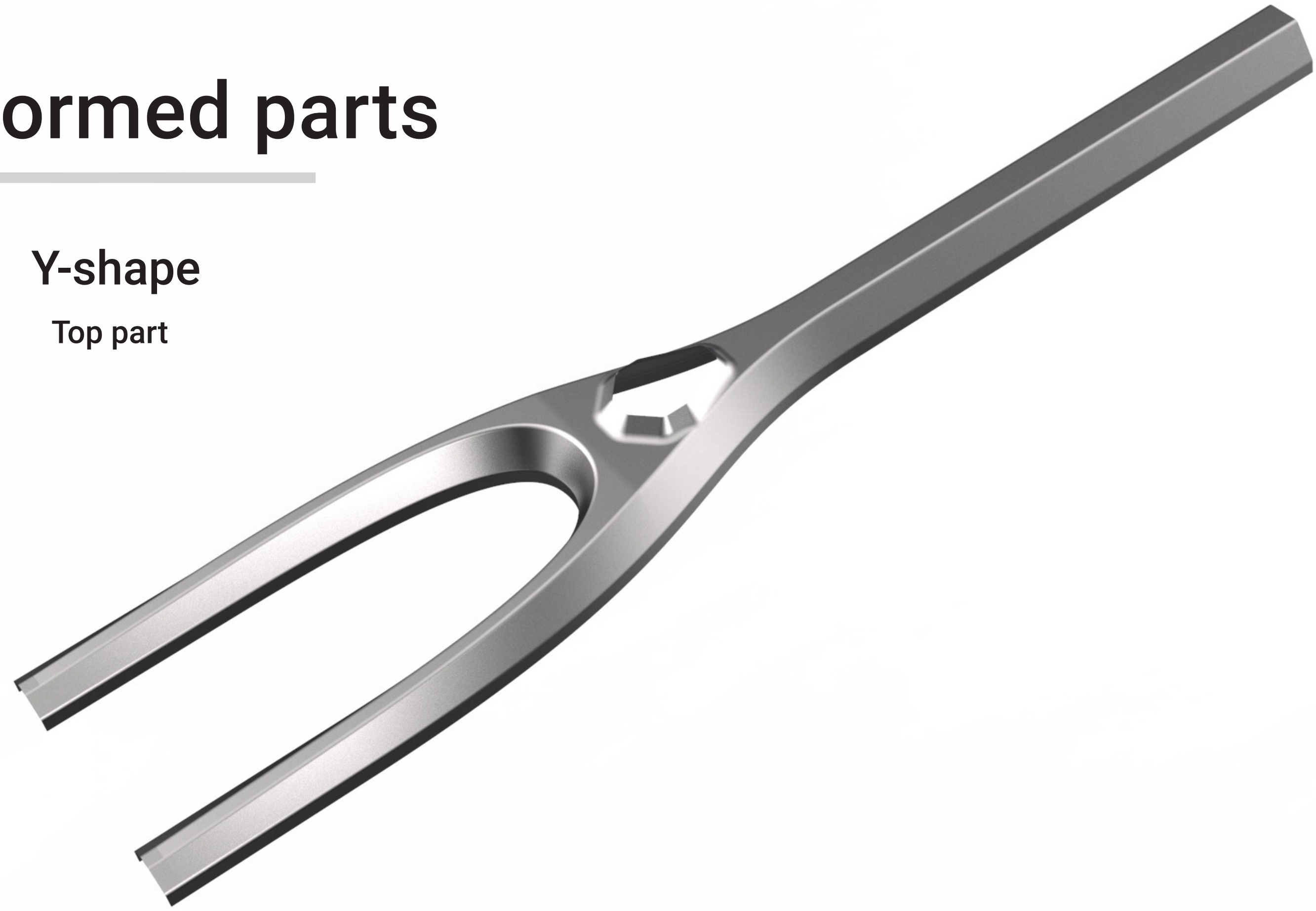



*Image 40: Middle part exploded view*

# Formed parts

## Y-shape

### Top part



### Bottom part

## Middle part

The middle part has an eye pressed into the shells, as can be seen in image 41. This eye makes it so the bicycle can be locked with a chain. because the open nature of the frame, the bicycle could not be locked otherwise. This eye also makes sure that the battery is locked to the bicycle as well, making it impossible to easily steal the battery pack, which is an emerging problem with e-bikes in general.

Underneath the middle part, an extra shell is brazed in the foot. This is the adapter plate for the electric motor. This is the part that later can be changed to support different e-bike motors as well. The plate is formed as can be seen in image 42, and is placed inside of the foot of the middle part. It is brazed in place and then the motor will be attached by three bolts. Sfter this, the covers of the Shimano motor will be attached by small screws, these covers fit the foot fo the frame perfectly.

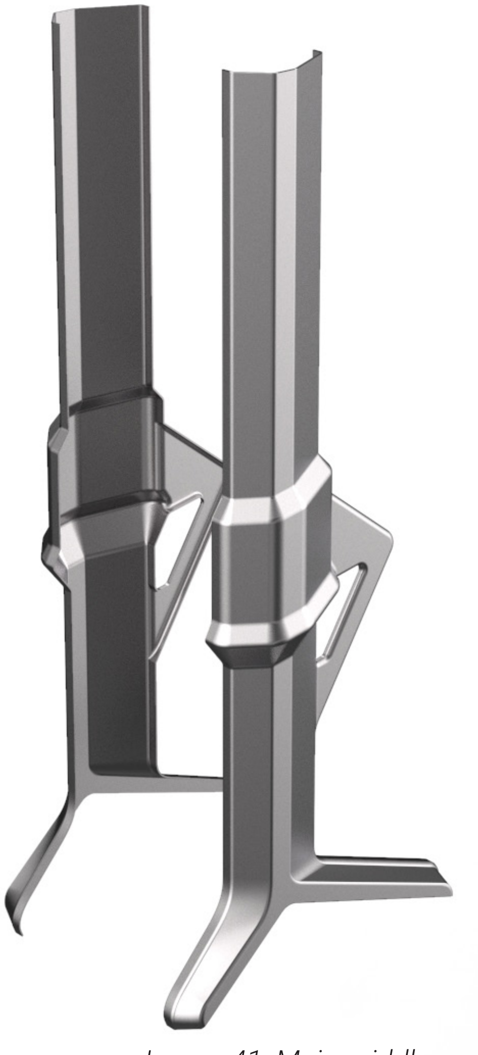


*Image 41: Main middle part shells*

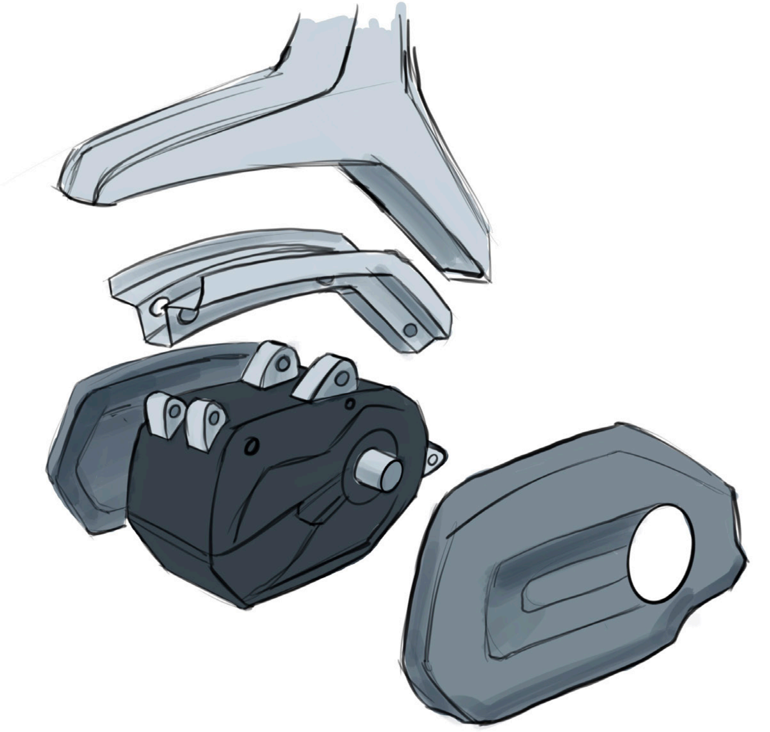


*Image 42: Motor connection through extra adapter plate*

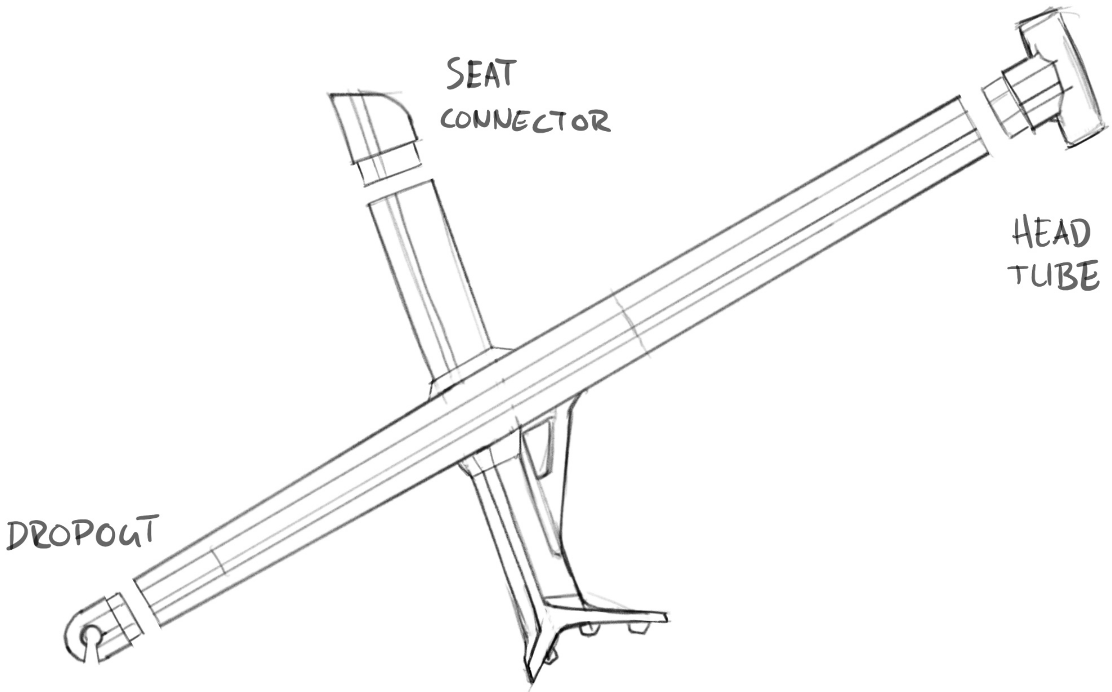



*Image 43: Side view casted parts*

# Casted parts

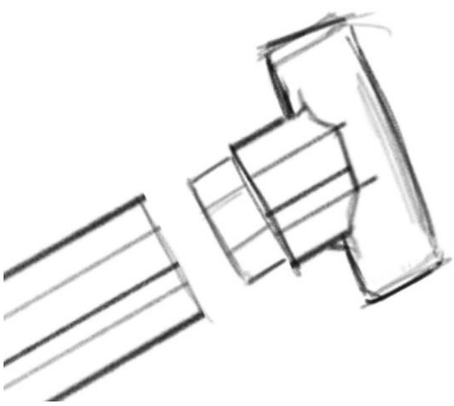
To make these formed steel parts into a frame, a couple of additional parts need to be added. These parts will ideally be casted, but they could be machined as well.

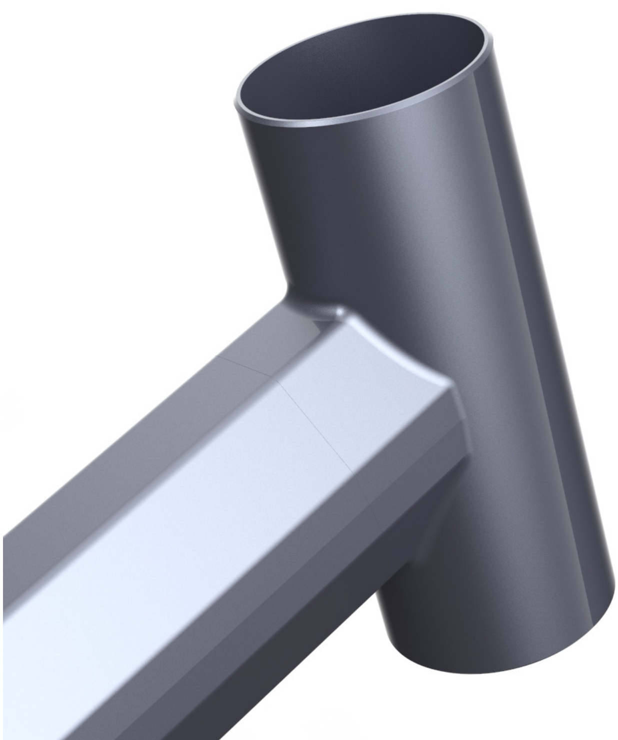
There are four additional parts that need to be casted for this frame to be a fully functional e-bike frame. These parts are the head tube, seattube connector and the left and right dropout.

