Cycle through life

Designing a non-stigmatising stabilised bicycle for Beixo

Master thesis

Integrated Product Design
& Design for Interaction

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Design for Interaction & Integrated Product Design

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Colophon

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Designing a non-stigmatising stabilised bicycle for Beixo

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Preface

In front of you lies my master thesis, which presents the process and result of my graduation project for my double degree in Integrated Product Design and Design for Interaction at the Delft University of Technology. It is the result of an exiting journey.

Before I started this journey, I promised myself that I would try to get the most out of it. My goal was to work hard, learn a lot, have fun and make something awesome. And so I spent every moment doing more or thinking about how I could do better. I did a lot of things that I had never done before. I met great people, showcased my work at the Dutch Design Week and enjoyed my time with the VanBerlo team. And I am very proud of the endresult.

This was all possible because of the right conditions. I had found a topic that I was enthusiastic about, a great client who was willing to invest time, money and energy in me and an internship company that was willing to teach and support me. And for this I am very thankful.

With this project I hope to show what the value of combining the skills you learn in Integrated Product Design and Design for Interaction can be. I believe that a project that combines a user-centred approach with an iterative design process can lead to valuable products that are desirable, feasible and viable.

Isabelle Lugert
Delft, November 2018

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This project was a great journey and learning experience and would not have been possible without the help of my supervisors, company mentors, colleagues, friends and family. I would like to thank you all for the support you gave me, whether it was support in the form of coaching, advice, help or motivation, without you I would have never gotten this far.

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Executive summary

This report presents the design process and the design proposal of a non-stigmatising stabilised bicycle designed for the bicycle company Beixo. With the trendy three wheel cargobike that has been designed for the problem of stability and stigma, insecure cyclists, including elderly, can cycle with confidence and stay mobile and independent.

Research
A literature study and user research using contextmapping methods were conducted to identify and understand the problem that this thesis deals with.

Problem
Age-related disabilities, such as reduced balance and strength, can cause elderly people to fall with their bicycle. A fall often leads to injuries and fear of falling again. This feeling of insecurity causes many elderly to stop cycling, giving up an important part of their mobility. Assistive devices that help elderly to stay mobile, like tricycles, already exist, but these aids are perceived as stigmatising and are not easily accepted by users. Stigma is a negative judgmental reaction from bystanders to a person or person using a product caused by the visible characteristics of the person or product that are perceived as socially undesirable.

Design strategy
This master thesis deals with the question if a bike can be designed such that it provides stability without being stigmatising. Existing research was used to find design strategies to deal with the problem of stability and stigma. The chosen design strategy included disguising the stabilizing function of the third wheel, adding additional benefits, making the design age independent and creating an association with an accepted product category.

Design process
The design process consisted of design and research activities. The research activities were needed to answer questions that came up during the design activities. The chosen design direction 'cargo tricycle' which has the potential to solve the problem of stability and of stigma was developed further into a concept and later the design proposal. Several iterations were made to get to the design proposal.

Design proposal
The proposed design provides a solution to the problem of stability and stigma by creating a reference to cargo bikes. The bike has two front wheels in between which the cargo container is located. The bamboo container is compact and allows for easy loading of small cargo, for example groceries. The designed steering system steers the wheels around the container, allowing for light steering. The frame has a low entry and large adjustability to allow for an ergonomic cycling position for all users. The integrated shaft drive motor provides pedaling support, making cycling effortless. Its function and appearance could make this compact cargo bike suitable for many more target groups than elderly insecure cyclists, for example people who have never learned to cycle, ALS patients, people with reduced balance due to hearing impairment, people who wish to transport small loads, etc.

Validation
To validate the design, a 'looks-like-real' working prototype was created. This prototype was showcased at the Embassy of Health during the Dutch Design Week 2018 where it received positive attention from visitors. The stability of the bike was tested by using it in everyday cycling situations in bicycle infrastructure. The subjective stability and stigma was tested with potential users, by letting them test ride the bike and asking about their experience.

Conclusion
The design provides stability when cycling a straight path, but stability in turns can be improved. Potential users feel instable when taking turns and need to get used to the feeling of cycling on this bike. The bike is a tricycle and will never give the user the same cycling feeling as a bicycle. With a tricycle there is a trade-off between stability and a bike-like feeling.

The opinion about stigma of the design differs between people. The reactions of the visitors of the Dutch Design Week were positive and indicated that avoiding stigma has been succeeded. However, not all the participants in the user evaluation agreed on this. Which product category the user compares the bike with when evaluating stigma is thought to influence the opinion about stigma and needs to be considered for the positioning of the product.


Delft

Content

Introduction

In the Netherlands the population is aging. Expectations are that by 2040 almost a quarter of the population is aged 65 years and older (CBS, 2010). As we get older our strength, balance, hearing and sight reduces (Rantakokko et al., 2013). At some point walking takes more effort and we start to feel insecure on the bicycle. After the age of 80 many people stop cycling (Fishman et al., 2015). Numbers show that elderly are at high risk of being involved in a bicycle accident and that most of these accidents are falls that happen when getting on or off the bike (Rijkswaterstaat Ministerie van Infrastructuur en Mileu, 2013). A tricycle could help these people to avoid falling with the bike. But, like other mobility aids, it is not easily accepted (Parette & Scherer, 2004). Most people do not like to use mobility aids because they fear becoming dependent on it and being seen as vulnerable (Resnik et al, 2009).

The motivation for this project comes from the observation that people who use mobility aids do not look empowered. The device often makes them look even more vulnerable. And from the stories about people who could benefit from a rollator, mobillity scooter or tricycle but are not willing to accept it. The interest grew to find out what causes this rejection. The question arose if there is a way to design a mobility aid in a way that it can help people to stay mobile without being stigmatising.

The challenge of this master thesis is to design a mobility aid that is not stigmatising. The client Beixo is a dutch bicycle company. A great part of their clients are elderly looking for a bicycle on which they feel more stable. The goal of this project is to enable these elderly to feel confident while cycling and avoid falling while getting on and off the bike.

Eventually a non-stigmatising stabilised bicycle can also benefit young people, for example people who have not learned to cycle or people with a neuro-degenerative disease or other disability.

This master thesis covers the complete design process from analysis of the context to proof of concept. This report presents the process chronologically, starting with the analysis in which a literature study and user research were executed to explore the context, followed by the exploration of the design space, concept development and prototyping. The concept was presented at the Dutch Design Week 2018 and validated with users. This is presented in the last few chapters.

1

Assignment and approach

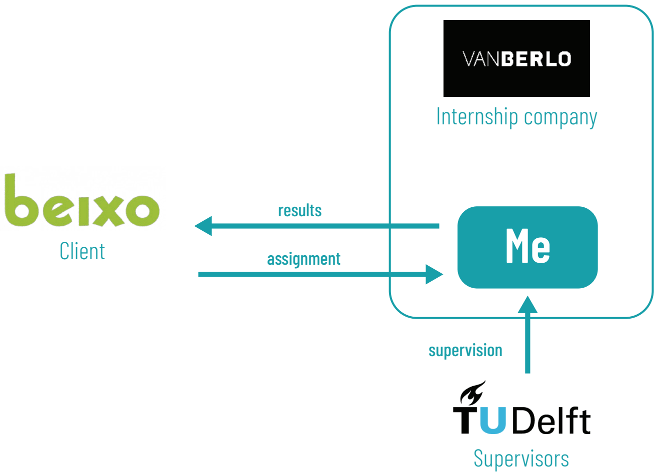


figure 1: Project partners and their roles

1.1 Initiating the project

This project was initiated by me, the graduation student. Finding the right project and project partners was a challenge in itself. This chapter briefly explains how this project came about.

Double degree
This project combines the masters Design for Interaction and Integrated Product Design. The aim was to find a project that offers enough challenges in both domains. Therefore the topic should have an interaction aspect as well as a technical aspect and ideally offer the possibility to develop a physical product.

The topic
The topic chosen for this graduation project is mobility of elderly. It comes forth of the motivation to enable elderly with mobility restrictions to stay independent in a way that is not stigmatising.

As the population ages, the amount of people with mobility restrictions increases. Yet there are very little products on the market that fulfill the mobility needs in a non-stigmatising way. The aim of this project is to create a mobility aid that people like to use and do not feel ashamed of.

Acquisition
Initially the idea was to do a project on improving mobility aids for elderly with walking problems. The topic was rather broad and several different companies were contacted for a cooperation, ranging from Rollz to No Isolation, Segway, Alinker and Siemens. The acquisition of these companies proved to be difficult, because the companies wanted to know in advance what would be the end result of the project.

To make acquisition easier, the project was narrowed down to designing a bicycle suitable for elderly. Several bicycle companies were contacted to pitch the project idea. Beixo from Urban Bike Concepts was very interested in the topic and eventually became the client.

1.2 Project partners

This project involves the bicycle company Beixo, design agency VanBerlo, the graduation student and the TU Delft (figure 1). Beixo fulfills the role of the client. The results of the project will be available to them for further development and market implementation. VanBerlo provides an internship for the duration of the graduation project and fulfills a coaching role. The supervisory team of the TU Delft is responsible for coaching and grading the project.

1.3 Project scope

The client Beixo is a bicycle company that develops bicycles and sells bicycles and accessories. The new design should bring value to Beixo and should therefore fit their vision and lie within their competences of bringing it to market. The project scope therefore lies in the bicycle domain.

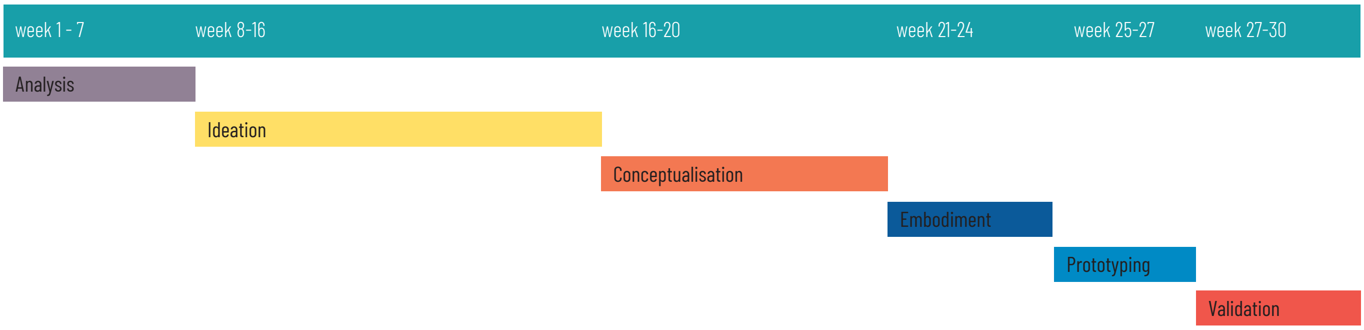


figure 2: Project planning

1.4 Approach

In order to successfully complete the two masters Design for Interaction (DfI) and Integrated Product Design (IPD) with this project, an approach was chosen that provides enough depth on user interaction level as well as on product level.

Bridging the masters
In DfI the focus is on the user and the interaction with the product. Important skills acquired in this master are doing user research to identify the user's needs and translating the insights into meaningful interactions. These skills help to set a good starting point for the design process in this project. IPD focuses on the desirability, feasibility and viability of the product. The skills acquired during the master are used to design, detail and prototype the product.

In figure 3 is illustrated how the skills applied in both masters are used to tackle the challenges of this project. In this project DfI skills will be used to focus on the user, the context of use and stigma. IPD skills will be used to focus on stability, product and technology. Both masters will be used to tackle aesthetics, interaction and funtionality of the design.

Project planning
The timeline of a double degree graduation project is 30 weeks, 1,5 times longer than that of a single master. This means there is more time to do a larger part of the design process, however it means that activities of the two masters need to be balanced. In this project this is done by using DfI skills to give direction in the fuzzy front end and by using IPD skills to narrow down and specify the design. In the validation skills of both masters are applied to set up a test to validate the desirability, feasibility and viability of the design.

The project consisted of several phases, as can be seen in figure 2. The project started with an analysis phase in which mainly research activities took place. The analysis was followed by the ideation, a phase in which design and research activities ran in parallel and many iterations took place. The third phase, conceptualization, consisted mainly of design activities but contained also some research about technological aspects. Then followed the prototyping and validation phase, in which a working prototype was created and used to validate the design.

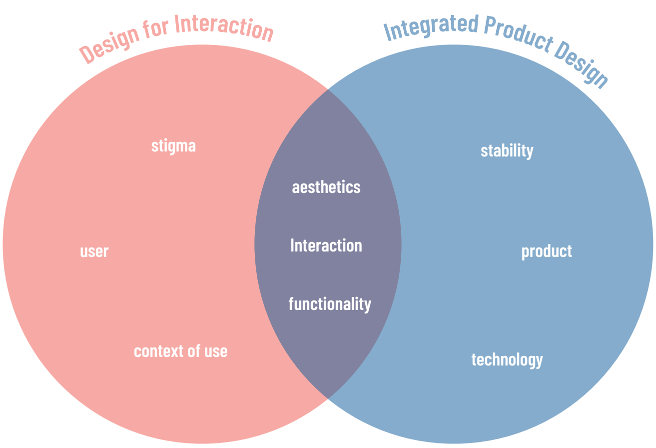


figure 3: Skills acquired in DfI and IPD are combined to tackle the challenges of this project

2

Analysis

figure 4: Beixo bicycle with shaft drive (source: Beixo)

figure 5: shaft drive (source: Beixo)

2.1 The client

This project is commissioned by Beixo, a brand of Urban Bike Concepts founded in 2005. The resulting product should be an addition to their portfolio. For this reason it is important to identify the opportunities for Beixo. This chapter will present Beixo's vision and mission, brand personality, design DNA and opportunities.

<u>Beixo's organization</u>
Beixo is a small scale company run by two directors. The two co-founders share responsibilities. One is responsible for the design and marketing, the other for sales. Other employees involved are an office-manager, an accountant and two logistics employees responsible for preparation and delivery of the products (A. Tummers, personal communication, April 20, 2018).

Beixo's headquarter and bicycle shop are located in de Bilt, near Utrecht in the Netherlands. Beixo dealers are located in various European countries, including the Netherlands, France, Germany, Spain and Austria, Italy and Hungary (Beixo, 2018b).

<u>Beixo's development process</u>
The engineering and production of new products is outsourced to Taiwan. This happens in close collaboration between Beixo and the production company in Taiwan.
When Beixo develops a new idea for a product, the sketches are sent to Taiwan where they are turned into technical drawings. These are sent to Beixo for verification. Once they are correct, the first prototype frames are made. They are again sent to Beixo for validation. At Beixo the team completes the prototype with parts from different suppliers. When a choice for the parts is made and the prototype is approved, the production of a first series of bicycles is commissioned by Beixo. The production company in Taiwan then produces the frames in collaboration with frame builders and orders the parts from suppliers. The bicycles are assembled in Taiwan and sent to the warehouse of Beixo where they are prepared for shipping to the Beixo dealers around Europe (A. Tummers, personal communication, April 20, 2018).

<u>Beixo's vision and mission</u>
The brand Beixo started as a hobby project driven by the motivation to design chainless bikes that would provide hasslefree mobility. All bicycles designed by Beixo are chainless and most use a shaft drive (figure 4 and figure 5). Beixo sees several advantages in the shaft drive; it is cleaner, needs less maintenance, it is silent, safe and practical. (Beixo, 2018a)

<u>Beixo's portfolio</u>
Beixo's current portfolio consists of folding bikes, electric folding bikes, e-bikes, city bikes and one BMX bike (figure 6).

figure 6: Beixo's portfolio (source: Beixo)

Beixo's brand personality

To get a better understanding of what the brand Beixo stands for, a brand personality workshop was organized. During this workshop the client used the 'Bull's eye tool' (see appendix A) to choose personality traits that make up the brand Beixo. Brand personality workshops and the 'Bull's eye tool' are methods VanBerlo utilizes to identify a company's brand personality. The outcome of the workshop (figure 7) shows that the brand Beixo is honest, wholesome, reliable, cheerful and spirited. Honest best describes Beixo's brand personality and refers to Beixo's ambition to tell an honest story. Their first priority is to satisfy their customers, rather than trying to sell as many products as possible. 'Wholesome' means "It is what it is." and refers to Beixo's transparency. 'Cheerful' refers to Beixo's ability to empathize with their customers. And 'spirited' refers to Beixo's ambition to develop cool bicycles for an older target group.

figure 7: Beixo's brand personality

figure 8: Beixo's design DNA

Beixo's design DNA

Beixo's brand personality is also visible in their design language. Beixo's portfolio was analysed to find the design language that makes Beixo products Beixo. The moodboard in figure 8 presents Beixo's design DNA. Beixo's brand personality is reflected in the use of warm materials, colour details, functionality, simple frames, attention to details and purity of materials. In general the design language is simple and pure with subtle use of colours.

Opportunities for Beixo

Beixo outsources the engineering and production of their bicycles to Taiwan where they have a vast network of suppliers and production facilities. Although outsourcing means having to put effort in good communication, it gives the opportunity to focus on marketing, customer service and new product development.

Their expertise with shaft drives is a competitive advantage, because it differentiates their bicycles from other bicycles on the market.

Beixo's best sold product is Electra low, an electric folding bike with a low entry and great adjustability. A majority of the customers are 65 years and older, looking for a bike on which they feel more stable. These users often lower the saddle so they can reach the ground with both feet (A. Tummers, personal communication, April 20, 2018). However, when lowering the saddle to reach with both feet on the ground the user sacrifices an ergonomical cycling position.

*figure 9: Beixo Electra Low is Beixo's best sold product (source: https://www.anwb.nl/fietsen/test/elektrische-vouwfietsen-2016/beixo-electra-low_*

Conclusion

There lies a business opportunity for Beixo to develop a bicycle that fulfills the needs of their elderly customers, who are looking for more stability. The new design should either be an add-on to one of Beixo's bicycles or be a new chainless bicycle design that fits their portfolio. This is important so Beixo can use its existing retail channels and production facilities. Beixo's experience with e-bikes and folding mechanisms could be used for the design of the new product. The design language of the new product should be simple and pure to fit Beixo's brand personality.

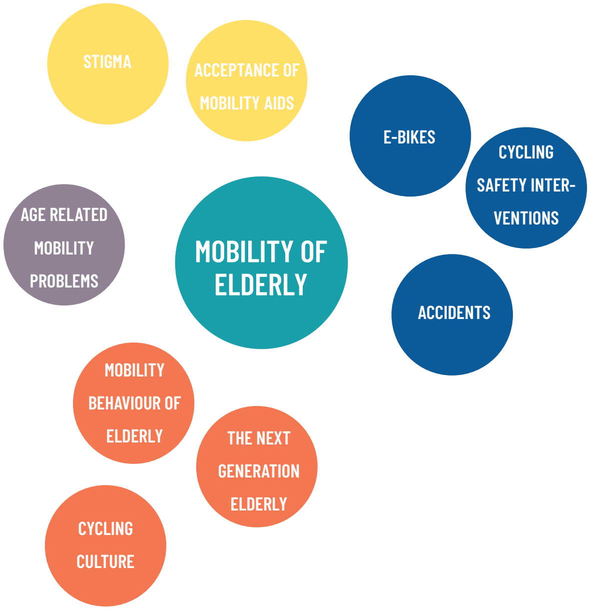


figure 10: Overview topics for literature study

2.2 Background

To get a better understanding of the topic 'mobility of elderly' and to find interesting areas for more in depth exploration of the context, a literature study was conducted. To structure the literature study several topics related to mobility of elderly were selected (figure 10). The colours indicate the relationship of the topics. In this chapter the most relevant findings are discussed per topic.

<u>Cycling culture</u>
The Dutch cycle a lot, the bicycle is the most popular means of transportation in the Netherlands. 27% of all trips in the Netherlands are made by bicycle and on average adults cycle for 74 minutes per week (Fishman et al., 2015). Especially for elderly who do not yet experience physical limitations, the bicycle is an often used means of transportation to go shopping, visit friends and family or to make a recreational tour (Rijkswaterstaat Ministerie van Infrastructuur en Milieu, 2013).

<u>The next generation elderly</u>
The Dutch population is aging quickly. The number of people aged 65 years and older is expected to grow from 2,4 million in 2010 to 4,6 million in 2040 (CBS, 2010). That is about one quarter of the population. The next generation elderly will be more mobile than previous generations, increasingly healthy at old age and used to an active lifestyle where mobility plays an important role (PBL, 2013). Additionally, increasingly more elderly people are working and thus need to travel to work (PBL, 2013).

<u>Mobility behaviour of elderly</u>
A study conducted by Rijkswaterstaat Ministerie van Infrastructuur en Milieu (2013) shows that when elderly reach the age of retirement their mobility behaviour changes. Transportation is used for different motives and on different moments. Also the distance travelled and the means of transportation change. Elderly move less often per day than the working generation. Leisure and social activities make up almost half of the motives for traveling. The study also shows that 45% of the time, people aged 65 years and older use the car, 30% of those times they are driving. 23% of the time they use the bicycle or scooter and about 23% of the time they walk. Only 5% of all travels are completed by public transport (figure 11) (Rijkswaterstaat Ministerie van Infrastructuur en Milieu, 2013).

<u>Age-related mobility problems</u>
A recent study by Rijkswaterstaat Ministerie van Infrastructuur en Milieu (2013) shows that in 2008 14% of the men and 32% of the women aged 65 years and older indicated to experience mobility problems. Mobility problems increase with age. Of the 75 to 84 year olds, 40% experiences mobility loss and of the people aged older than 85 years, 60% experiences mobility problems. 80% of all people with mobility problems indicated to move less due to this (Rijkswaterstaat Ministerie van Infrastructuur en Mileu, 2013).

Signs of mobility problems are having difficulties with walking, carrying things and bending over to pick up something from the ground. These problems are often caused by arthritis, rheumatism,

Transport use among people aged 65 years and older

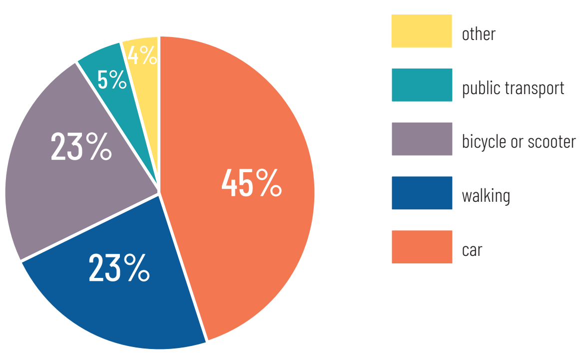


figure 11: Transport use among people aged 65 years and older

Average weekly minutes of cycling per person in The Netherlands 2010-2013

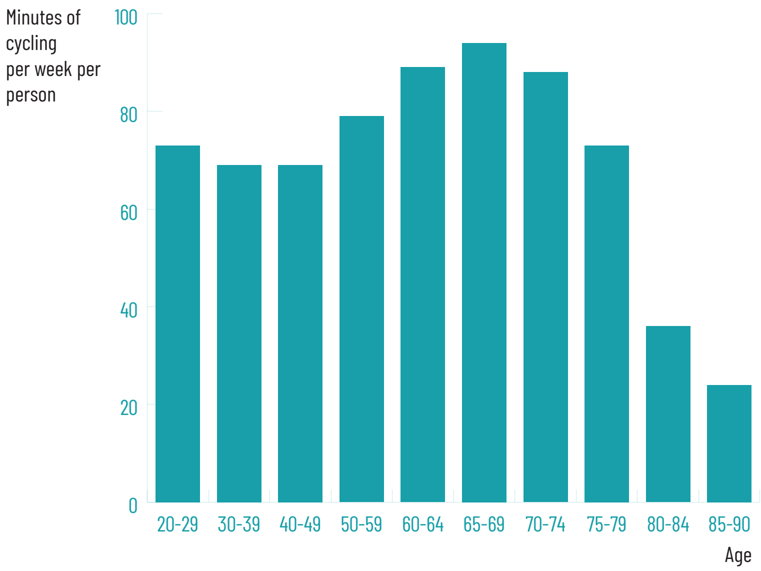


figure 12: Minutes spent cycling per week per person of different ages

severe back problems, COPD or a stroke. Physical exercise for 30-60 minutes on 5 days a week can help to avoid these chronic diseases (GGD Gelre-Ijssel, 2007). A study by Rantanen (2013) shows that especially in the early phase of mobility decline people can easily increase their physical health without support of others, so it is important to promote exercise among elderly. To do this it is important to avoid stereotypical images and negative messages (Rantanen, 2013).