## Headtube

A headtube will be casted as well. The headset and the front fork will be inserted into this part. Ideally, an integrated headset will be used inside of the headtube, which routes the wires needed for breaking through the handlebars and headset, so no wires are visible on the outside.

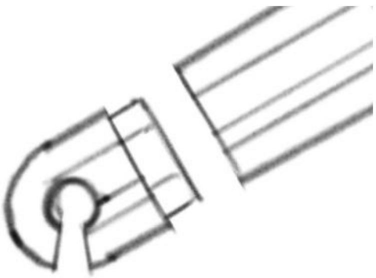
*Image 44: Headtube connector*





## Left and right dropout

The dropouts are modelled to fit the Shimano Nexus Inter 5e rear hub. These parts will be inserted into the assembled y-shaped part. They are designed similar to the current Mokumono dropouts, however these dropouts follow the profile of the rear fork, so that after brazing, the transition looks smooth.



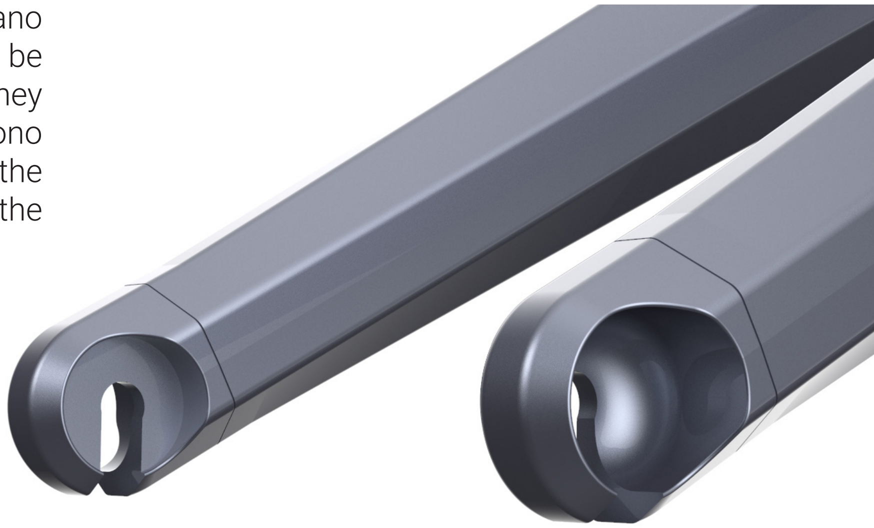
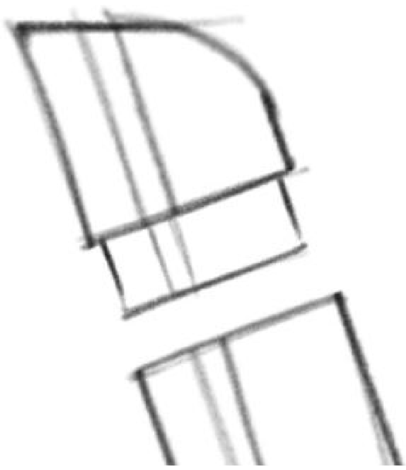
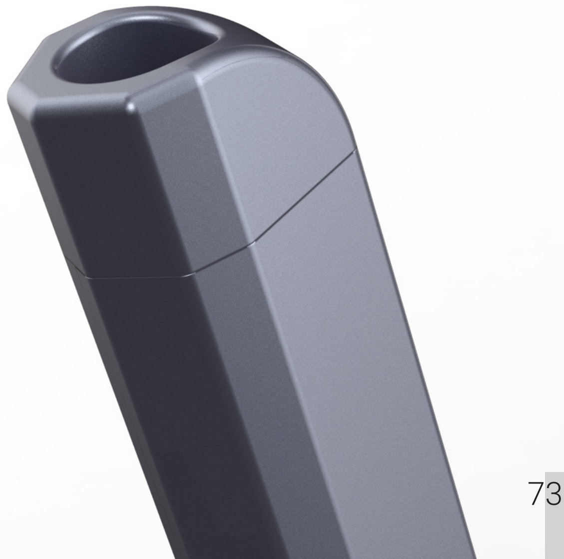


*Image 45: Dropout design*

## Seattube connector

This part holds the seat post. There is a hole in this part that runs inside of the formed middle part. This ensures the seat post to have a sturdy connection to the frame without wobble.





# Additional components

The components to be used in the bicycle are selected. These components are selected together with Bob and Tom of Mokumono. These are mainly the products that are used on the curent Mokumono Delta, which are selected to fit the quality that Mokumono seeks in their products.

**The motor**

The chosen motor for this e-bike is the Shimano Steps E6100. This choice is made because using a Shimano motor ensures it compatability with different Shimano products. The E6100 is an excellent e-bike motor. This motor is also highly compatible to use with Shimano Crank sets.


*Image 47: Shimano Steps E6100*

**Rear hub**

For the rear hub, the Shimano Nexus Inter 5E will be used. This rear hub contains automatic integrated gearing, which will make for an even more relaxed cycling experience. This rear hub system is also widely compatible with Shimano disk brakes and drive belts. With this system, no rear derailleur is needed.


*Image 48: Shimano Inter 5E*

**Drivetrain**

For the drivetrain, a drive belt is used. Because Mokumono wants decent products on their e-bike, a drive belt is preferred over a regular chain. Drive belts are maintenance free, requires no lubricant, are more quiet and have a lower installation cost than regular chains.

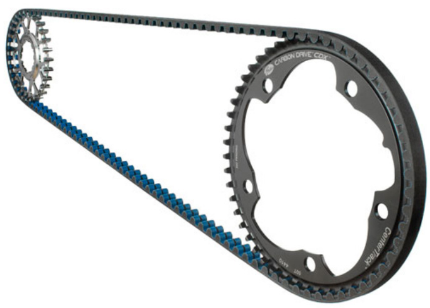


*Image 49: Gates carbon drivetrain*

### Disk brakes

For the braking of the e-bike, Shimano Disk brakes are used. These disk brakes will be attached to the front fork and the rear fork. Disk brakes provide with extra braking power, are reliable in wet weather and reduce the wear on wheels when compared to regular braking blocks. Also wider tires can be used, which further increases grip and riding comfort.

*Image 50: Shimano disk brakes*

### Fenders

Since the design of the frame is quite open, fenders are needed to defend the user from mud and water. The fenders used are the Pletscher R50 fenders. These can be ordered in the specific size needed.

*Image 51: Pletscher R50 fenders*

### Luggage carrier

The fenders provide an option to attach a bag carrier. It is preferred to provide this option, since the Mokumono e-bike is aimed at commuters, who often carry a bag with them. The Pletscher carrier is an elegant solution to luggage over a regular luggage carrier.

*Image 52: Pletscher carrier*

### Seat post

As a seat post, the Lightskin LED seatpost will be used. This seatpost has an integrated LED light in the back. This seatpost can be internally connected to the power of the battery and fits all regular saddles.

*Image 53: Lightskin seatpost*

### Saddle

To fit the style of the Mokumono Delta, the same saddle is used for this e-bike, which is the Brooks All Weather C15 saddle. The saddle is comfortable, looks sleek and is made for years of riding.


*Image 54: Brooks All Weather C15 saddle*

### Steer fork

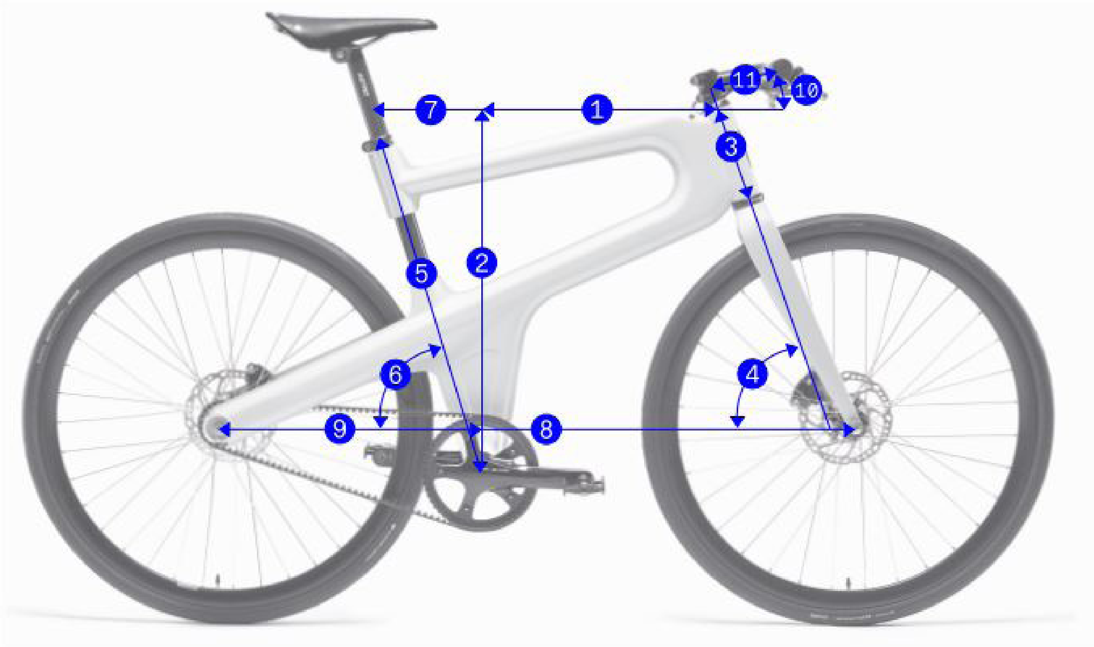
As a steering fork, the default Mokumono Delta steering fork is used, which features an aluminium crown and carbon blades.

# Frame sizes

Ergonomics is very important for any bicycle on the market. This ultimately leads to many different frame sizes in the industry. Mokumono handles a three sizes model for their current bicycle. These measurements will be used in the design of the e-bike frame as well. A great aspect of their current sizing system is that is can be done without having to use different mould sets for the production phase of the frame. The frame halves are produced, and after this, the two halves are trimmed to the correct size at the attachment point of the head tube. By varying the distance at which the frame is welded to the head tube, the other measurements of the bicycle will change as well.

Because of the casted parts, there can be different versions of these parts for the different frame sizes. The seat tube and the head tube will differ with varying frame sizes.

The exact measurements might differ a bit from these values given by Mokumono since with the design of an e-bike, some other factors come into play. However, these measurements will be the foundation for small adjustments along the way.




| | SMALL | MEDIUM | LARGE |
|---|---|---|---|
| 1.REACH | 384 | 384 | 394 |
| 2.STACK | 591 | 591 | 619 |
| 3.HEAD TUBE LENGTH | 154 | 154 | 182 |
| 4.HEAD TUBE ANGLE | 71.2 | 71.2 | 72.5 |
| 5.SEAT TUBE LENGTH | 566 | 566 | 596 |
| 6.SEAT TUBE ANGLE | 72.5 | 72.5 | 72.5 |
| 7.TOP TUBE LENGTH | 568 | 568 | 589 |
| 8.WHEELBASE | 1038 | 1038 | 1048 |
| 9.CHAINSTAY LENGTH | 435 | 435 | 435 |
| 10.STEM ANGLE | -17 | -7 | -7 |
| 11.STEM LENGTH | 80 | 110 | 130 |

*Image 55: Mokumono size chart (Schiller, 2014)*

# PART 4: EVALUATION

# PRODUCTION

## Pressing simulation

To evaluate the created design in terms of producibility, a company specialised in 3D sheet metal forming was contacted. Together with Rene Bukkems of the company Phoenix 3D Metaal the design has been discussed. Pressing simulations were executed.

Because these simulations take time and therefore simulating all parts was not feasible, the most difficult part to press has been selected. According to Rene Bukkems, the top shell of the y-shape would be most difficult to press, because of the size of the part, the depth of the part and the overall geometry.

For this simulation to work, the pressed blank needs to be designed. To ensure that eventual wrinkles fall outside of the product, 15 mm. extra material is added, as can be seen in image 56. These areas will later be trimmed off the product, as can be seen in image 56 and 57.