After the age of 80 years the use of a bicycle strongly declines (figure 12) (Fishman et al., 2015). At old age, people lose the ability to cycle due to balance problems and reduced strength in the legs. Additionally, elderly often suffer from loss of cervical lordosis, which causes more effort to stretch the neck to look forwards and to rotate the neck (figure 13) (Bosma, K., Physiotherapist, personal communication, April 11, 2018) The main reasons to stop cycling are physical limitations, the busy traffic, and feeling insecure in traffic (Fishman et al., 2015). The elderly primarily stop cycling recreational routes, but continue to use the bicycle to go shopping (Rijkswaterstaat Ministerie van Infrastructuur en Milieu, 2013).

<u>E-bikes</u>

E-bikes are popular in the Netherlands. Figures published by SWOV (2017) show that in 2014, there were about 1,4 million e-bikes in the Netherlands and in 2015 about one quarter of all bicycles purchased were e-bikes. E-bikes are especially popular among elderly. In 2014 34% of the elderly aged 65 to 75 years old used an e-bike and 45% of the elderly aged older than 75 years old used an e-bike. The faster e-bikes, speed-pedelecs, are very popular among males who use it as an alternative to a car to get to work (SWOV, 2017). The most common motives to use an e-bike are leisure, cycling to work and shopping (figure 14) (Ministerie van Infrastructuur en Milieu, 2017).

figure 13: Loss of cervical lordosis (source: http://www.chirokzn.co.za/)

Percentage of cycled kilometres by e-bike per motive in 2016

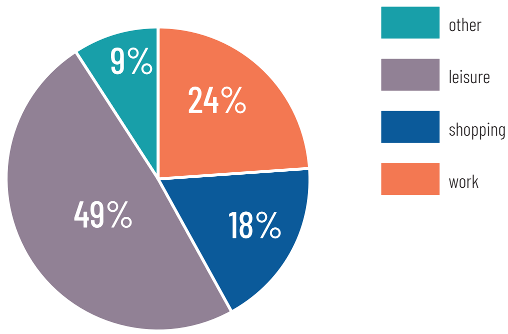


figure 14: Percentage of cycled kilometres by e-bike per motive in 2016

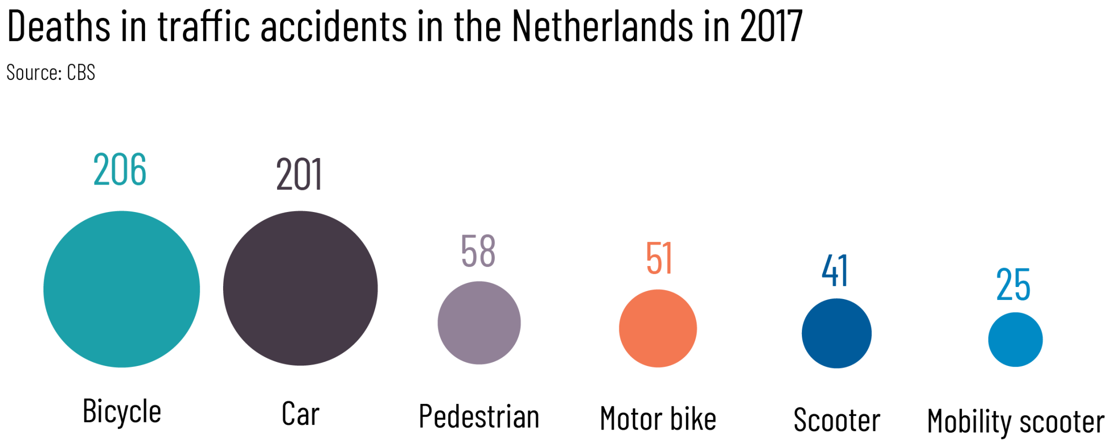


figure 15: Most deaths in traffic in 2017 were cyclists

Accidents
In 2017 there were more deadly bicycle accidents than deadly car accidents (figure 15) (CBS, 2018). A recent study by PBL shows that elderly cyclists are at higher risk of being involved in an accident. In 2009 one third of all deaths and injured caused by traffic accidents in the Netherlands were 65 years and older (PBL, 2013). Numbers provided by SWOV (2017) show that 85 percent of all traffic accidents involve cyclists and pedestrians. Two third of these accidents do not involve a second party. They are accidents caused by falls (60%). Especially with e-bikes, these falls often happen when getting on or off the bike. This is mainly due to balance problems. The e-bike is faster and heavier than a normal bicycle, making balancing more difficult. Risk of an accident with an e-bike is highest for cyclists older than 75 years. These cyclists are likely to choose an e-bike, because of their reduced muscle strength. However, with old age not only comes reduced strength, but also reduced balance and reaction time, which increase the risk of an accident (SWOV, 2017).

Accidents lead to fear of participating in traffic. For 25% of the victims this fear caused a decrease in usage or abandonment of the means of transportation (Rijkswaterstaat Ministerie van Infrastructuur en Mileu, 2013).

Cycling safety interventions
Safety of cyclists is a concern of the Dutch government. To improve the safety of cyclists the government has set goals for 2020. These are presented in the publication 'Agenda Fiets 2017-2020' (Tour de Force, 2016). The government wants to achieve a growth of 20% of the total kilometers cycled over the period of 2017 to 2027. Eight goals are listed that are to contribute to this growth;

1. The Netherlands as a bicycle country example for other countries
2. More space for bicycles in the cities
3. Improving the quality of busy routes or routes with potential
4. Optimizing the transition between bicycle and public transport and car and bicycle
5. Stimulating cycling
6. Reducing bicycle accidents
7. Reducing number of stolen bicycles
8. Strengthen knowledge infrastructure

The ambitions of the Dutch government indicate that there will be a growth in cyclists and that cycling could become safer in the future. As an example for how biycle accidents can be reduced, it is listed that the development of trendy safer bicycle for elderly that are lighter, more stable and with adjusted pedaling support should be supported. Other actions include improving the safety of the cycling infrastructure, changing the behaviour of cyclists and creating awareness for senior-proof infrastructure (Tour de Force 2020, 2016).

Acceptance of mobility aids
People with mobility problems can make use of a wide range of mobility aids, like canes, rollators, mobility scooters, tricycles and wheelchairs. Of the people aged 75 years and older that experience difficulties walking, 70% use a cane, walker or rollator and 25% use a wheelchair or mobility scooter (GGD Gelre-Ijssel, 2007).

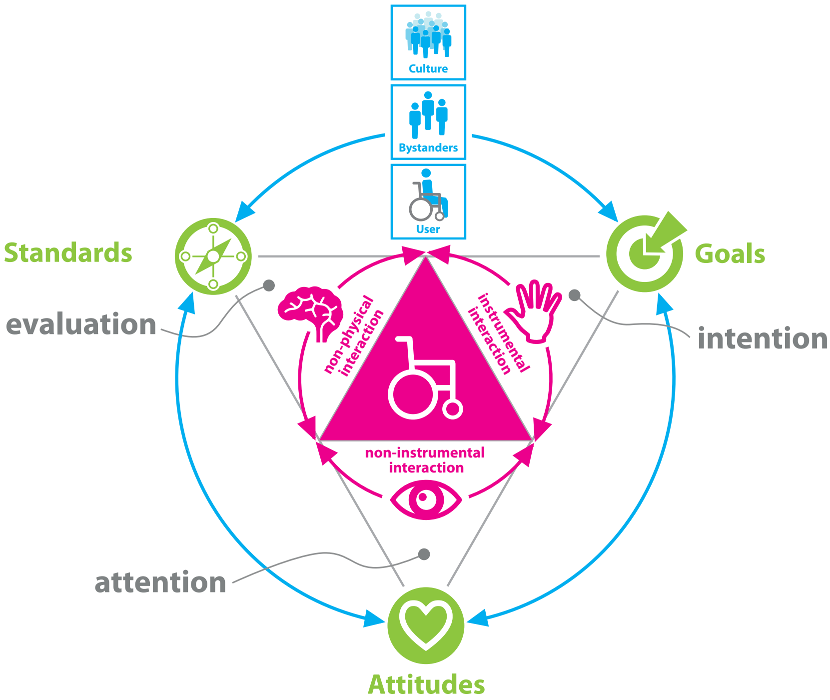


figure 16: The Product Appraisal Model for Stigma developed by Vaes (2014a)

Benefits of using a mobility aid include reduced fall risk and more confidence and autonomy (Hedberg-Kristensson et al., 2009). However, mobility aids are not easily accepted by people with mobility loss. Before starting to use a mobility aid, people often need to first overcome a threshold. They fear that by accepting a mobility aid further decline is inevitable and are afraid to get dependent on the device. (Resnik et al., 2009) Non-acceptance of a mobility aid can be caused by the unwillingness to show dependence on the device and is influenced by others' opinions (Hedberg-Kristensson et al., 2009).

Stigma

Society sees users of assistive devices as being impaired, therefore assistive devices are socially undesirable, uncomfortable and unpleasant for the user. Assistive devices are stigmatising, they elicit stigma, a negative judgmental reaction from bystanders to a person or person using a product. The reaction is caused by the visible characteristics of the person or product that are perceived as socially undesirable. (Vaes, 2014a)

The model developed by Vaes (2014a) (figure 16) illustrates how stigma works. The center of the model is the product and its three product stimulus components; product perception, product use and consequences of product use. The product stimulus components cause the user, bystanders and culture to experience the product. Around the center are positioned the three appraisal types; standards, goals and attitudes. These three appraisal types are human concerns and influence how people react to the product. Standards are a person's expectations and beliefs about how others and objects should behave. Attitude refers to what a person likes or dislikes. Goals are what a person wants to achieve. All three concerns differ between people and situations, which explains the wide range of emotions that a product can cause.

This model implies that stigma can be elicited in different ways. The user can experience stigma because of a reaction of a bystander, or because the product does not comply with the standard of the culture. An example of product stigma is when a bystander sees a person in a wheelchair. From the visual qualities of the wheelchair he concludes that the user must be impaired. According to the bystander's standards it is socially undesirable to be impaired. Based on this concern the bystander experiences an emotion, for example compassion.

In the described situation there is a conflict between the concern of the user and the bystander. The product helps the user achieve his goal of being mobile and at the same time conflicts with the appraisal of the bystander, who sees the user as being impaired. To improve the acceptance of products, designers must try to balance the needs of the different stakeholders and try to avoid conflicting concerns (Vaes, 2014a).

To help designers with this challenge, Vaes has proposed 17 design interventions for designing out stigma (figure 17).