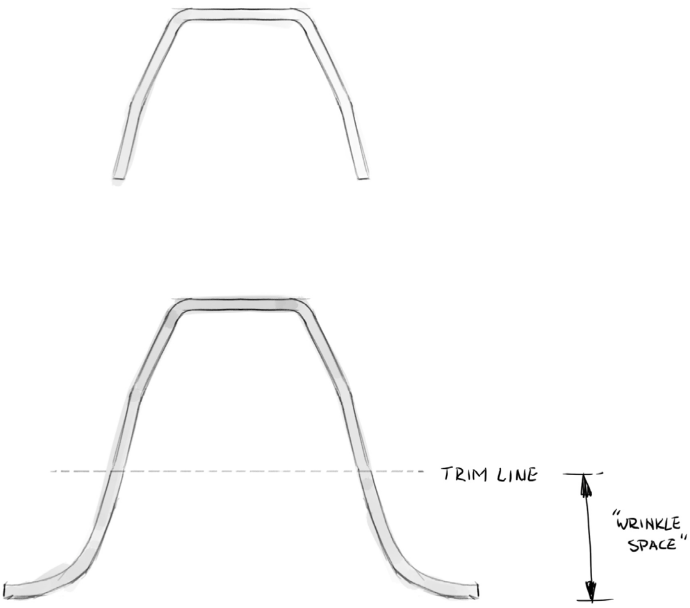



*Image 56: Trim line location and "Wrinkle space"*

*Image 57: Simulated and trimmed part*

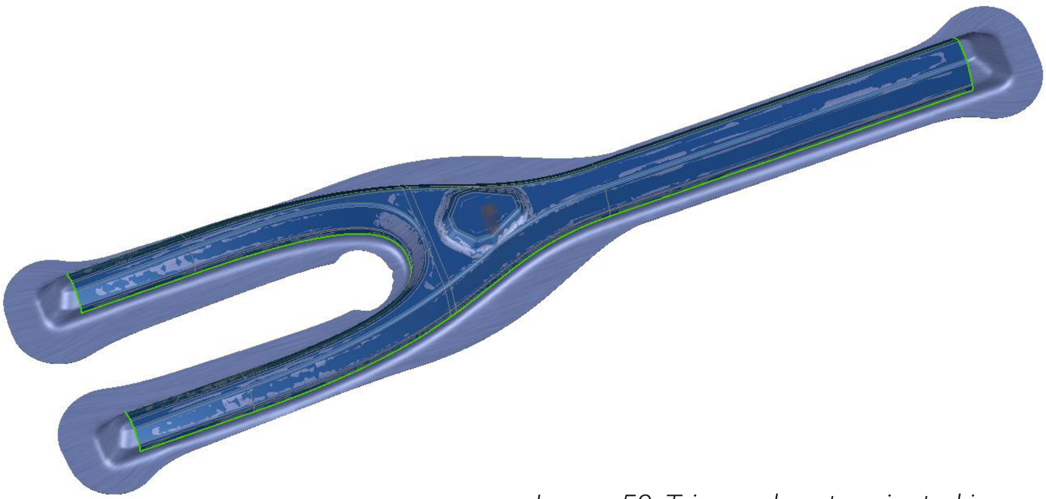


*Image 58: Trimmed part projected in pressed part*

As can be seen in image 58, the overall shape of the formed part has been adjusted further for the simulation. The ends of the parts have been extended further to improve formability.

In image 59 the overall formability is displayed. Red areas indicate problems, and green areas the ideal situation. In an ideal world, the whole product would be green in this image, as this represents the areas in which the material is in between elastic behaviour and tearing. Although this would be ideal, in real life (and in simulations) this never happens.

The red part in this image, located in the rear fork, is a part where the material will tear during pressing. This red area falls outside of the trim lines of the product. Although the tear will be trimmed from the part, it does influence the pressing of the rest of the part. The tear in the material leads to a situation in which the rest of the material can not be pulled as much as it could without the rupture.

There are several ways to eliminate the red area. This can be fixed by applying extra pressure to the blank in different locations, or by increasing the angle inside of the rear fork like in image 60.

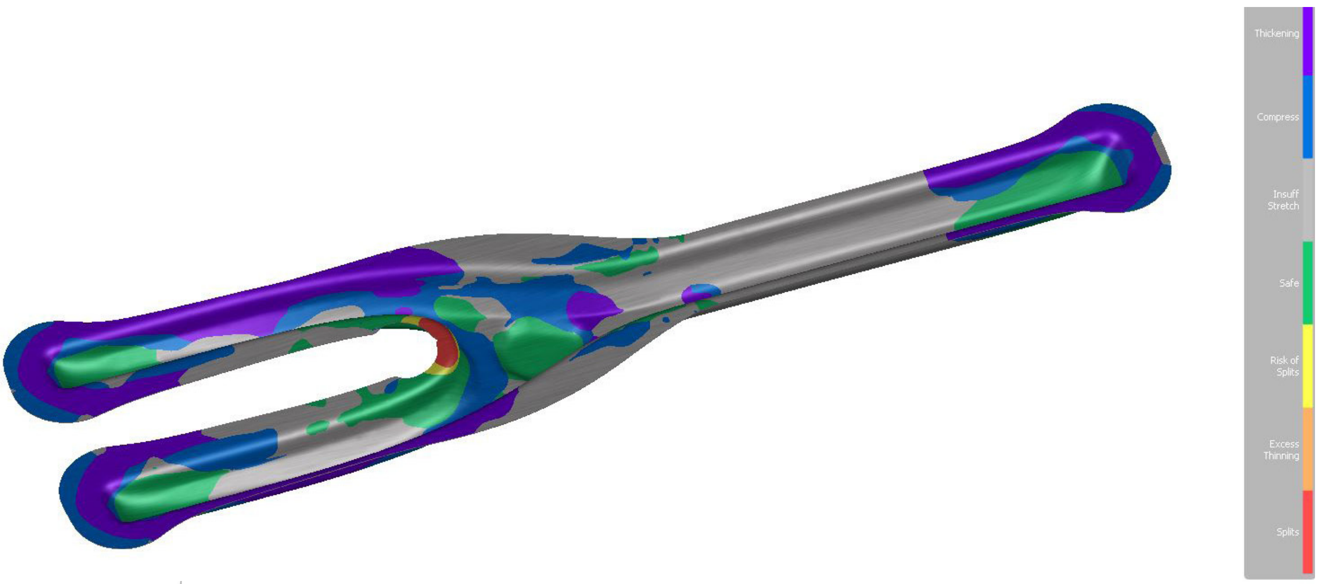



*Image 59: Overall formability*

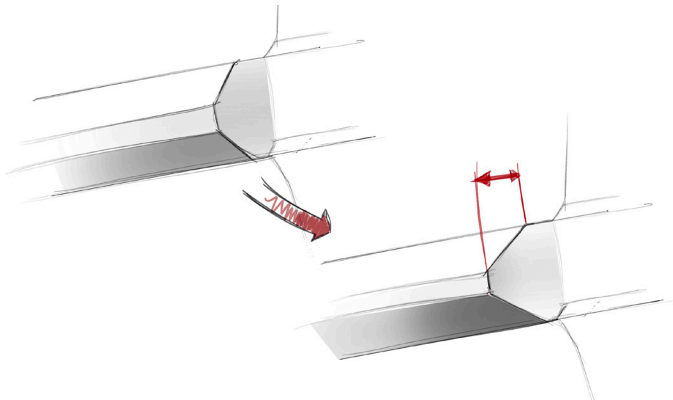


*Image 60: Rear fork design solution*

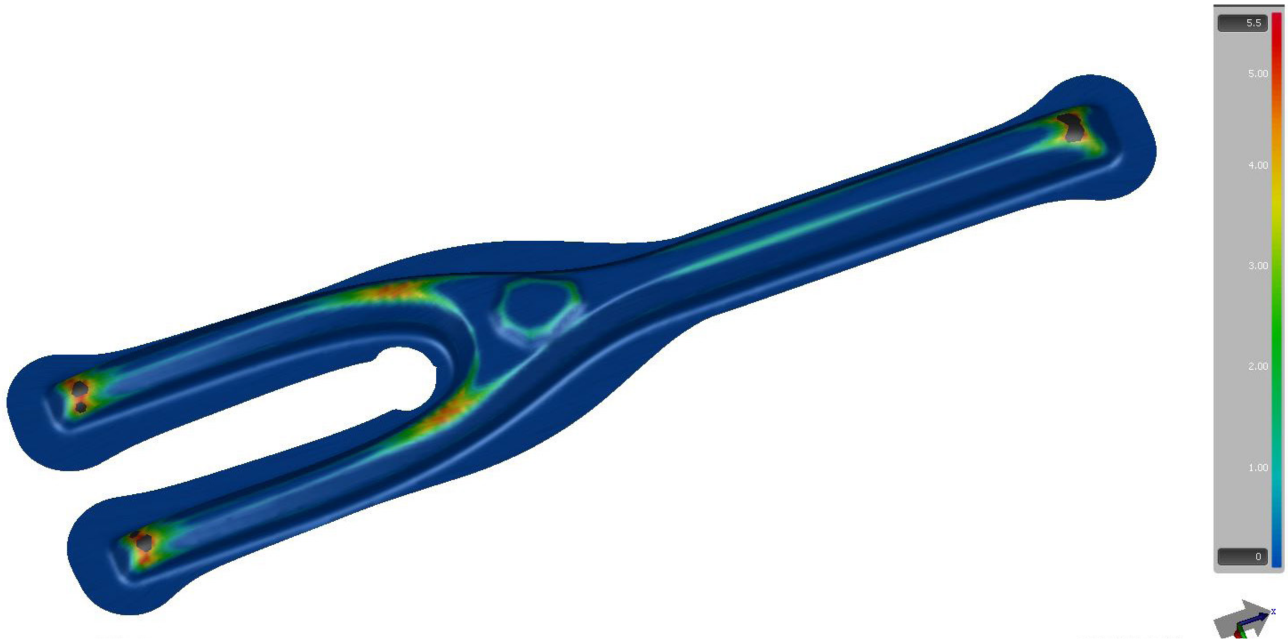



*Image 61: Contact distance after pressing*

In image 61 we can see the contact distance after the pressing is done. The red areas here indicate a distance of 1mm to the dye. For these areas, a larger radius is preferred. The red areas at the ends of the product can be neglected, as these fall outside of the trim lines.

Image 62 shows the springback. These values came out to be lower than initially expected. Because of the large shape, overall strength and the geometry of the shape, it was expected to have larger springback throughout the product. It has to be noted that this is the springback after the shell is trimmed and is measured in free form, so without gravity.

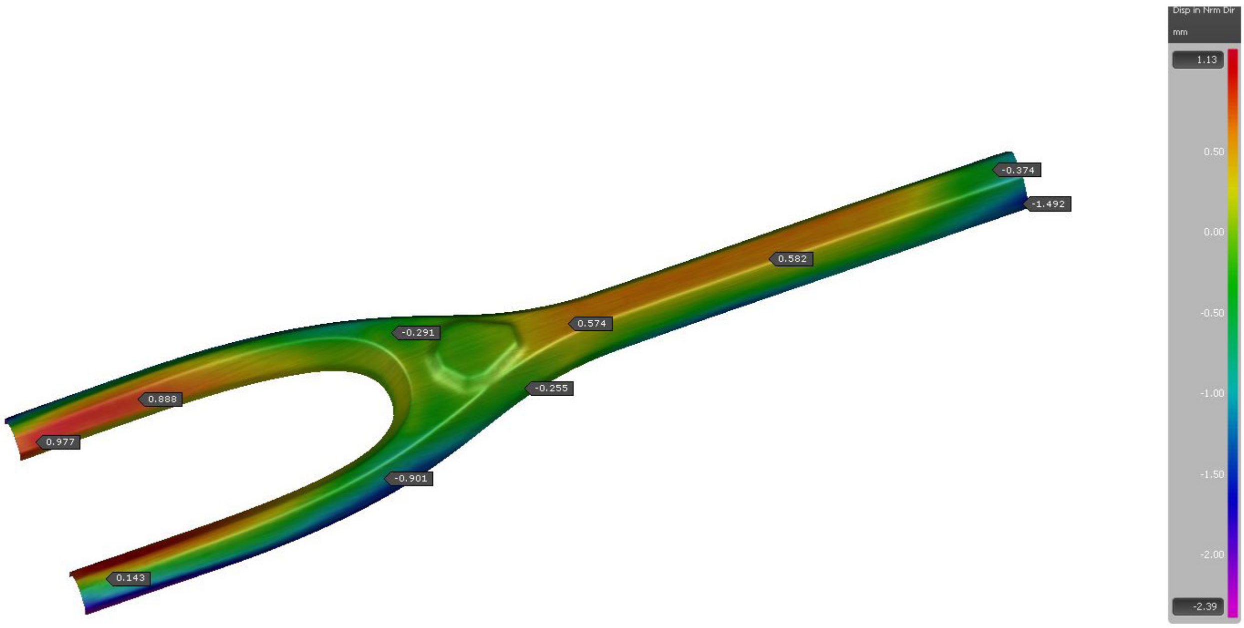



*Image 62: Springback*

In images 63 and 64, the thinning and thickening of the product after pressing can be seen. This indicates how much thinner the product becomes after pressing. It can be seen in these images that the thinning of the material is very minimal. The most impact within the trim lines of the product can be seen in the rear fork. Here the thinning is almost 0.1 millimeter. This can also be reduced by the redesign indicated in Image 60. The further large thinning takes place outside of the trim lines.

What is interesting to see is that we actually have some thickening of the material as well, However, this is located outside of the trim lines as well and is relatively small.

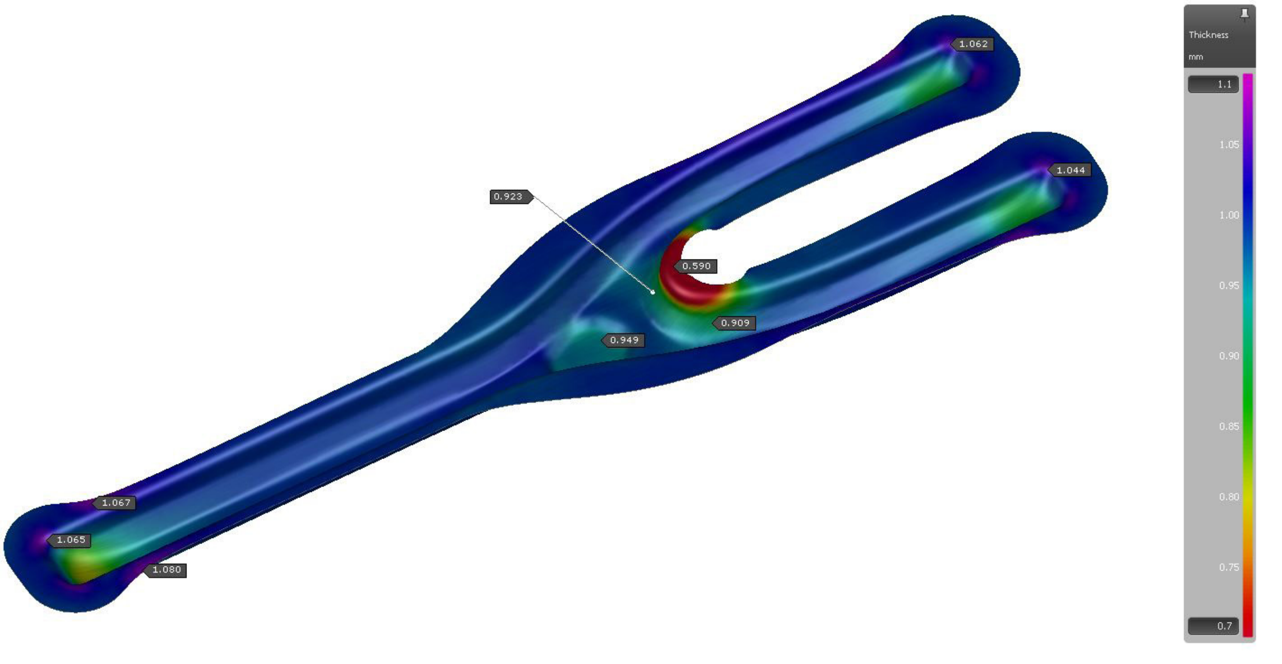



*Image 63: Thickening*

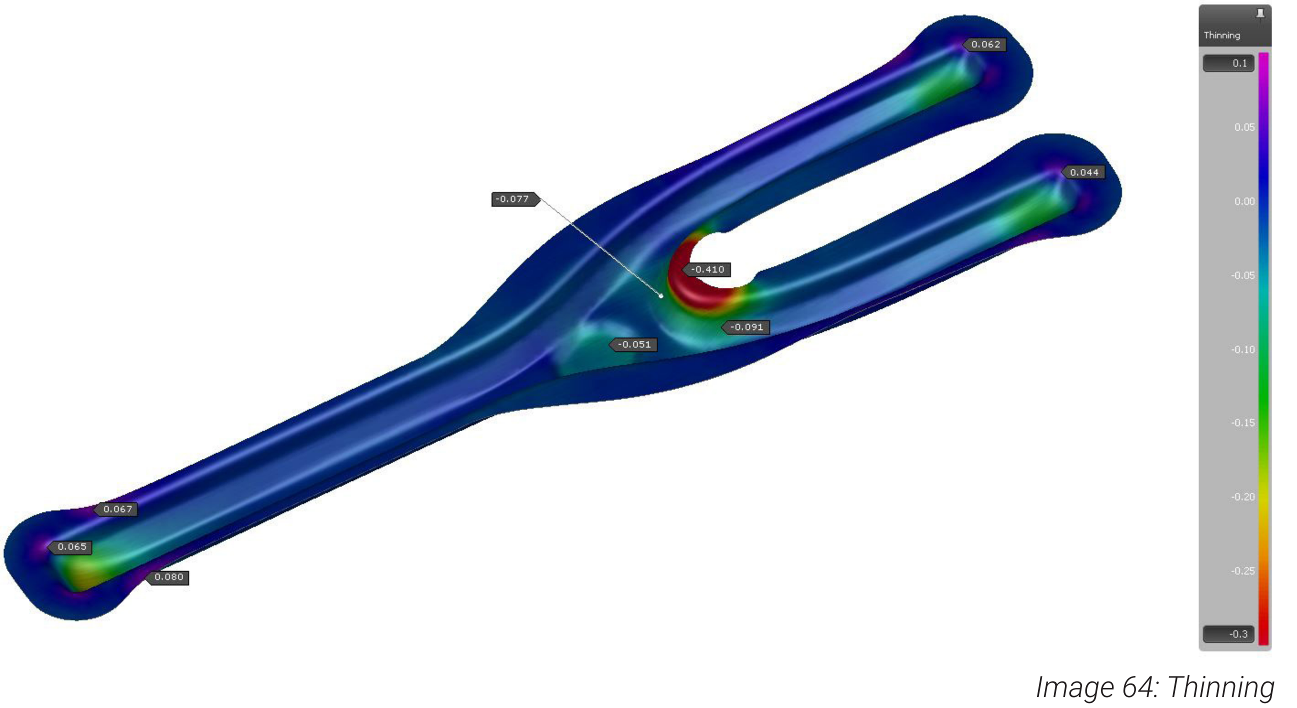



*Image 64: Thinning*

# STRENGTH AND STIFFNESS

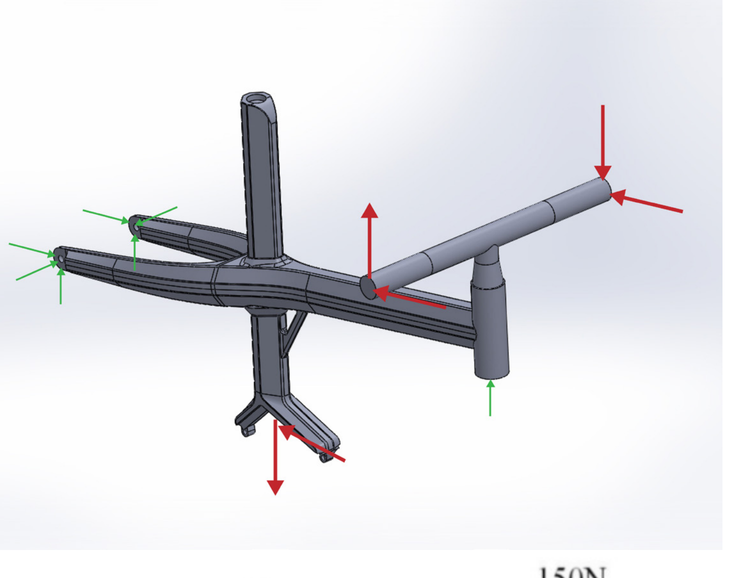
## FEM analysis

To ensure that the frame can withstand normal use in terms of strength and stiffness, FEM (finite element method) analysis is executed. There are two main test that are standard in the bicycle industry when it comes to testing the strength and stiffness of bicycle frames, the out of saddle test and the saddle tube strength test. These two FEM simulations are executed with different material types, until a sufficient material has been selected. For an ultimate scenario, the two simulation criteria have been combined. The results shown in image 66, 69 and 73 are those of the selected material, which will be elaborated on later.

### Out of saddle test

In the out of saddle test, a rider is simulated who is standing on the pedals and starts riding. In this situation, the rider is also pushing and pulling the handlebars. In this simulation, there is torsion on the headtube and force on the motor connection points.

As can be seen in the results, the overall stress is low enough to stay within the yield stress. When looking at the displacement, it is important to check if the clearance around the wheels and the belt drive is still sufficient. The maximum displacement of the frame is 1.5 millimeter, which lies well beneath the maximum possible displacement for these parts to still function.