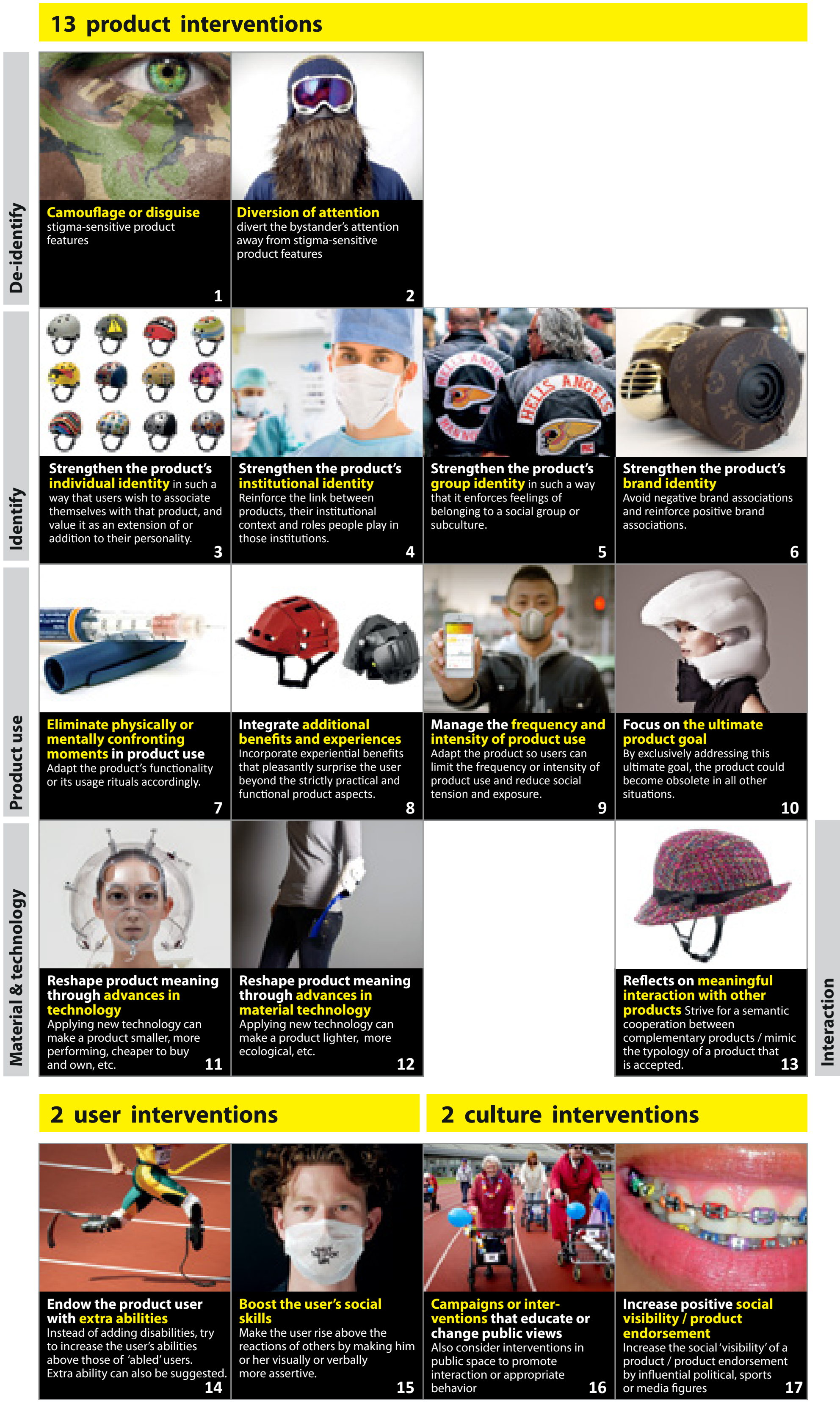


figure 17: Design interventions as proposed by Vaes (2014a)

The foundation The Age of No Retirement proposes the 'Intergenerational Design Principles' as guidelines for designing products that appeal to all ages (The Age of No Retirement, n.d.). These 10 principles are presented in figure 18. These principles are related to the interventions of Vaes (2014a), because they aim at avoiding an association with a certain group of people, in this case elderly.

THE 10 PRINCIPLES OF INTERGENERATIONAL DESIGN...

SAFE AND SECURE

Having your rights of safety, privacy, information security looked after, being respectful of personal rights and not discriminating.

CLEAR AND INTUITIVE

Being easy to understand, or easy to work out how to use.

TIME – EFFICIENT

Optimising your use of time, not being too slow nor too fast.

DELIGHTFUL

Finding things to be pleasing, beautiful or enjoyable.

ACCESSIBLE

Being easy to find, reach or use either online or off; being accessible as and when required without being intrusive.

HUMAN CONNECTION

Helping you feel connected to other people, or having two-way conversation.

FLEXIBILITY

Being given choice, being easy to adapt and not punishing errors too harshly.

RIGHT EFFORT

Needing the right level of physical effort, mental effort or is easy on the senses - sight/sound/ touch, etc.

EMPOWERING

Feeling that things contribute to self and social worth, or that they promote your development and autonomy.

SUSTAINABLE

Things being sustainable, either in terms of environmental or economic development, durability, social unity or inclusivity.

figure 18: Intergenerational Design Principles developed by The Age of No Retirement (n.d.)

Conclusion

From this literature study it can be concluded that cycling is an important part of the Dutch culture. A lot of people use the bicycle as a means of transportation to go shopping, visit friends or family or for leisure. However, due to age-related disabilities such as reduced strength and lack of balance, elderly people give up cycling out of fear for falling. Giving up cycling means giving up an important part of mobility and being dependent on alternative means of transportation. By finding ways for people with disabilities being able to keep cycling safely, these people can stay mobile and independent.

Cycling is not only convenient, it is also healthy. It has been proven that regular physical exercise helps to avoid chronic diseases. For people with mobility problems physical exercise is important to avoid further decline.

The government wants to stimulate cycling because of these health benefits and the sustainable impact it has on the environment. The aim of the government is to increase the number of cyclists and improve the safety of cyclists by improving the infrastructure and changing the behaviour of people participating in traffic. The fact that there is a lot of attention for cycling safety indicates that there is a real need and that business opportunities lie in this domain.

Improving the safety of cyclists is important, because many cyclists are involved in traffic accidents. Elderly are at highest risk to get involved in bicycle accidents. Especially falling when getting on or off their bicycle is common among elderly, due to lack of balance. To solve this problem interventions on product level are needed. As the government suggests, there is a need for trendy safe bicycles for elderly.

The acceptance of assistive devices is low, because of the unwillingness of the user to show dependece on the device. When designing a safe bicycle for elderly it is therefore important to avoid stigma, in order to increase its acceptance. To achieve this it is important to aim for a balance between the concerns of the user and those of the other stakeholders. The interventions for designing out stigma as proposed by Vaes (2014a) and the Intergenerational Design Principles developed by The Age of No Retirement (n.d) could be used as guidelines to design a non-stigmatising safe bicycle for elderly.

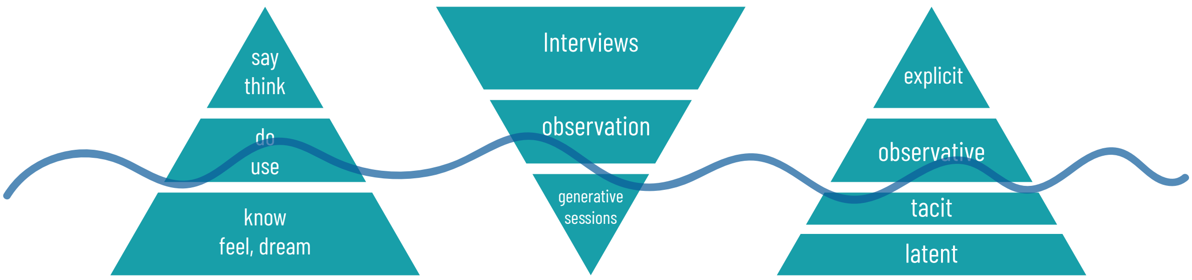


figure 19: Levels of knowledge (Sleeswijk Visser et al., 2005)

2.3 User research

To dive deeper into the context of mobility of elderly, user research was conducted. The aim of the user research was to better understand the needs of the target group, in order to formulate the design brief and requirements.

Research questions

From the literature study it became evident that the acceptance of mobility aids is low, because they elicit stigma. When designing a mobility aid, it is important to understand what causes this lack of acceptance, what is considered stigmatising and how people learn to cope with having to use a mobility aid. Therefore, the main research question focused on the acceptance of mobility aids.

Acceptance of mobility aids is a topic which is emotional and may contain a lot of latent knowledge that is not easily retrieved from the target group. As figure 19 shows, latent knowledge are dreams and feelings that lie underneath 'the surface' and cannot easily be retrieved through interviews and observation (Sleeswijk Visser et al., 2005). In order to approach this topic, the research was built around a scope (figure 20) that contains easily approachable topics related to the acceptance of mobility aids. These topics are activities, transportation, mobility restrictions and assistive technology.

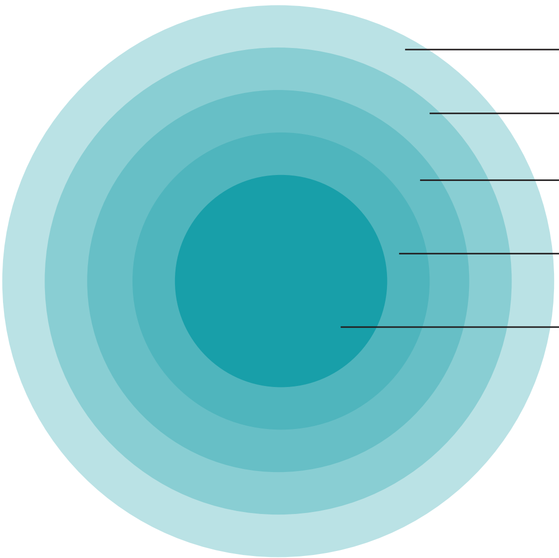


figure 20: Research scope

The research questions for each topic were:

1. Activities

1.1. Which are the most valuable activities for the target group?
1.2. Which activities does the target group do by foot?
1.3. Which activities does the target group do by bike?
1.4. Which activities does the target group do by car?
1.5. Which activities does the target group do by public transport?
1.6. Which activities does the target group want to do at old age?

2. Transportation

2.1. Which ways of transportation does the target group use?
2.2. Which is the target group's favourite means of transportation and why?

3. Mobility restrictions

3.1. How does having a mobility restriction make the target group feel?
3.2. How does being less mobile influence daily life?
3.3. How does the target group cope with a mobility restriction?

4. Assistive technology

4.1. What are reasons for the target group to use an assistive device?
4.2. What are reasons for the target group not to use an assistive device?
4.3. Which assistive technology do people with mobility problems use?
4.4. What do users of mobility aids find the advantages of their mobility aid?
4.5. What do users of mobility aids find the disadvantage of their mobility aid?

5. Acceptance of mobility aids

5.1. Which requirements must a mobility aid fulfil to be accepted by the target group?
5.2. What convinced users of mobility aids to use the product?
5.3. How did users of mobility aids feel about the product before they used it?
5.4. How do users of mobility aids feel about their mobility aid after using it?

Method

The user research consisted of two parts, a group session and interviews. For both, methods used in Contextmapping were applied, because the generative tools used in Contextmapping help to evoke latent knowledge and to let participants express their future needs.

On the one hand the research aimed at understanding the mobility needs of the future generation of elderly and on the other hand the research aimed at learning from the experiences of elderly with mobility problems. Therefore, the group session was held with participants aged 50 to 65 who are still working and do not have mobility problems and the interviews were held with elderly with mobility problems.

Interviewing using generative tools was chosen as a method for the elderly participants with mobility problems for two reasons. The first reason is that the research questions focus more on the present and past instead of on the future, which is knowledge that can more easily be retrieved through interviewing. Still, the topics discussed with this target group can be quite emotional. To prepare the participants for this, sensitizing was used. The second reason was a logistic reason. The participants have mobility problems and thus it would take them a lot of effort to travel to a group session.

Method group session

The content of the group session was based on the scope and the corresponding research questions. Several generative tools were utilized to reach the tacit and latent knowledge levels. Sensitizing booklets were used to prepare the participants for the session. This section will explain the method and tools used for the group session.

Participants of group session

For the group session 3 men and 2 women without mobility problems aged 50 to 65 were recruited. This age group was chosen, because they belong to the next generation of elderly. The participants were recruited through the personal network of the researcher.

Time schedule of group session

The session had a duration of 2,5 hours and was planned on an evening. The complete plan can be found in appendix B. The session consisted of an introduction, two photo exercises and a making exercise, with a dinner break in between.

Assistant

To be able to focus on moderating and the content of the conversations, a befriended second year bachelor student from Industrial Design Engineering was asked to assist during the session. Her tasks were to make sure the recording apparatus was constantly recording, taking photographs and preparing the materials for the next assignments.