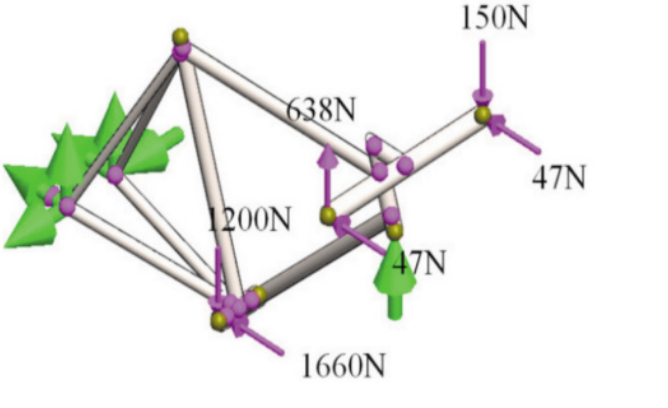



*Image 65: Out of saddle test input forces*

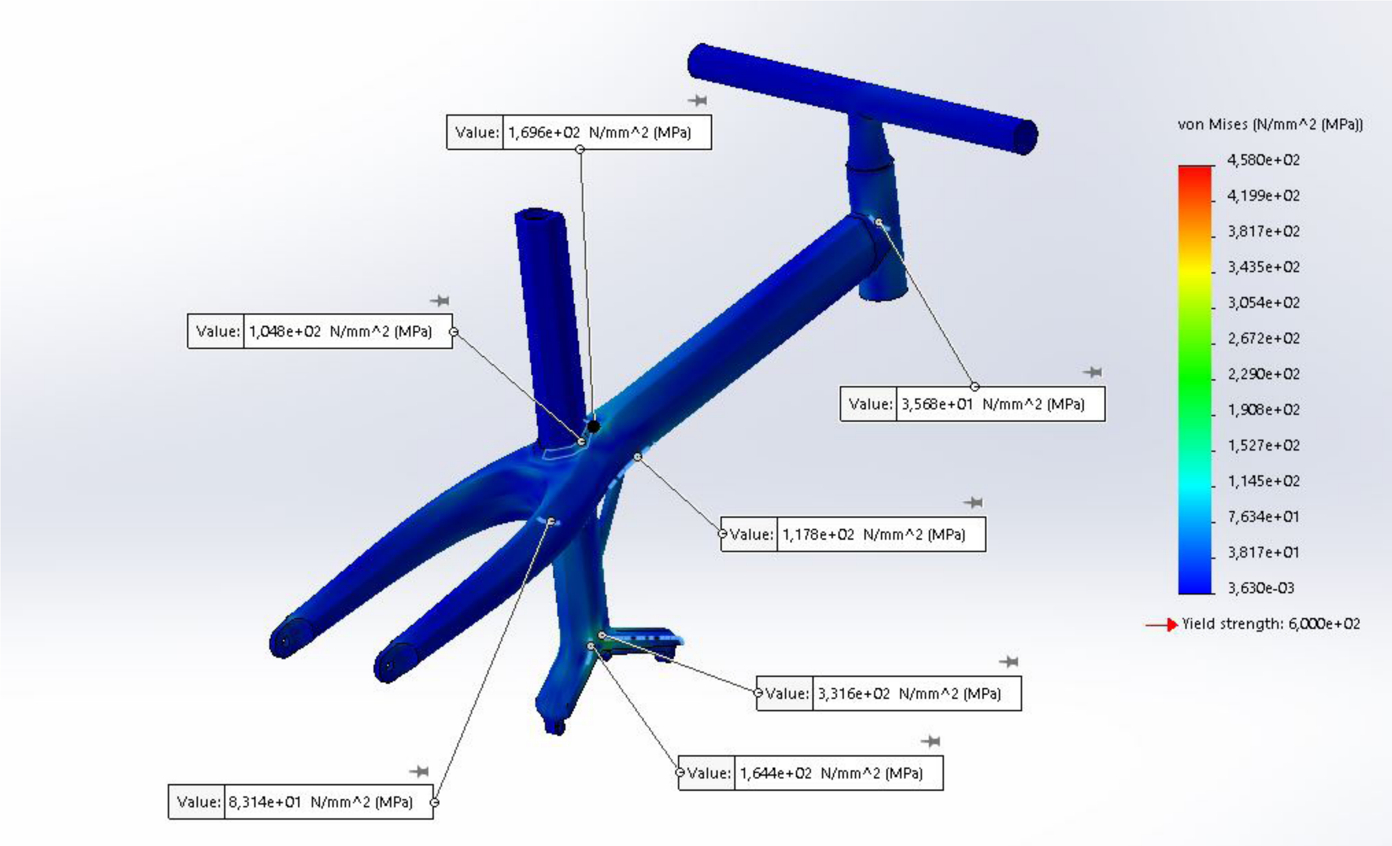



*Image 66: Out of saddle test stress*

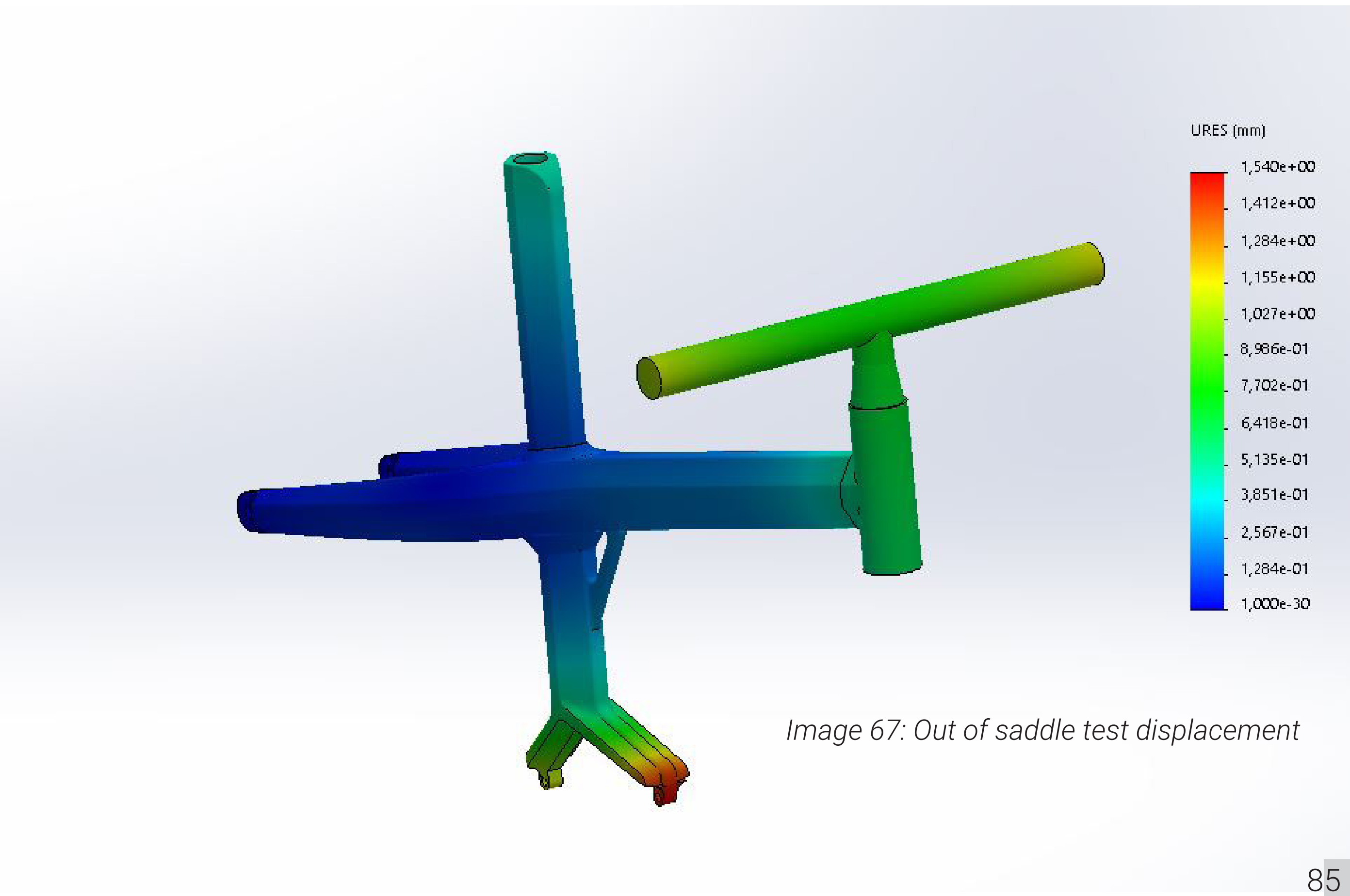



*Image 67: Out of saddle test displacement*

## Saddle tube strength test

For this test, the strength of the saddle tube is tested. To do this, a simulation is used that simulates a person of 120kg. going full speed over a bump in the road. In this action, the whole weight of the rider slams on the saddle. To simulate this, a force of 2400N is used, applied on the saddle tube, which roughly translates to 240kg.

In this scenario, the overall stress in the frame is still wel beneath the yield strength, as can be seen in image 69 and 70. The displacement is behaving as can be expected in this scenario. There is some displacement occuring, which is actually preferred over no displacement, because this dampens the impact on the user. This displacemt lies beneath 1mm. so no implications will follow from this.

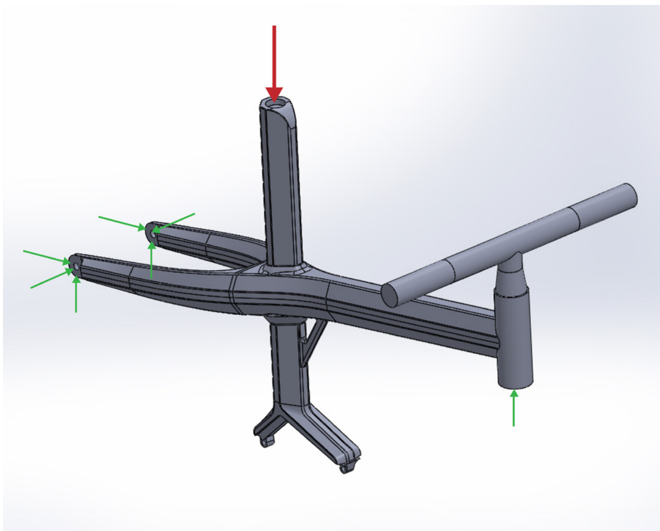


*Image 68: Saddle tube strength test input*

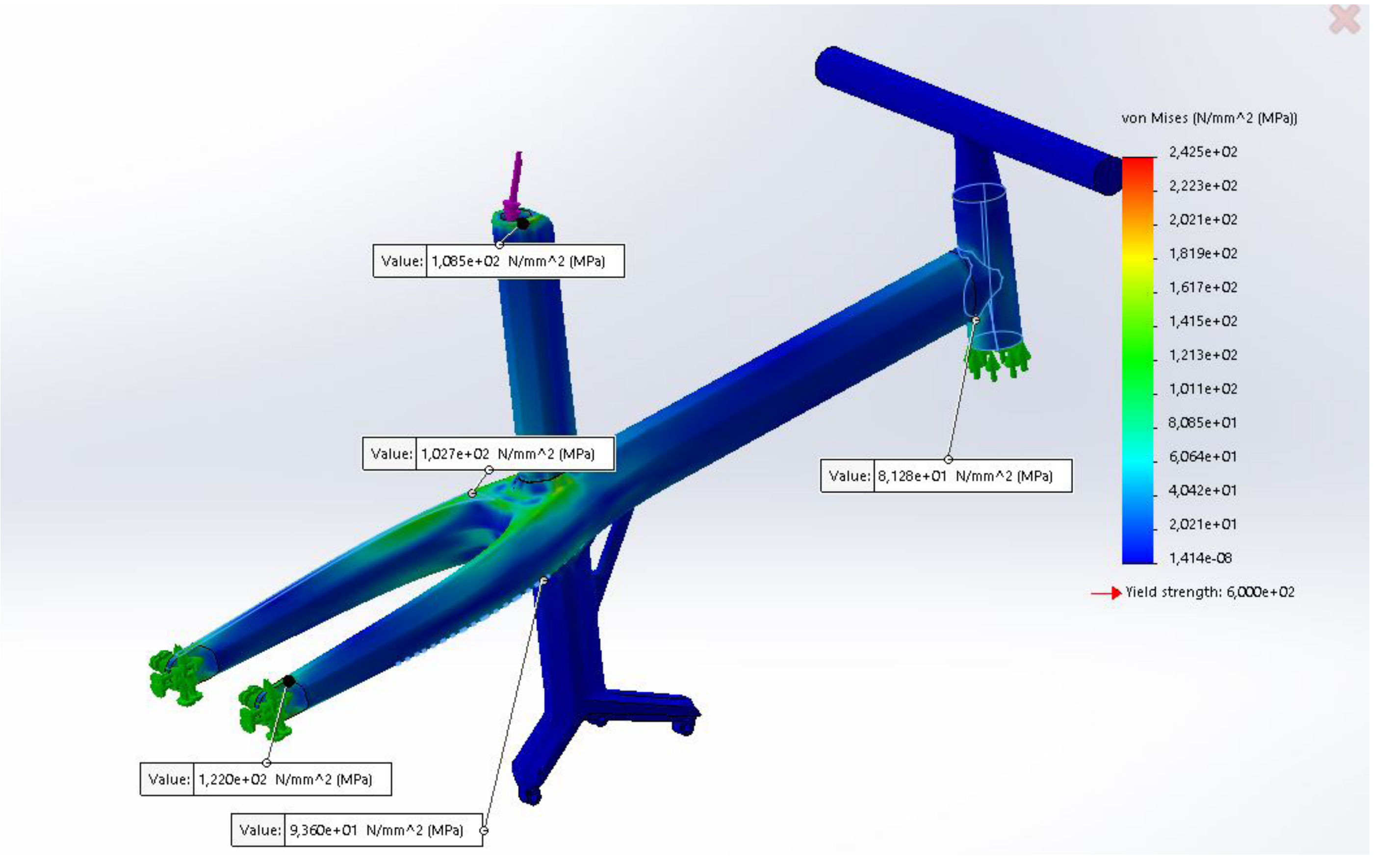



*Image 69: Saddle tube strength test stress*

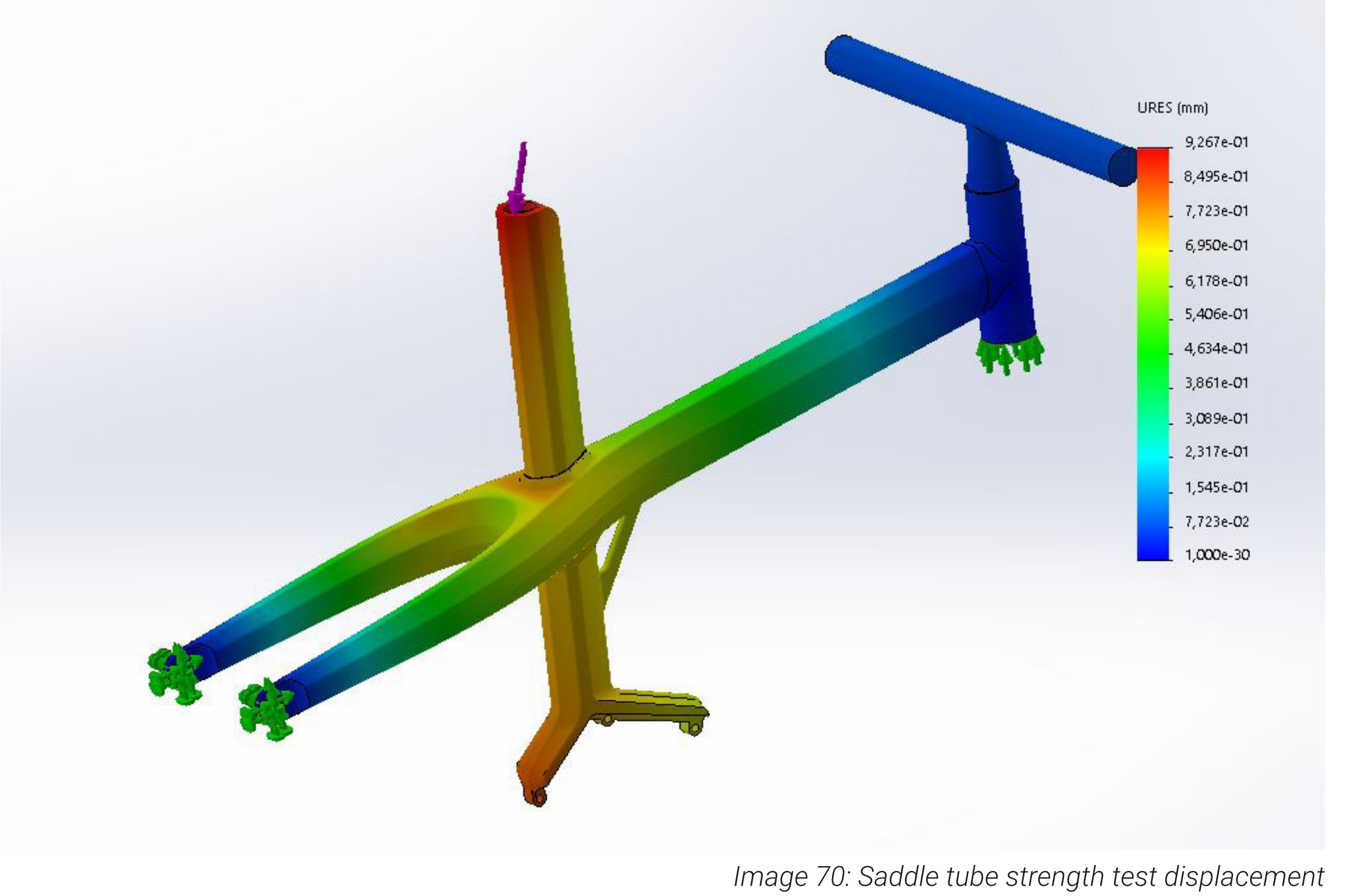



*Image 70: Saddle tube strength test displacement*

## Combined scenario test

To be absolutely certain the bicycle frame can withstand extreme use, the two scenarios described are combined into one. These forces will presumably never occur during real life use, however it does function as an extra safety factor. If the frame can withstand these forces applied, then the frame is believed to be strong and stiff enough.

As can be seen from image 73 and 74, the stress does not exceed the yield strength of the chosen material. The occuring displacement is larger than in the two previous simulations, which is to be expected because of the combined forces. The displacement is still well within the acceptable limits.

We see that there is a concentration of stress occurring in the foot of the frame in every simulation executed. After analysis of this problem, it is most likely that this has to do with some issues in the CAD file, since the curvature at said part of the frame is not constructed well (see image 72). This is the cause of the high stress at this specific point. It can be seen that in the other critical parts of the design the stess is significantly lower.

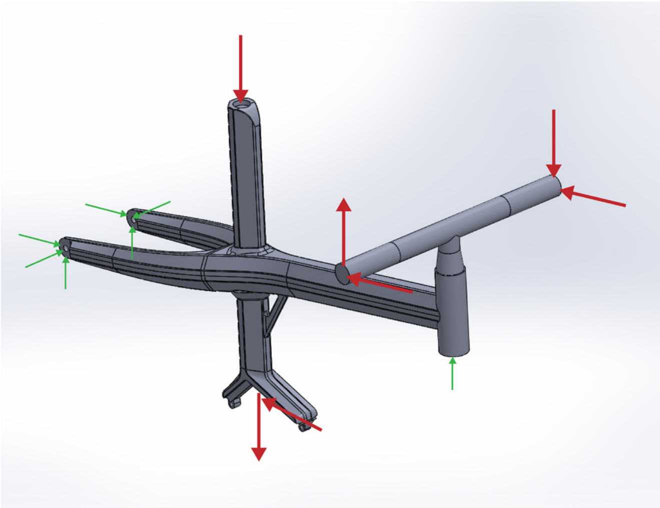


*Image 71: Combined scenario test input*

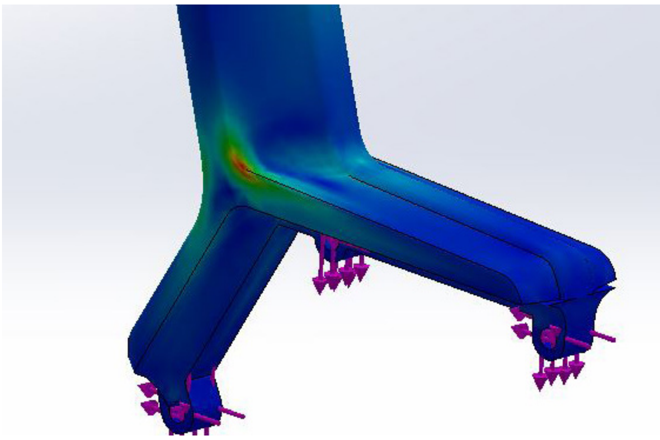


*Image 72: Stress concentration*

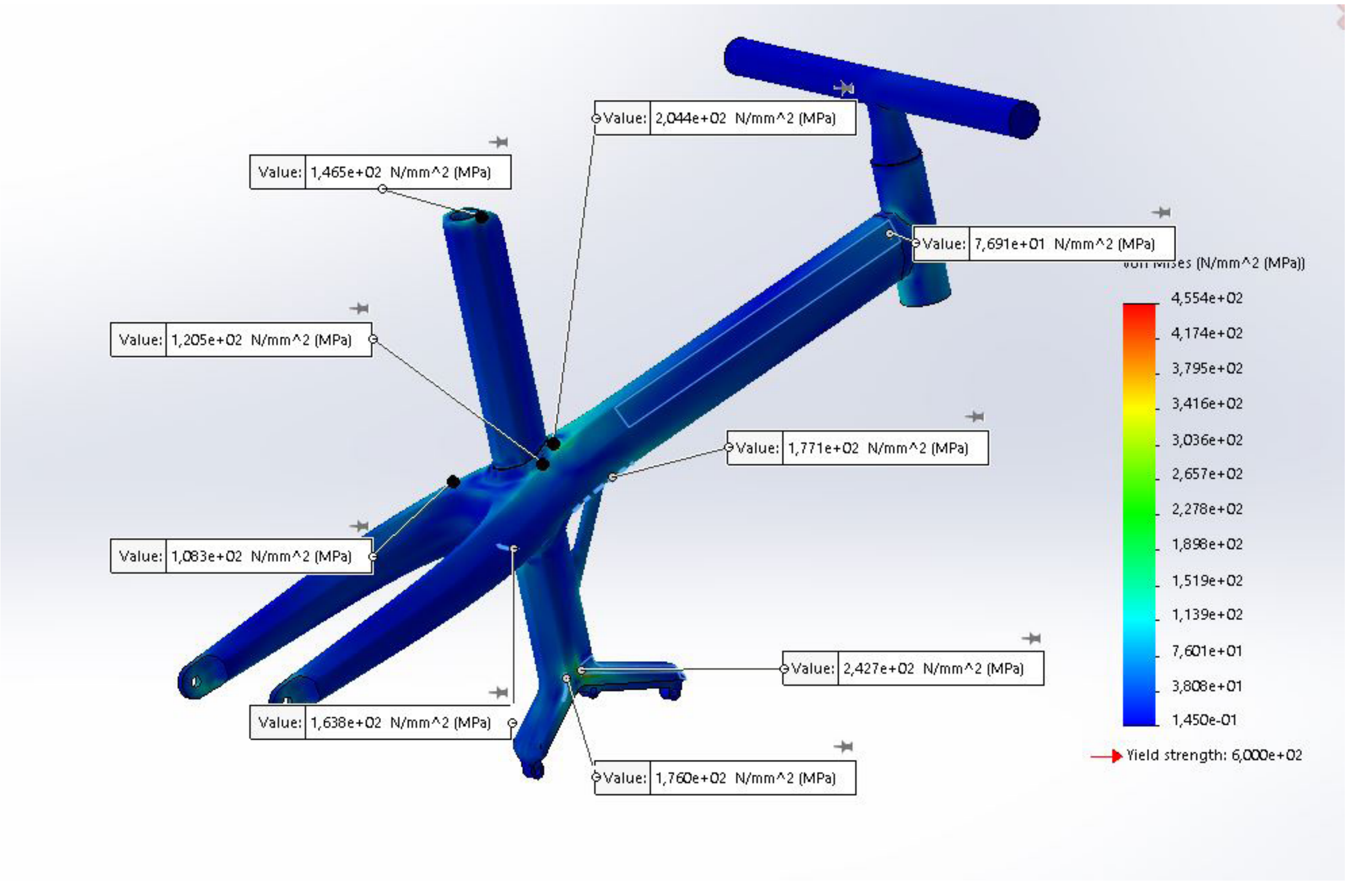



*Image 73: Combined scenario test stress*

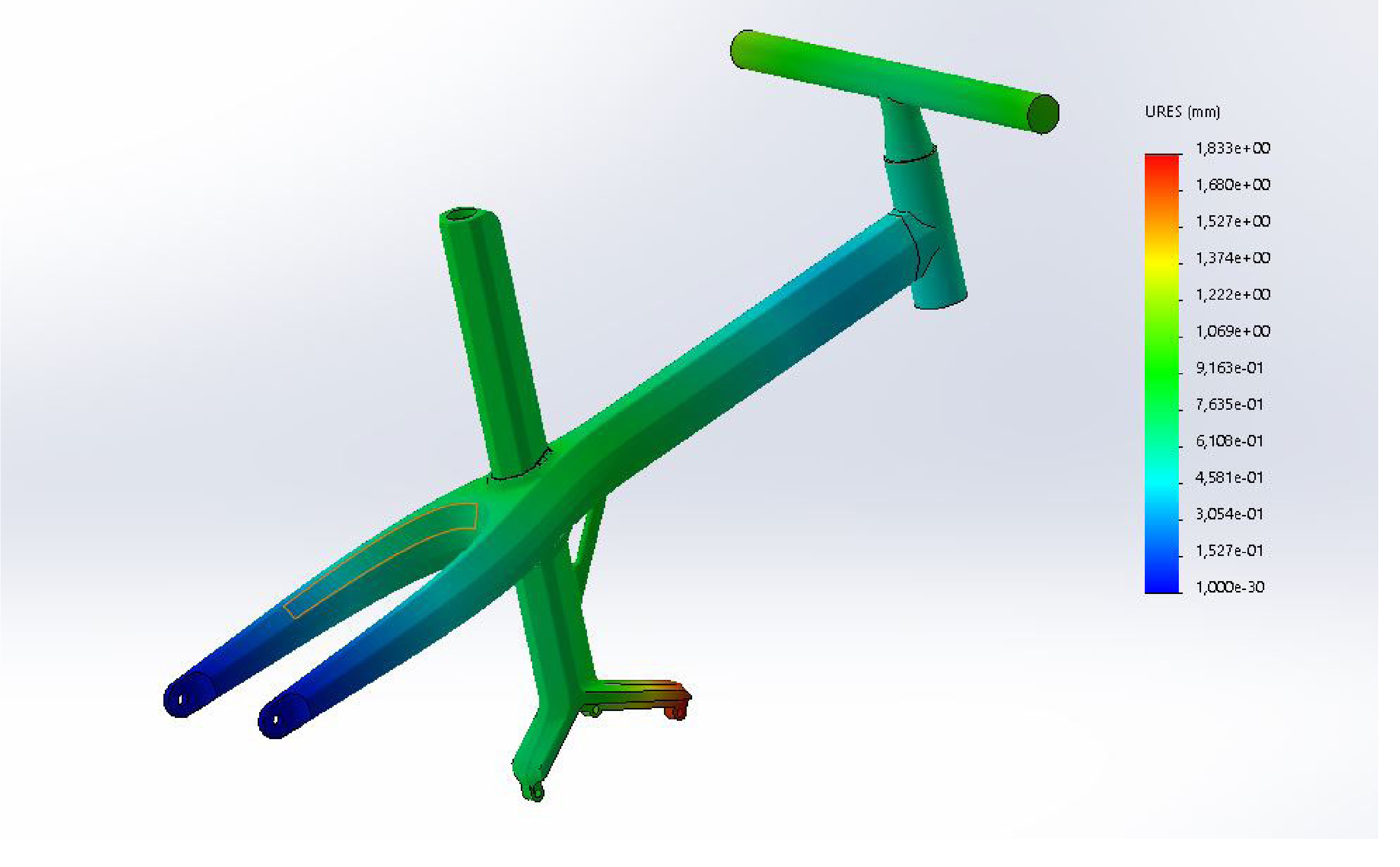



*Image 74: combined scenario test displacement*

# Material choice

The FEM simulations have been executed with different types of steel, as well as different sheet metal thicknesses. For the selection of these metals, the Cambridge Engineering Selector (CES) has been used. Besides this, research has been done into which materials are used in the automotive industry. The automotive industry uses lots of steel which is both very strong and formable by sheet metal forming.

One of the most used types of steel nowadays is advanced high strength steel, or AHSS. These types of steel have a tensile strength higher than 780 MPa. While these materials are still very strong, they still remain formable. As can be seen in image 76, the AHSS steel types have high tensile strengths while still being able to withstand large elongation (Hall & Fekete, 2017).

The use of this material is steadily increasing because the car bodies can be produced with thinner sheet metal, which can lead to a lighter product.

After the FEM simulations, steel type of choice is TRIP YS450 steel. This specific type of high-strength steel alloy is a Transformation induced plasticity (TRIP) alloy. These type of steel alloys are known to have a great combination of strength and ductility. More specific material properties can be found in image 75.