Sensitizing for group session

Each participants received a sensitizing booklet a few days prior to the contextmapping session. By letting the participants observe and reflect upon experiences, they are more likely to have less difficulties to express their thoughts about the future (Sleeswijk Visser et al., 2005). The sensitizing booklet can be found in appendix C. It contains two exercises, which focus on the participant's activities (figure 21). The participant is asked to indicate which activities that require transportation he/she did on one day and which means of transportation was used. The next assignment is to indicate which means of transport he/she likes best and which of the activities he/she enjoys most. The assignment is fact based, and thus targets the explicit level of knowledge. This is a level that can be accessed without preparation (Sleeswijk Visser et al., 2005).

Tools for group session

The completed sensitizing exercise was used during the group session as a conversation starter. Talking about something they have prepared is easier than talking about a completely new topic. Four more tools were used to lead the discussion. The tools were a set of photographs representing feelings, a set of photographs of transportation and mobility aids, creative materials, pen and paper and a story. The story was written according to the creative facilitation method "guided fantasy". The story contained questions and gaps that needed to be filled by the participants. This was done to trigger the participants' fantasy. All the tools that were used can be found in appendix C.

Procedure of group session

As an introduction the participants were asked to present themselves and tell something about the means of transportation they use. This was followed by a discussion about the activities they do by foot, by bicycle and by public transport.

After the introduction the participants are given three more assignments, each followed by a group discussion. The first assignment aims at the level of mobility restrictions. Participants are asked to think about a past experience when their mobility was limited. This could be when their car was broken or after an operation. From a pile of photographs (figure 22) that can be interpreted in countless ways, participants are asked to choose one or two that describe how they felt during that moment. The participants are asked to present why they chose the image(s).

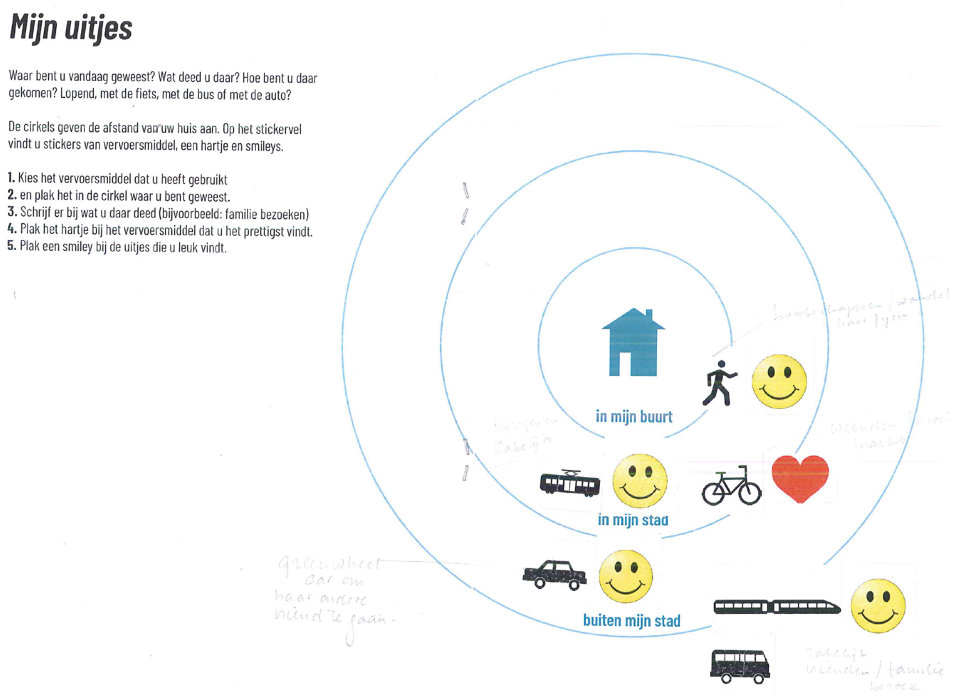


figure 21: Tool about activities used for sensitizing and conversation starter for the Contextmapping session

figure 22: Assignment 1 of Contextmapping session was to choose a photograph that describes how they felt in the moment when they were less mobile

The second assignment targeted the assistive technologies layer. Referring to the same moment when the participants were limited in their mobility, the participants are asked to choose an image of a product that could have helped them in that moment (figure 23). The participants are then asked to present why the product would have helped them, if they used it and what they did instead to cope with the situation.

The third assignment was a making exercise that aimed at the layer of acceptance of mobility aids. The participants were asked to fill the gaps of the story that was read by the facilitator to build their own story about their future. Then the participants were asked to build a mobility aid that would help them in that future. When completed, the participants were asked to present their design.

figure 23: Assignment 2 of the Contextmapping session

Data analysis of group session

For the analysis the three-phase analysis method as described by Sleeswijk Visser et al. (2005) was followed. From the recorded video and audio data a transcript was made that formed the basis of the analysis. From the transcript interesting quotes were selected and paraphrased to create 'statement cards'. The statement card contains the original quote and the interpretation of the researcher (Stappers, 2012). These statement cards were first clustered by topic (figure 24) and then analysed to find insights and answers to the research questions (figure 25).

figure 24: Statement card from the context mapping clustered by topic

figure 25: Insights from context mapping

Method generative interviews

The generative interviews were held with elderly people that use mobility aids to learn about their acceptance process and experiences with the mobility aid. The interview focused on the layers "assistive technology" and "acceptance of mobility devices" by asking about current and past experiences with mobility aids. Because these people are less mobile the interview's were held at their homes.

Interviewees

For the generative interviews 3 men and 4 women of 65 years and older and that were expected to use mobility aids were recruited through the network of Manja Ellenbroek from Dare to Care. The participants of the generative interviews are from here on referred to as 'interviewees'

Sensitizing for interviews

The interviewees received a sensitizing task to prepare for the interview. The interviewees were given an empty timeline (see figure 26) on which they were asked to write milestones from their experience of losing mobility (see appendix C). This is factual information, thus it is explicit knowledge and can be easily retrieved without preparation.

Tools for interviews

During the interviews, a map of the region in which the interviewee lives, was used as a second tool (figure 26). The map was used to indicate the activities and distances travelled by the interviewee and the means of transportation used to do this. This was used to learn about the mobility patterns of the interviewee.

Procedure of interviews

The interviews were semi-structured. They all started with a short introduction about the project followed by questions about the interviewee's experience of mobility decline. Depending on the knowledge already provided by the interviewee, clarifying questions were asked to touch upon the topics that were defined for the interviews. The map tool was only used when it was expected that it would reveal relevant information.

figure 26: Tools for the generative interviews

Data analysis of interviews

The audio of all interviews had been recorded. Transcripts of this audio were made, but irrelevant conversation was left out. Similar to the analysis of the group session, interesting quotes from the transcripts were selected and paraphrased to make statement cards, which were then clustered according to topics (figure 27) and analysed to create insights (figure 28) and answer the research questions (figure 29).

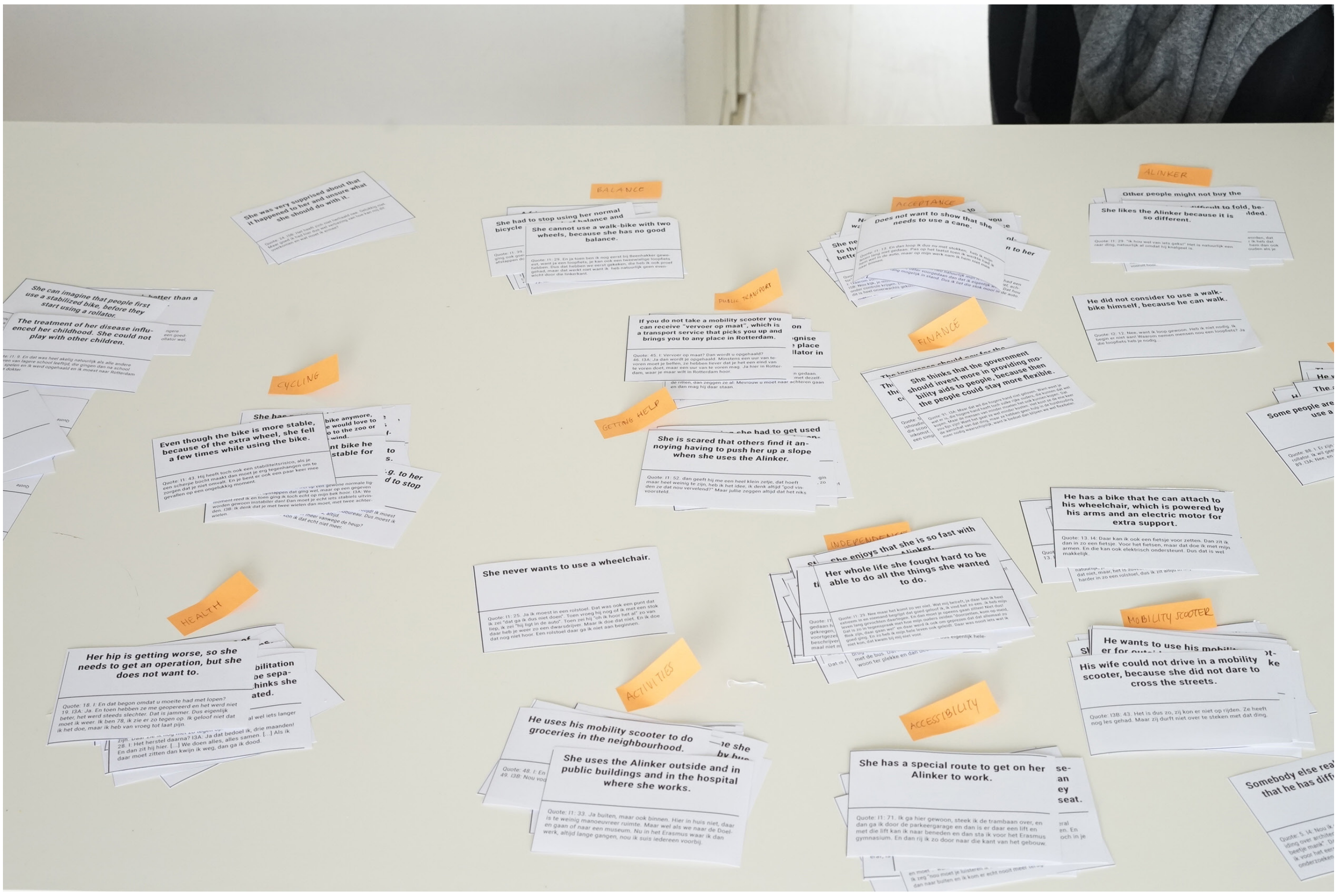


figure 27: Clusters of topics of generative interviews

figure 28: Insights from generative interviews

figure 29: Answering research questions with insights from generative interviews

Results

The data from the group session and the generative interviews was used to answer the research questions. The transcripts can be found in appendix D. The results that were most relevant for the project are presented in this section. Additional results can be found in appendix E.

Results group session

After scanning the transcript of the contextmapping session for interesting quotes and paraphrasing these, the statement cards have been clustered according to topics. In this chapter these topics will be presented.

Cycling

All participants cycle and most of them also enjoy it a lot.

"Privately I prefer walking and cycling. I live next to the forest, that is very nice." (Participant 4)
"…But the bicycle does have my preference." (Participant 2)

"Something like: nice bike! And I just feel free. The same with a normal bicycle. While cycling I can get real tired." (Participant 5)

The range of cycling is about 10 kilometres.

"I actually do everything by bike that is good to cycle, and I would say that it up to 10 kilometres." (Participant 3)

One participant even takes the bicycle when it rains. She feels proud afterwards.

"It is a sport for me to put on my rain suit and cycle up the Erasmus bridge. That is because I realized that I am very satisfied after I did that." (Participant 5)

Not everyone likes to take the challenge to cycle through the rain. "I am a nice-weather-cyclist. I find it annoying to get wet." (Participant 3)

In the sensitizing booklet the participants indicated that the activities they do by bicycle are shopping, visiting friends, going to the forest or park and client visits.

Being disabled

The participants explained how they felt when they were temporarily disabled. They felt dependent, unable to go anywhere and had to take rests regularly. One participant said he felt like a wreck.

"That was when my knee did not work anymore. You really feel like a wreck. You cannot go anywhere. That was crack in the knee and then it was over. Then you walk with crutches, stumble. You can't drive a car, you can't push the pedals. Biking is also not possible." (Participant 1)

Using a mobility aid

The participants said they would use a mobility aid if it is really necessary, because they want to stay mobile and independent and continue doing the things they want to do.