With this material, the overall weight of the frame is estimated to be around 3,5 kg. for the main shells. This is the weight of only the frame, with a sheet thickness of 1mm.

| Mechanical properties | | | | |
|---|---|---|---|---|
| Young's modulus | 191 | - | 231 | GPa |
| Specific stiffness | 24,3 | - | 29,4 | MN.m/kg |
| Yield strength (elastic limit) | 450 | - | 600 | MPa |
| Tensile strength | 780 | - | 900 | MPa |
| Specific strength | 57,3 | - | 76,4 | kN.m/kg |
| Elongation | 21 | - | 32 | % strain |
| Compressive strength | * 450 | - | 600 | MPa |
| Flexural modulus | * 191 | - | 231 | GPa |
| Flexural strength (modulus of rupture) | * 450 | - | 600 | MPa |
| Shear modulus | * 73,6 | - | 89,1 | GPa |

*Image 75: TRIP YS450 material properties (CES, 2019)*

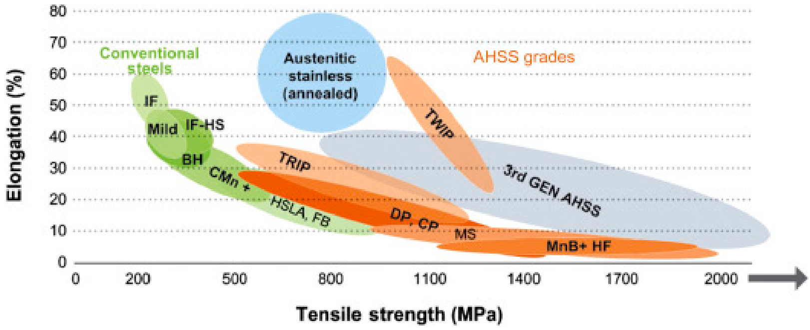



*Image 76: Graph displaying different types of steel (Hall & Fekete, 2017)*

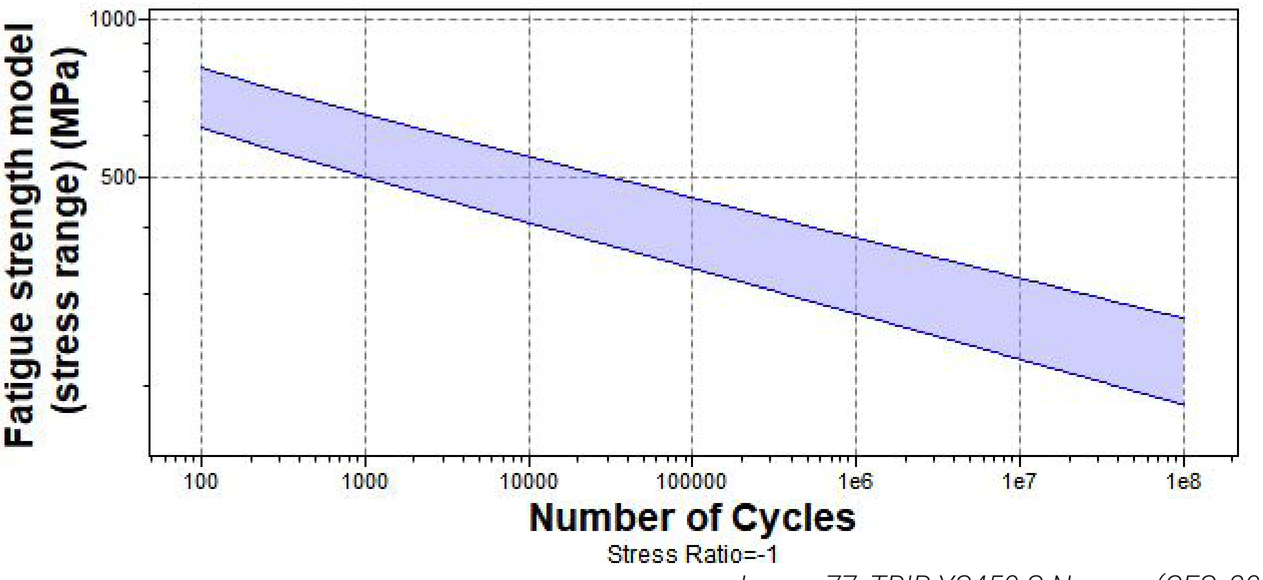



*Image 77: TRIP YS450 S-N curve (CES, 2019)*

When looking at this material, we also need to look into the so called SN-curve of the material. An SN-curve is a graphical representation of what the impact is of alternating stress on a material. With this curve we can look into the stress applied on the material over time, to give an indication of how much weaker the material becomes over time. This is especially relevant for this frame, because it will constantly be applied to stress during use. The SN-curve of TRIP YS450 can be seen in image 77. As can be seen in this image, after a million cycles, the fatigue strength is nearly 380 MPa, which is half of the initial tensile strength. This will need to be taken into account. It has to be noted that these SN-curves are actually quite regular for most steel alloys. The reduction of strength of a steel product over time is simply inevitable.

When looking into the overall extreme stress simulations, we see that there is a large margin from the occurring stress towards the yield strength. Since a safety factor has been used, we can conclude that after a million cycles, the frame can still hold up to regular use.

It is adviseable to perform simulations on this frequency stress to see whether the fram will actually hold up over time. If this proves to be an issue, this can most probably be solves with a slightly thicker sheet of steel. Where we currently use a 1mm. thick steel sheet, we could opt for a 1.5 mm. steel sheet,. This will decrease the overall stress in the frame, while increasing the weight of the frame by 1,75 kg. This weight is still within the allowable parameters, according to Mokumono.

# COLOURS

## Colour study

With the final design mostly ready, a color study has been executed. From this, a selection of colors has been made to fit the current colors of the Mokumono Delta, while adding extra colors to the selection. The chosen color options can be seen on the right hand page.

## Coating

The frame needs a coating to be protected from the elements and surface damage. The same type of coating coating will be used as is used for the Mokumono Delta.

The frame will be coated after the brazing is done. When the frame is checked for eventual anomalies, the frame will be sent to the coating company, which is Decocoat in Heerenveen. The frame is coated in three steps, whereas cheaper bicycles are usually coated in two steps.

The first step is the base coat, this is necessary to ensure good bonding of the actual color coating. This coating acts as a primer for the following steps. After this, the colored waterborne wetpaint is applied. This is the pigmented paint that gives the frame it's color.

The choice has been made to not add decals to the frame, to keep the minimal aesthetic of the Mokumono brand. If the opinion of Mokumono on this matter changes over time, these decals can easily be added in later batches.

Finally, the coating is finished with a transparent matte or glossy powdercoating. This last step serves as protection for the actual coloured coating. This coating process is fairly standard, and is used in many steel and aluminium products. The costs of this process can be found in appendix A.






# PRICE

To determine a sales price for the e-bike, an excel sheet has been used, which can be found in appendix A. With this excel sheet, Mokumono currently determines the sale price of their current bicycles. Because it was difficult to determine the individual prices of certain parts, assumptions have been made. Together with Mokumono, we looked into which parts will be used to finish the e-bike. The import prices of these products have been estimated where no specific prices were available. Since most of the parts are roughly the same as on the Mokumono Delta, these prices could be copied.

For the estimated price of the frame itself, some assumptions have been made as well. To be able to use the current Mokumono Delta frame as a benchmark, we use the process of rubber pressing for this cost price estimation, which will also be the most logical way for Mokumono to begin the production of this e-bike. Together with Phoenix 3D Metaal, a company specialized in rubber pressing, a cost price for the frame parts has been estimated. This is mainly based on their expertise within the industry since it is difficult to determine actual part prices beforehand with processes like this.

In the new frame design, there are more parts than in the current Mokumono Delta. However, this does not necessarily lead to a higher cost of the frame. Since the e-bike frame is divided in multiple parts, these parts are less expensive to produce, since the individual parts are a lot more simple to manufacture using rubber pressing. In the Mokumono Delta, there is a costly calibration step after the initial pressing, to make sure the tolerances are correct. From the discussion with Phoenix 3D Metaal, it was concluded that this step is not needed with the new structure of the frame. However, there are more parts to be pressed, which is why the production costs of all the different shells do come in a little higher than the current frame costs. However, this difference is cleared by not having the insert for the rear fork. The total pressing costs of the frame are estimated to be roughly the same of the Mokumono Delta frame.

A large improvement relative to the current frame is in the post-processing of the frame. The overall laser welding of the current Mokumono Delta frame will cost roughly the same as the laser brazing of the new frame. However, the costs of the post-processing of the Mokumono Delta are much higher than with the e-bike frame. This is because there is virtually no post-processing needed with the brazing of steel, whereas there is a lot of post-processing needed after the welding of aluminium. Where the current Mokumono Delta frame costs an estimated € 312,20 per 50 frames, the new frame will cost around € 179,00 per 50 frames, which is a cost reduction of 41%. It is good to see that our initial thought of having more parts in the frame itself ultimately will lead to a less expensive frame.

With all the fitted extra parts to make the frame a fully functional e-bike we estimate one complete e-bike to cost around € 1.403,37. Mokumono handles a margin of roughly 55%. With this in mind, we get to a retail price of € 2.974,38, which will ultimately lead to a catalogue price of € 3.599,00 including VAT, which is a margin of 52,8%. Even though this price is quite high, it is within the range of the Mokumono Delta bicycles. Where it can not compete with the prices of current 'regular' e-bikes, it can compete within the high-quality segment of the e-bike industry. It has to be noted as well that all the estimations in this cost price calculation are chosen to be as high as possible, so in reality, this price will most probably be lower than calculated here. Also, the parts chosen to fit this e-bike with are all top-segment parts, and this specific type has all the possible extras fitted as well. An easy way for Mokumono to lower this sale price is by choosing less expensive parts. With this product being an e-bike, it was actually expected to be in a higher price class since the price class we are in is not that much higher than the current Mokumono Delta with all the upgrades.

This estimated price is higher than the price range initially set together with Mokumono, which was a retail price of less than € 3000. However, there are ways to further decrease the retail price of the e-bike. While the current price is estimated at a low volume production, the price will decrease when producing at larger volumes (>500 frames). When this is possible for Mokumono, their retail prices can be further reduced. Mokumono could also choose to reduce their margin on the bicyle, which will at least take the retail price below the € 3500.

# PART 5: RECOMMENDATIONS

# RECOMMENDATIONS FOR MOKUMONO

Mokumono, in the current state of the company, has many opportunities to grow. It is logical that, since the company is still young, they do not have as big of a market share as they would like. There are multiple reasons for this.

Eventhough the further development of this e-bike is costly, it can be a great opportunity for Mokumono to solidify their position in the high segment e-bike market. Since the e-bike market is growing so rapidly, it would be desirable for Mokumono to get in on this market.

The e-bike frame has been designed in such a way that it is easily scalable for multiple production volumes. The development and eventual production of the Mokumono Dune can be divided into multiple phases.

First off, the product needs to be developed further. Since this has been an individual graduation project, the end result is not yet a fully developed frame that can immediately be manufactured. Since the scope of this project has been mainly on the frame itself, the electrical systems still need to undergo the most development. The choice to place this outside of the scope of this project has been made because as an industrial designer, we are not skillful enough with electronics to make a viable option. Especially the battery pack needs to be developed. This will have the highest cost, since it needs to fulfill the various safety norms on this matter.

For this further development, funding is needed. Because Mokumono is still a small company without great sale volumes, this is a very important factor. There are multiple options for Mokumono to fund this project further. One method that has worked great for them in the past is crowdfunding. Although crowdfunding is a great way for smaller companies to gain the funds needed for new projects, there are downsides to this as well.

Since the required funds for the development of an e-bike are higher than that of a regular bicycle, it might be more beneficial to seek an external investor. It is possible that with the help of an external investor, this project can be developed much sooner than with the help of an extensive crowdfunding campaign. Also it would be easier to obtain the amount of funding needed this way. Mokumono also needs to find an electrical engineer to work on the electrical systems of the e-bike. This will minimise risks that eventual issues occur when the electrical system is tested.

Besides the actual e-bike design, it is also relevant for Mokumono to utilise the research done into the production method. It can be concluded that there is a clear benefit to be obtained by using steel instead of the current aluminum. The overall weight of the bicycle does not have to increase drastically by changing from aluminium to steel, especially when using an advanced high strength steel.

The amount of shells in the frame is an area that is very relevant for Mokumono to look into. It is seen that with a different construction of the frame shells, the overall costs of the frame can be reduced. It will also be relevant for Mokumon oto dig deeper into the world of brazing instead of welding. This is believed to be necessary to be able to produce higher volumes. When laser brazing is used instead of laser welding, it is seen that the overall production costs can be reduced, mainly due to the lack of post-processing. With this process together with the new configuration of shells, the process can now be truly automized, as was initially desired by Mokumono.

After the initial further development of the product, it will be advisable for Mokumono to start with a small volume serie of the e-bike. The design of the frame is applicable for both rubber pressing as for matched die forming. The first smaller serie should be rubber pressed. With rubber pressing, there can easily be small adjustments to the manufacturing process. Mokumono can use this to finetune their production flow, which they already did with their Mokumono Delta bicycle. The reason to use rubber pressing for this initial phase is that the recommended production volume is lower, and that the die can undergo small adjustments, since the rubber of the press will adjust automatically to the die. This also means that with the same die, different materials and material thicknesses can be used.

After this initial production serie, Mokumono should scale up their production volume. The initial serie serves as a mean to still identify and fix problems occurring in the frame. When the frame is fully optimised after this initial phase, a larger serie should be produces to fully utilise the automation possibilities, and further drive down the prices of the final e-bike. For this, a new set of dies needs to be created, so that Mokumono can start using matched die forming, which eventually will be a more consistent method for large volume manufacturing. For this, Mokumono also needs to find new partners, since Phoenix 3D metaal only focusses on rubber pressing.

# DESIGN-BASED RECOMMENDATIONS

Since this has been an individual project that is limited by time, not all the area's could be explored to the fullest. Decisions have been made to focus the project mainly on the frame itself and the manufacturability, this because this already proved to be quite a great challenge. However, a design in seldomly finished. This has proved to be very true in this project as well. Even in the last period, a lot of new insights are gained towards the design of the frame and adjacent issues. In this section we will look into these problems, and what would be logical steps to solve these issues. because of time, these aspects could not be fully incorporated into the design, and thus will function as recommendations for Mokumono to further develop this product.

## CASTED PARTS

The choice of making casted parts for the dropout, seat tube connector and the head tube is still a viable option, however, it will most likely only be beneficial when producing in large volumes, so the initial investments can be spread out more. There are more elegant solutions to these parts as well. These solutions will be explored and explained in the following section.