"Yes, you want to stay mobile, everyone does I think!" (Participant 1)

"I also don't want to stay inside" (Participant 3)

"If it is necessary I would use such a thing" (Participant 1)
"Well, you want to keep walking, because then you are independent." (Participant 1)

"If that is the situation, I think I can't avoid it. Then I have to take it with two hands, because then I can continue doing the things I want to do." (Participant 2).

Acceptance

Even though the participants said they would eventually use a mobility aid, they do find it difficult to accept that they need a mobility aid.

"I think that I really would not admit that I have anything that would mean that I am less mobile" (Participant 2)

And they also have people in their network who did not easily accept it.

"She had to use assistive devices of course, but she really had to get used to the thought that "Okay, I am less mobile, I need to solve my problem now"" (Participant 3).

"My father was 89 and really opposed against using a rollator. My mother-in-law is now 80, she slowly accepted it. She always said "No, I am fine like this". You see everyone postponing it." (Participant 4)

Coping

Before people accept their mobility problems, they pretend they are fine. Two participants coped by taking painkillers instead of using a mobility aid.

"Because I took Paracetamol, just keep walking and take enough rest." (Participant 5)

"I had an accident during a cycling tour at the Ijsselmeer. I walked down a hill and injured my knee. We did have to finish the tour, that was very painful." (Participant 2)

Another way of coping is looking for other things that may help them, that are not mobility aids, for example a scooter or automatic car.

"She couldn't bike, so she bought a scooter. Then her car broke and she bought an automatic car." (Participant 3)

Also an exoskeleton would be preferred above mobility aids.

"I am thinking more about devices that support movement, for example of the knee. I can imagine something like an exoskeleton. If you can put that around your knee to support it and keep it moving, I would support that kind of developments." (Participant 4).

Image
Some participants care more about what others think of them with the mobility aid than others.

"But I am not ashamed to ask for help and I am not embarrassed for it." (Participant 3)

"Oh I am also not ashamed, but I don't want to be seen on [a mobility scooter]." (Participant 2)

"I am also not ashamed, but if there are alternatives I would definitely look for those." (Participant 4).

Similarly, there are participants who care more about the image of their car than others.

"It does have to have style I think. A car needs to be beautiful. A scooter can look old, vintage." (Participant 2)

"Not in your case, but there are situations where you can imagine that..you do something with bicycles, then you can't arrive in a Green Wheels car." (Participant 2)

"The other day I rented a Borent car for 14,50 euro a day, one with a big sticker on it. I just drive around with it, no problem, even to the director's office. If they want to judge me on my car that's fine." (Participant 4)

Trendy
Related to the image is the appearance of the mobility aid. Some participants state that the mobility aid must be trendy and fun to use. As examples they give the Irreal of Toyota (figure 30), an exoskeleton and Segway.

"I think there are a few terms that apply at that moment, at least for me, it has to be hip, let's say I am vain then. I am thinking about an adaptive vehicle. With adaptive I mean that it can change its shape." (Participant 2)

"Look! Someone who wears an exoskeleton suddenly enjoys getting up and moving. I have never seen anyone in a mobility scooter with a smile. I want to illustrate that the experience is very important. That's why I said it must be hip. You need to have some fun with it." (Participant 2)

"Segway for example.""That is so big!" "But you can think about the form.""Yes, I would also get on a Segway." (Participant 4, 3, 1)

"I see myself doing groceries on a Segway, if it is necessary." "Yes me too!" "And then hoping you are mobile again soon. Of course there are crutches and all that, but this is actually something fun. It has something. People will ask you what is going on, instead of.." "Looking at you with pity." "On a Segway you are taller than everyone." "Yes that is why! Keeping a bit of overview." "Yes and they are so nicely mobile and agile. Big horn on it." (Participant 4,1,2)

Positive attention
The participants agree that it is nice to get positive attention from people when using a mobility aid.

"When I am unhappy, which does not happen often, I go out with the Alinker. Because then I meet a lot of people who smile at me." (Participant 5)

"At some point you had these Senz umbrella's. I was one of the first to have one. I walked through the rain with it for fun. The people look at you: what kind of weird umbrella do you have! And everyone likes it. Then it is not so bad to walk through the rain." (Participant 4)

And it is even nicer if they do not notice that you are using a mobility aid.

"I once came walking to the tram and the driver came to me and said: "bicycles are not allowed in the tram" "Sir this is not a bike, it is my alternative for a rollator." "You do not look sick!" "Keep it that way! Thank you!" People said I should send a complain, but I said: "No, this is the best compliment that the man could give me". Because he only sees a nice bike." (Participant 5)

Mobility scooter
All participants agreed that the mobility scooter is not something they would like to use.

"I think I really would not want to be seen on a mobility scooter, even if I could not. Every other method is fine." (Participant 2)

"I pity those who have to sit in a mobility scooter or use a rollator." (Participant 4).

This has several reasons, namely it is slow, unsafe, unstable, stigmatising and the user sits under eye level with other people.

"They are way too slow, they are low, so you are lower than the rest of the traffic. It makes you look even more dependent than you already are. And they are very unstable. Those things are not safe." (Participant 3)
"And they are stigmatising." (Participant 4)

"I think that there is a big difference between sitting in a wheel-chair and sitting in a mobility scooter. A wheelchair is a medical device in all kinds of versions of course. And a mobility scooter is, I think, a sort of cheap alternative. I can't tell exactly, but there is something about it that I really don't like." (Participant 2)

figure 30: Toyota i-REAL (source: https://www.ultimatecarpage.com/gallery/Toyota-i-REAL-111493.html)

Results interviews

In this section the most relevant results from the interviews are presented. Additional results can be found in appendix E.

Activities

The interviewees try to keep doing the activities that they like. Some activities that were mentioned by the interviewees are going to the market, doing groceries, visiting a museum, going to the theatre, going to the park or doing (voluntary) work.

"She walks faster than me, I don't walk that far anymore. But I do go to the theatre and to museum." (Interviewee 5A).

Independence

The interviewees mentioned they want to do things independently as long as possible.

"I don't know if I see using a mobility scooter as a step back, but I don't want to make that step, for as long as possible, preferably never. Even if you could only step by step take 5 steps outside, you are outside and you do have contact with people. And if you use it indoor, then I think it is good because you are moving, you can take care of yourself." (Interviewee 5B).

And that they do not like it when others empathize that they cannot do something.

"She says "I can do that for you", no whining, no "Can you do that?", she just does it. And I have many positive experiences like that." (Interviewee 5B).

The interviewees feel good when they are able to do things that they used to do.

"On my way I met a young couple who said "Oh madam, we saw you at the Erasmus bridge and now you are here, how great! That you can still do that, fantastic!" I got home and I said to her "Guess where I have been?" Those are old days that live up again." (Interviewee 5B)

A mobility aid enables getting this independence and freedom back.

"From the first second that I use the Alinker it is fantastic, I race like an idiot through the streets. Very dangerous!" (Interviewee 1) "It gives back mobility and freedom, that walking. You are still limited, because you need to use the rollator. Can I go in there? Is there an elevator? But still, it is good to have it." (Interviewee 5B).

But it does need a positive attitude and creativity to keep doing these things when you are disabled.

"I do not know that, look I could not yet do it, but now I did it. And last week I walked the Willemsbridge to get to the market and I took the bus back. You should not think "Can I do that?", you have to decide on the moment." (Interviewee 5B)

"And then you see how you get back and otherwise if you can't because you are too tired, you go to a hotel or we stay at your brother's place. I mean you need to be creative." (Interviewee 5B)

"That is how I lived my whole life. There was never anything that I could not do" (Interviewee 1)

Acceptance

A lot of interviewees mentioned that it is difficult to accept your disabilities and start using a mobility aid.

"Look, you have to get used to everything. You have to get your thoughts under control. You think "nonsense, I will get better". Because it came very suddenly. But then you don't get better." (Interviewee 5B)

"And now I walk with a cane, I have never done that in my whole life. Only much later, when I had to work, I put it in my car, but I did not take it with me inside." (Interviewee 1)

The moment of giving in to a mobility aid is very emotional, because it means admitting that you are disabled.

"Well it does crush your ego. I always hiked, I could do everything, go to places. And now you have to walk with a rollator and everyone makes place for you and tries to help. Well that is acceptance. I did not think that it would be so tough, but it is." (Interviewee 5B)

One participant, who had a very slow decline of mobility, experienced it as less emotional.

"Well it happened gradually. Then you get used to it. If it happens suddenly, I don't know, I think that it a psychological process. But I did not have that. There are a lot of things I can't do, that is a pity, but also a lot of things that I did do." (Interviewee 4)

For some people pain or a fall is a reason to start using a mobility aid.

"I think that they will try to continue as they are used to, that they will try cycling on their bike for as long as possible. And some will succeed for a long time, without falling. But when they fall it is over, then they cannot use their bike anymore." (Interviewee 4)
"Yes..wanted to..you have to! You do want to keep walking of course. The pain kept getting worse." (Interviewee 3A)

"Eventually they will use it, after they have fallen several times and at the request of their children they will use the rollator." (Interviewee 2)

What can also help with the acceptance of the mobility aid is when it restores the mobility of its user or when it seen as something normal.

"Well, it is okay now. I walked across the Erasmus bridge with my rollator. So I can again do what I used to do! Not every day, but I did it." (Interviewee 5B). "

Just like it is nowadays totally normal to take your rollator or other mobility aid to the supermarket. Nobody looks up anymore." (Interviewee 5B).

Some mobility aids are more easily accepted than others. One interviewee said she would never use a wheelchair.

"Yes I had to use a wheelchair. At that moment I said "I am not doing that". He then asked if I use a cane and I replied "It is in my car." He said "Oh I see.". He thought I am another of those rebels. But I do not do that. I will never start using a wheelchair." (Interviewee 1)

Image
Many interviewees mentioned the importance of the image of the mobility aid. If the image is not right, they do not want to use it.

"I would never sit on the Alinker. I don't like it. I don't like its image. If it is really necessary I would use the two wheeled walk-bike, then I can easily manoeuvrer between people. If I get balance problems, god save me..." (Interviewee 2)

"No, they are really ashamed to walk behind the rollator." (Interviewee 3A)

It is important that they like the appearance of the mobility aid and that it fits their style.

"So the new solution should be an Alinker with a bit of the Brompton concept." (Interviewee 2)

"You walk behind the rollator, so it is part of you and you want a nice appearance. As car I always had a Käfer, that car suited me. You want the same with your rollator. Where I go people say "what a nice rollator you have!". If you walk with a normal rollator of ANWB they don't say that." (Interviewee 5B).

There is a stigma around mobility aids.

"But it is true. When I started to have problems walking, people immediately noticed it. We human beings are very aware of how people walk. It seems to be more important than if someone is mentally stable, because it is one of the primary skills of a human. If you can't walk properly, you are not a human." (Interviewee 4)

Therefore people would rather not be seen using a mobility aid. "I had to use crutches. I walked with them around the building, but only at night, so no one could see me." (Interviewee 2)

After some time, some interviewees got used to this stigma.

"I really don't care about stigma." (Interviewee 4)

Health
All interviewees had different health problems that caused their mobility restrictions. For some it was a chronic disease like Polio or PLS, others got injured or had problems caused by old age, such as back problems and balance problems.

Cycling
Most interviewees do not cycle anymore. Some have not cycled for many years, because they did not need it.

"I have not biked since I am thirty or forty. I did not need a bicycle. I did not have a job where I had to cycle. We lived on the top floor, so I couldn't put the bike anywhere." (Interviewee 5A)

Others used to cycle a lot, for example to work.

"I biked to the TU in Delft." (Interviewee 3B)

"Yes, you biked quite far. We always biked a lot. To Scheveningen and Hoek van Holland." (Interviewee 3A)

"I always biked. Always! I had to get to Schiedam where I worked in an employment agency. Always on the bike of course." (Interviewee 3A)

Some interviewees would love to cycle again. One interviewee would love to cycle with this beautiful weather and visit the zoo. She does not care if there is wind.