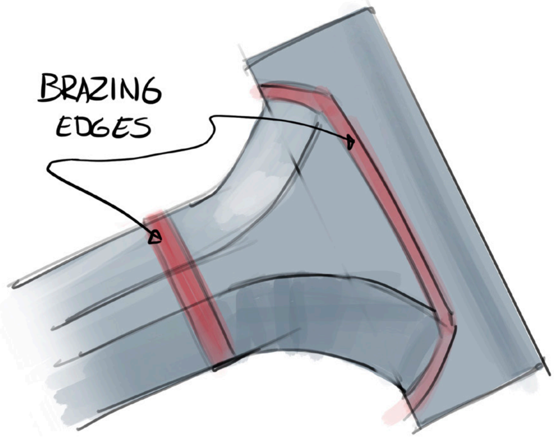



*Image 78: Headtube lug design*

### Head tube connection

While the head tube is a casted part in the current iteration of the design, a more elegant version of this is designed as well. The idea behind this is to use a lug design. The lugs are designed to fit the headtube and the Y-shape. Lugs are a traditional way of manufacturing bicycle frames. It can reduce the overall costs and fit the overall design philosophy to create a lug that is sheet metal formed for the problem of the connection between the frame itself and the head tube (see image 78). As a head tube, a standard head tube can then be used. In the same mold as the different frame shells, an extra part can be added. This lug will slide over the frame itself and around the head tube. This will provide an interesting detail and is well suited for the chosen production method. It will also help reduce the overall weight of the frame itself.


*Image 79: FSA ACR bearings*

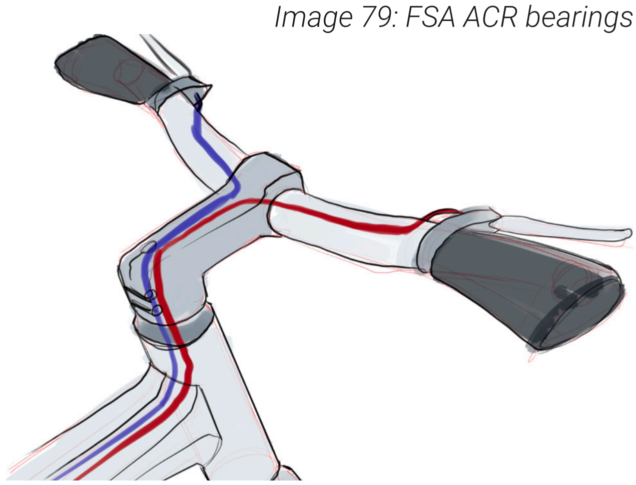


*Image 80: FSA ACR stem cable integration*

The head tube will contain integrated bearing shells, so that FSA ACR bearings can be used, as can be seen in image 79. These bearings support integrated cables to go through the head tube into the stem. As a stem, a FSA ACR stem will be used, as can be seen in image 80. This will create a minimalistic look of the handlebar area, because all of the cables will be integrated. This includes the cables to the disk brakes to the brake levers on the handlebar.


*Image 81: Eccentric bottom bracket*

## Dropouts

The dropouts are casted parts in the current design. This has however proven to be impossible for the bicycle to function. Because of the use of a drive belt, we need to be able to tension this belt. In the current Mokumono this is solved by using a eccentric bottom bracket, as can be seen in image 81. However, because we use a middle motor in the current design, the use of an eccentric bottom bracket is not possible. To still be able to tension the drive belt, this has to be done in the dropouts. There are multiple way to do this, but the most apparent options are using sliding dropouts or horizontal dropouts. With this in mind, the dropouts need to be redesigned. A way of fixing this problem is through a horizontal dropout, as depicted in image 82, however, this is not an ideal solution because of the angle of the frame. To still make the dropouts fit the overall frame, a custom dropout is designed. This has not yet been applied into the CAD model of the design. This dropout will most likely be produced by a combination of milled steel and aluminum parts, as well as standard sliding dropout parts that can easily be ordered. Image 83 shows the design of these custom sliding dropouts.


*Image 82: Horizontal dropout*

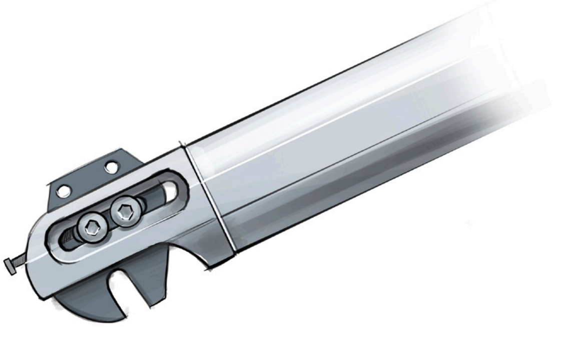


*Image 83: Sliding dropout*

## Seatpost clamp

Currently, the seatpost clamp is implemented as being a casted part as well. This can easily be a machined part as well. The connecting part should have a clamping mechanism integrated to clamp the seat tube in place an allow the user to tweak the height of the seat, this can be done as described in image 84. If such a part is used, an external seatpost clamp is not needed anymore, which fits the minimalistic nature of the bicycle.

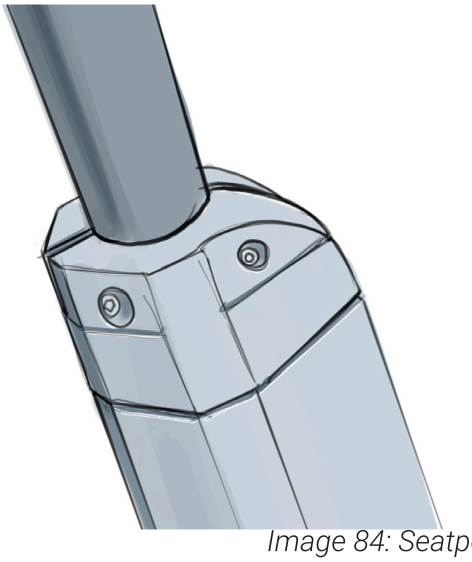


*Image 84: Seatpost clamp*

# PART 6: REFLECTION

# PROJECT REFLECTION

This project has proven to be a more difficult project than initially expected. There have been multiple factors that influenced this. In this section, we will look into these aspects and into how the overall project went.

First of all, I have had a lot of trouble with this being an individual project. Of course, it is a logical thing for a graduation project to be individual, but this still was difficult for me, since a majority of the project at Industrial Design Engineering are executed in groups. This also made me want to do almost everything myself, which has proven to be not realistic. As a product designer, it is very important to be able to rely on the experience of experts in the field you are designing for. I think it would have been beneficial for the project and for me to approached experts earlier on in the project since their insights helped me and the project tremendously.

This project may not be the highest quality we have seen in IDE graduation projects, but I do dare to say that I have learned a lot more from this project than when the project went smoothly. The main lesson I have learned is that a good foundation of your project is very important. In the beginning phases of the project I have not been as focussed as I could have been, which made for a less than optimal foundation for the rest of the design. This came back to me over and over again, and has cost me a lot of time backtracking steps I took earlier on in the project.

What I found very difficult about the individualism of the project was that there is limited space for fresh insights from the outside. When working in a group, each decision will be made in deliberation with the other team members, and for more difficult decisions, elaborate discussions will take place. This was difficult for me personally, and made me postpone having to make these important decisions. However I now see that it is very important to make these decisions as early on in the project as possible, especially with a time-limited project like this.

Also, I wish I would have taken more time before the project started to already get more insight into the market and the company. Because the project brief has been written beforehand, I constantly experienced that this project brief was not totally accurate for how the project turned out. It became apparent to me that what I thought I could do in this individual project was based on the group projects I have executed in the past, which was simply not very doable within the time, at least not for me. For upcoming projects, I will make sure that I have a better understanding of the matter before I begin the project, and thus will guard myself from making promises that I cannot keep.

Besides this a notion needs to be made on CAD modelling and especially Solidworks. This has been a very important part of this project. Where I thought I was quite skilful in this project, it quickly proved to be very difficult for me to create a CAD model from the sketches, ideas and rough models I had. Where I was already skilful in the solid modelling part of Solidworks, this quickly proved to not be relevant in this project, because I could not get the shapes I needed. This has lead to a lot of frustration and wasted time by trying different types of modelling techniques, while still giving myself the opportunity to adjust the design easily afterwards. Finally, I made the decision that these types of shapes were not doable for me with the solid modelling skillset I had. To counter this I have learned surface modelling in SolidWorks. While I have had the basic principles of surface modelling in SolidWorks in my bachelor, I have never used surface modelling for a project before. This meant that I had to quickly learn this different way of working in Solidworks. While at the time it was hard for me, I am now confident to say that this skill is a very useful one. While the complete part of the CAD modelling has taken up a large portion of time, it provided me with a whole set of new skills that I am sure of will be useful in my further professional career.

Besides the overall CAD modeling in Solidworks, the Simulation aspect has been full of challenges as well. While i have executed many FEM simulations during my study at IDE, I have never executed such complex FEM simulations with thin-walled products before. This resulted in a huge load of Solidworks error messages and frustration. I have been trying to get some workable results for a long time. Each failed simulation I learned more about the way these simulations work, and what I would need to do to make it successful. Eventually it worked, and I knew that I had yet again learned a very relevant new skill for a product designer.

Overall, I am satisfied with the outcome of this project. For me, when I look at all the failed attempts and frustration, this was all worth it in the end. I would personally have liked the product to be in a more complete state at the moment, but I also realise that this might not be possible within the timeframe of a graduation project, at least not for me.

I hope that Mokumono will find the product appealing. However, what I find more important, is that Mokumono will look into the changes into the manufacturing process and that they can benefit from this in all the following products they will develop.

# PERSONAL REFLECTION

This project has been a rough but extremely educational experience for me. While I thought differently of it at the time, now I think that the setbacks have made this project very valuable for me.

First I want to talk about the rest of my studies at Industrial Design Engineering (IDE). Since my greatest interest has always been the aesthetic side of designing, this is what I have focussed on the most, because I felt that this was the area with the highest potential for me actually finding a job. Since I was young I have always been drawing a lot, so I always like the sketching and creative side of product design.

Before my graduation project, I came to a conclusion for myself that I was not all too developed in the technical area of designing. When looking at the grades I got at IDE, they have always been high for design projects, but certainly lower for the more technical courses,.

It was during my job at a company that designed and produced chemical analysis equipment that I found that I am actually more sufficient in this area than I might have given myself credit for. This is why I wanted to see during my graduation project if I had it in me to also tackle this side of product design, the technical side. While this has always proven to be difficult for me, and felt very daunting at first, I quickly came to the conclusion that I just cannot graduate from a Technical University with just good looking sketches.

This is how the project came together. It still seemed like a great combination between creative thinking and showing my designer skills, while also embracing the production and material side of designing. I have been very happy with my project overall, however, the road has been bumpy all along the way.

It started at the beginning of the project. When I just started, I received news that my father is ill. This has struck me harder than I initially would have thought. I know it is not an excuse, and I do not want to use it as such, but the first few weeks of the project, my mind was not as focussed as it should have been. This had lead to me not treating my graduation as I should have, and thus not laying down the foundation I needed in these first weeks. When the summer holiday came, I got a chance to clear my head and get my life back together. While the news of my father was very distracting at first, I eventually got used to it.

It was around this time that I approached my midterm meeting, and just before that my coach, Olaf Wit, told me he could no longer coach me in my project because of a job offer. He helped me out a lot in finding a new coach and there was Joep Trappenburg. I really appreciate what Joep has done for me and for the project, I am even daring to say that this would not have ended so well without him. However great the help of Joep has been, the transition from Olaf to Joep has been a difficult one for me. With Olaf as a mentor, and my mental state at the time, my graduation project was a mess. I did not document enough, and the choices I have made were mostly made during face to face meetings with Olaf. I think Olaf also saw that I was not doing so well, and that it heavily influenced my project quality. Olaf encouraged me to keep working the project. I was not as motivated at the time and thus we believed it would be in my best interest that I would keep going in a way that motivated me, thus by sketching and designing. In this phase, I dropped the ball and did not do as much research as I should have done. This also leads to me not going to experts for help, because deep down I knew that my work was not good enough to show people as a graduation project.

It was after the midterm meeting that something changed in me and in the project. This had to do with the situation around my father being less stressful, and because of the tremendous help of Joep. After the midterm I found a new drive to create something that I could believe in. After two weeks of backtracking my movements of that messy beginning, I was more focussed than ever before during the project. I think this can easily be seen in the work I have provided. While the quality of the work improved drastically, the rough start of the project left its marks. This has learned me a lot about how important the initial phase of a design process is.

During this project, I got confronted with myself quite intensely multiple times. Especially since there was so much room for improvemt in the beginning of the project, I have received a lot of feedback on what had to improve. This has led to periods of me doubting everything I did, because I started believing that I might not have it in me to finish this project successfully. When this self doubting became too much I started taking action against it. I had to remind myself to keep looking at everything I had done that did succeed, and not get caught up in the areas that needed improvement. This motivated me greatly, and gave me the will power to improve as much as I could within the given time.

Overall, I think I have learned more from this single project than I have learned during my complete Master education at IDE. A key realisation for me has been that we as students are not complete designers after the education we followed. I think that especially for product designers it is extremely important to keep learning during your professional life. Since the world changes so fast, product designers need to change with it, and this can only be done by staying curious and studious. This is something I value highly and I cannot wait to start learning and working in professional product design environments.

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