"Really a pity, because it is fun to cycle. Look what a nice weather! Maybe there is a lot of wind, but it is beautiful. Cycling to the zoo or something, amazing. Yes, cycling was ideal for me." (Interviewee 3A)

One interviewee owns a stabilized bicycle with a special frame that makes it easy to get on the bike. It is called walk-in bike and has two wheels in the front (see figure 31).

Balance
Some interviewees had to stop using the bike due to balance problems and reduced strength.

"I used to have a normal bike, but at a certain moment I could not get off the bike, due to reduced strength and balance." (Interviewee 1)

Also other cyclists and getting off the bike can be a problem.

"All those bikes go so fast! I don't know if they feel safe." "Especially when getting off I think." "My brother and his wife went cycling a lot, but at some point, when they had to stop, his wife could not get off and then she would fall. Those are things, if you have an additional wheel it does not happen." (interviewee 5B, 5A)

Even the walk-in bike (figure 8) is not so stable, interviewee 1 has fallen a few times with it.

"It also has a stability risk. If you make a narrow turn, you have use your weight not to fall. And you also fell a few times." (Interviewee 1B)

One interviewee believes she cannot use a walk-bike, because she is too old for it.

"You have to keep your balance, keep attention to your surrounding and move your legs well. One wrong step and you can break your bones. It sounds dramatic, but that is how it is." (Interviewee 5B)

figure 31: Walk in bike from interviewee 1

<u>Insights from the user research</u>
In this section the insights from the group session and the generative interviews that are relevant for this project are presented per topic. The topics are activities, means of transportation, mobility problems and acceptance of mobility aids.

Activities
The participants and interviewees both value similar activities. Doing groceries or going shopping, cultural activities like visiting a museum and enjoying nature are activities both groups like to do. The participants indicated that also at old age they would like to travel to other cities and enjoy nature.

Means of transportation
The means of transportation that are being used differs between the participants and the interviewees. Due to their mobility problems the interviewees are unable to cycle and some of them cannot drive. Most activities are done by foot, using a mobility aid or being taken by car with someone else. Some of the interviewees also make use of the bus, metro or tram.

The participants are still mobile and most of the time they use their bicycle or the car to get to places. The car is mainly used to travel outside the city, for example to travel to work. Cycling is seen as a convenient and enjoyable means of transportation for in the city and distances up to 10 km. The participants use their bicycle to do groceries, go shopping, visit friends or family or to make a recreational tour. Public transport is used by the participants if it is faster and cheaper than taking the car or bicycle.

Cycling
Most of the participants indicated that the bicycle is their favourite means of transportation, because it is convenient and healthy. They use it a lot to travel small distances, for example to the supermarket or city centre. Also some of the interviewees used to cycle a lot. Due to lack of balance they cannot cycle anymore and pity this, because they miss the freedom cycling gave them.

Mobility problems
For the participants it is difficult to imagine that one day they will be less mobile. They all indicated that being mobile is important to them and that they would not like to be dependent on others. They would like to be able to continue doing the things they like to do. For these reasons they would eventually use a mobility aid if necessary.

The interviewees indicated that having mobility problems has consequences on their quality of life. Some interviewees feel unhappy because they feel dependent or limited and long to do things they used to do. Not all places are accessible for people using mobility aids. This makes some of the interviewees feel discriminated.

Acceptance of mobility aids
Accepting a mobility aid is difficult. Some interviewees explained that it was an emotional burden for them to use a mobility aid, because it means having to accept that they have a disability. Only some of the participants have experienced being less mobile and in all cases it was temporarily. One of them used crutches and felt like a wreck, being unable to cycle or use the car. Another participants still uses the Alinker from time to time. She likes to use it, because it does not look like a normal mobility aid. Some people think that she is using a bicycle. None of the participants wants to use a mobility scooter. They do not like its image and consider it slow, unsafe, unstable and stigmatising. They also do not like that the user is under eye level of other people.

The participants indicated that they would find it easier to accept a mobility aid if it is trendy and does not have the image of a device for disabled. The Segway was mentioned as an example for a device they would use. They like this device because it is agile, it is trendy and it gives them overview. For the interviewees feeling less pain, reducing the risk of falling and being mobile again were reasons to accept the mobility aid.

Mobility aids
All except one of the interviewees use a mobility aid. They use rollators, canes, a mobility scooter, wheelchair and the Alinker. Even though for most accepting the mobility aid was difficult, they now appreciate the device for the mobility and independence it gives them. Still, there are many points for improvement mentioned by the interviewees. For example, they find it important that they can access buildings and public transport with their mobility aid. What is also considered important is that the device is safe, stable, agile, flexible in use and that they are at eye level with other people when they use it. Also aesthetics is considered important.

Discussion

In order to gain empathy and understand the user's needs, a qualitative research method was chosen. The insights from the research created deeper understanding of the context, but also need to be treated with care. The limitations of this study are explained below.

Qualitative study

The results from this qualitative user research can be used as inspiration for the design process, but are not scientifically proven. However, certain aspects have also been discovered in literature, such as which activities are done by bicycle. Also the reasons given by participants for finding it difficult to accept a mobility aid are similar to those found in literature. Even though these insights are not new, talking to the participants did help to empathize with the user and to being better able to imagine what having mobility problems feels like. This will very likely benefit the design process.

Participants

The target group for this project are people who feel insecure on a bicycle because they are scared of falling. This target group had not been specified before the user research, thus the participants and interviewees that participated in the user research belong to a wider target group and not all insights are considered relevant. But by recruiting people who do not yet have mobility problems and people who use mobility aids, insights were gained from people who might in the future experience a feeling of insecurity on the bicycle and people who have already given up cycling for reasons including fear of falling. This creates understanding about the concerns of future users and about which aspects are important for improving the acceptance of the mobility aid.

All participants and interviewees live in a city. People who live in rural areas or small villages might do different activities, use different means of transportation and experience mobility aids differently. Thus, the limited variety of participants might have influenced the results.

Analysis

The data analysis was conducted by one researcher, thus the interpretation of the data is also done by one researcher. Doing the analysis in a group might have led to slightly different interpretations of the data.

Conclusion

From the user research it can be concluded that having to use a mobility aid due to mobility problems is an emotional burden and acceptance may take time. It is especially difficult to accept not being able to do everything anymore and being dependent on others or on the device. The acceptance can be increased when the mobility aid is trendy or used by many others in the user's surrounding. This indicates that it is important that the product is seen as normal and can also be used by other target groups. Also aesthetics may have large influence, because it can help to make the product trendy.

Next to the image of the mobility aid, functionality is also important for acceptance of the product. Functionalities that are mentioned as advantages by the participants and interviewees are flexibility in use, agility and safety.

Mobility is important for participating in activities. From the user research it can be concluded that a few activities seem to be important for elderly. These activities are related to shopping and leisure. It is important to enable the user to do these activities with the product and therefore both use scenarios should be considered during the design process.

The participants found it difficult to imagine being less mobile in the future. This indicates that it may be difficult to introduce a product that helps people who are in the early decline of mobility. This should be considered when positioning the product on the market.

Cycling is an activity that the participants do and enjoy a lot and that most interviewees had to give up due to their disability. Some of the interviewees miss being able to cycle, because they miss the freedom it gave them. This indicates that there is an interesting design opportunity to design a bicycle solution that enables people with mobility problems to be able to cycle despite their disabilities.

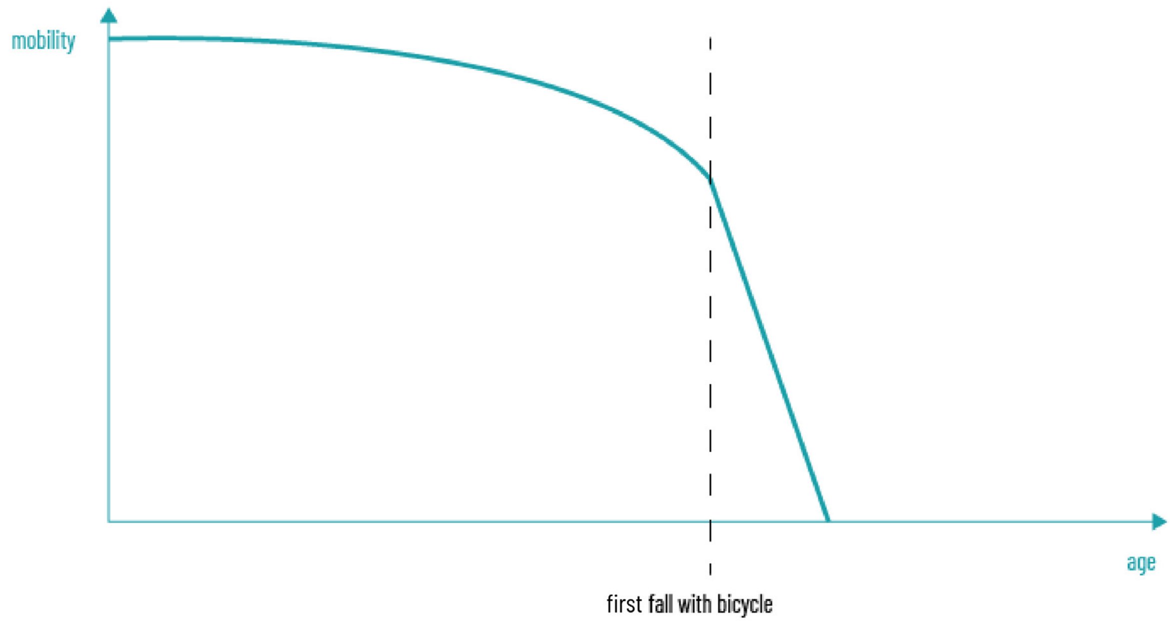


figure 32: Age-related disabilities lead to mobility decline and increase the risk of falling with the bicycle

2.4 Defining the problem

The analysis of the context led to the discovery of two main problems. The first insight is about stability and was found in the literature study. To summarize, the problem is that elderly people are at high risk of falling with the bicycle. This is due to age-related disabilities and e-bike use. The second insight is about stigma and is a result of the user research and can be validated by literature. To summarize, the problem is that mobility aids are stigmatising. The problem of stability and stigma are further discussed in this chapter.

<u>The problem of stability</u>
With increasing age people may experience age-related disabilities, which include a reduction of strength, reduced balance, deterioration of sight and hearing and a reduction of reaction speed that cause a decline in mobility (figure 32) (SWOV, 2017). When and which of these disabilities occur differs per individual.
To compensate for a lack of strength, many elderly use an e-bike. In 2014 34% of the elderly aged 65 to 75 years old used an e-bike and 45% of the elderly aged older than 75 years old used an e-bike (Vlakveld, 2016). Recent numbers show that the number of deadly accidents with e-bikes increase, especially among males. In 2017 there were 57 deadly accidents with an e-bike, 17 more than in 2016. In total this makes up a quarter of all bicycle accidents. Amongst the elderly most accidents with a bike are fall accidents that do not involve a second party (Rijkswaterstaat Ministerie van Infrastructuur en Mileu, 2013). With e-bikes most falls happen when getting on and off the bicycle (Vlakveld, 2016). 25% of people who fell stopped using the bicycle or use it less out of fear of falling again (Rijkswaterstaat Ministerie van Infrastructuur en Mileu, 2013).

<u>The problem of stigma</u>
Increased risk of accidents due to mobility problems that occur at older age increases the need for a safe means of transportation for the elderly that allows them to stay active. Available mobility aids like rollators, mobility scooters and wheelchairs provide support for people with mobility problems, but their acceptance is low, because they are stigmatising (Parette & Scherer, 2004). People do not want to be seen by others as being old, vulnerable and independent. People prefer not to use products that are different than those that the general population uses. (Resnik et al, 2009)

<u>Problem definition</u>
Because of their instability, bicycles and e-bikes are not suitable for elderly with reduced balance. A stabilised bicycle could help to avoid elderly from falling, but in order to be accepted by the users it must not create the association with a disability to avoid stigma.

<u>Project focus</u>
The focus on the project will be on stability and stigma, because creating a bicycle that is stabilised and non-stigmatising are equally important in fulfilling the needs of the target group.

3

Exploring the design space

3.1 Design brief

Based on the insights about the problem and the target group, the design brief consisting of the design goal, target group description and scope has been formulated to provide direction during the design process.

Design goal
The goal of this project is to maintain the cycling mobility of elderly people. Being mobile is very important for an individual's quality of life. It means being independent and having the freedom to do the things one likes to do. Mobility is required to make use of the facilities in the neighborhood, to participate in social and cultural activities and to have physical exercise. The latter is very important for healthy aging.

To achieve this goal both stability and stigma are important aspects. It is important to avoid a fall with the bicycle and to provide a suitable solution that elderly like to use. The design goal is therefore to:

"Design a non-stigmatising bicycle for elderly that provides stability when getting on and off the bicycle."

Target group
Although several target groups could benefit from a non-stigmatising stabilised bicycle, the decision was made to focus on one specific target group. This allows to set specific requirements and helps to make design decisions.
The target group is elderly who feel insecure when cycling on a normal bicycle due to balance problems. Some may have experienced a fall and are afraid of recurrence. This group has cycled up to this point and does not want to give up cycling. They have sufficient overview in traffic to take part.

Scope
The solution space is wide. There are opportunities to explore new bicycle designs or add-ons for existing bicycles. However, the activity the user performs should be cycling. Cycling promotes an active lifestyle, because it is physical exercise. Cycling also fits the scope of Beixo, because the company operates in the bicycle market. The user should experience confidence while using the solution. Confidence means having no fear for falling, having an overview in traffic, being balanced, being able to get to the desired destination and feeling in control.

Design criteria
Based on the insights from the analysis, the following design criteria have been set:

1. The product is non-stigmatising
2. The product provides stability during use
3. The design of the product is simple
4. The product ensures easy handling
5. The product is age independent

These criteria will be used to evaluate the design. The design must satisfy these criteria in order to fulfill the needs of the user and the client.

3.2 Design strategy

The challenge of this project is to design a stabilised bicycle that is not stigmatising. In order to avoid stigma, a design strategy based on the theory of Vaes (2014) and the principles of The Age of No Retirement (n.d.) has been used. Vaes proposes several interventions to avoid stigma in design. Of these, three seem most relevant for this project;

- reflect on meaningful interaction with other products
- integrate additional benefits and experiences
- camouflage or disguise

Furthermore, the design strategy is to avoid the association with a certain age group. To achieve this, the principles developed by The Age of No Retirement (n.d.) will be used as guidelines. The principles that seem especially relevant have been translated into design guidelines:

1. The product allows for flexibility in use
2. The product asks for the right effort of the user
3. The product empowers the user
4. The interaction with the product is clear and intuitive
5. The product is accessible, it can be used by anyone

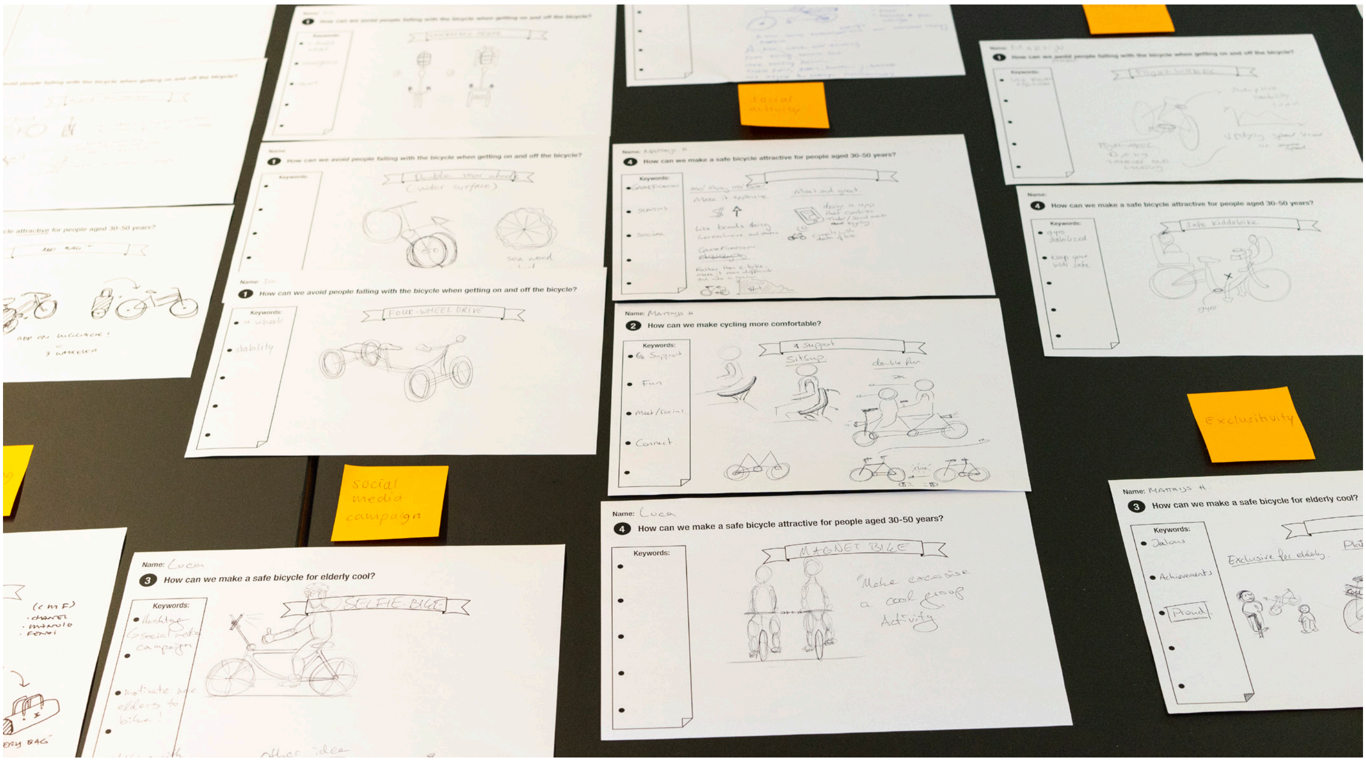


figure 33: The ideas generated during the creative session were clustered

3.3 Design direction

The first step in the design process was to find a promising design direction. The steps towards a choice for a design direction are explained in this chapter.

Creative session
To explore the possibilities and to think out of the box, eight designers of VanBerlo were invited to participate in a creative session during which the design space was explored. After a short introduction to the topic the designers were provided with how-to's that guided the brainstorm (see appendix F). The how-to's focused on stigma and stability. Many ideas were generated during this session. The ideas were clustered to create an overview (figure 33). This resulted in the clusters:

- three wheels
- emergency support
- lowering saddle
- gyroscope
- assisted cycling

Design directions
The clusters created from the ideas generated in the creative session were used as input for ideation. The clusters were further explored and turned into design directions (figure 34). One of the directions was 'support bags', carrier bags with integrated support wheels. To avoid stigma the stabilising wheels are hidden in the bags. Another direction was 'cargo tricycle', a tricycle with a cargo area for transporting goods between the two front wheels. This idea reminds of a three wheel cargo bike, a product category that has no stigma. A third design direction was 'emergency support', support wheels that would only unfold when the bicycle destabilizes, in order to prevent a fall. 'Smart saddle' is a saddle that automatically moves downwards when the bicycle slows down, in order to allow the user to reach the ground with two feet and take a stable position. The design direction 'gyro bike' is bicycle with an integrated gyroscope and flywheel to stabilize the bicycle. 'Assisted cycling' is a bicycle that uses sensors to assist the user while cycling. The information provided by the sensors makes cycling more safe.

Choosing design direction
The design directions were evaluated on the five design criteria described in the design brief (figure 35), to make a choice. Also relevant for the choice were the business opportunities for Beixo. When looking at the evaluation of the concept directions, the cargo tricycle seems promising, because it scores high on the criteria simple, age independent and stable. Other concept directions score higher on non-stigmatising and easy handling. It will be a challenge to design a cargo tricycle that is non-stigmatising and easy to handle. From a business perspective, it would be most profitable for Beixo to develop a complete bicycle solution to expand their portfolio. For this reason, the 'support bags', 'emergency support', and 'smart saddle' are less interesting. The concept direction 'assisted cycling' does not solve the stability problem, but would be interesting to combine with another concept direction. For these reasons the 'cargo tricycle' was chosen as a design direction.

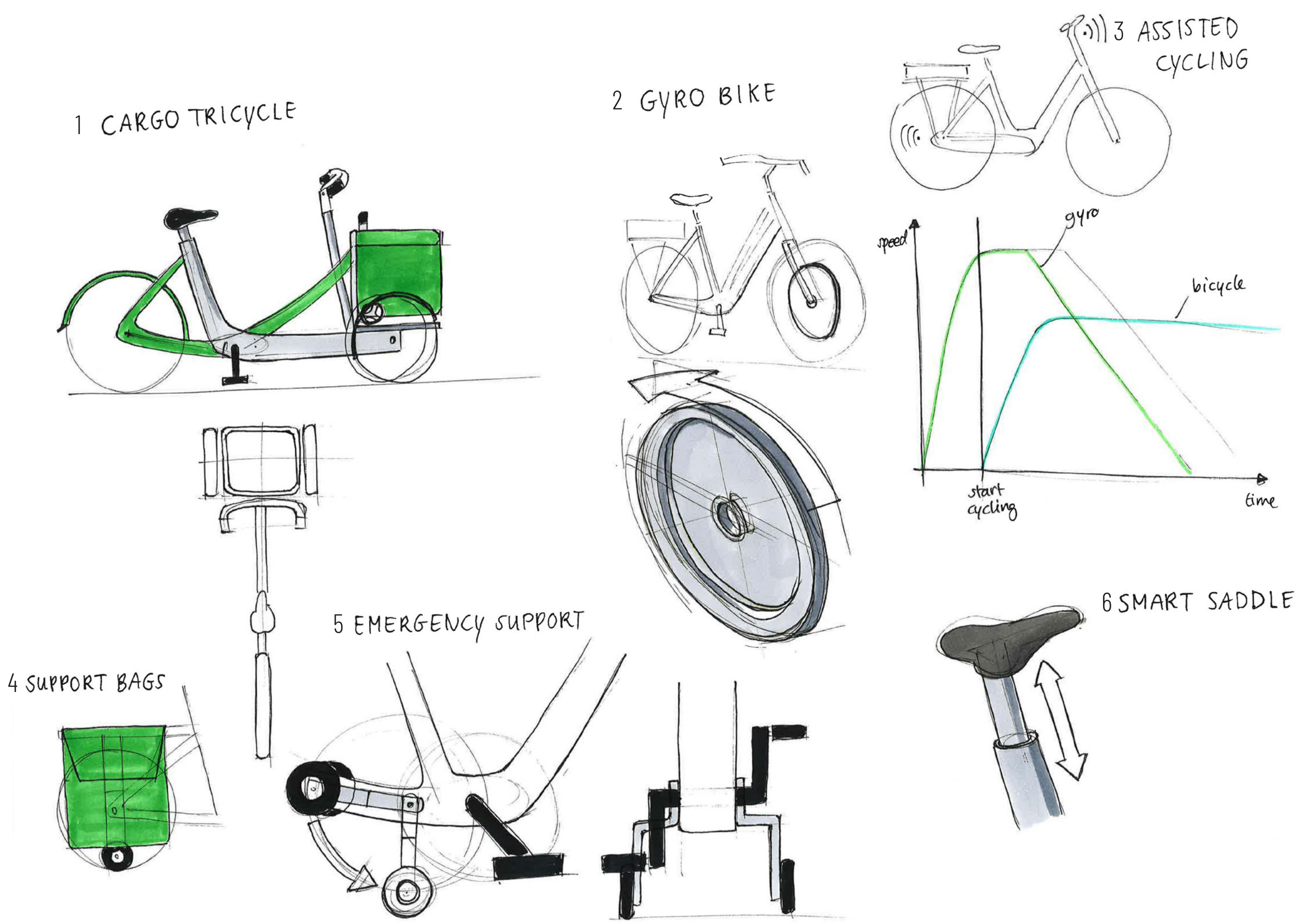


figure 34: The design directions

	Simple	Non-stigmatizing	Age independent	Stable	Easy handling
1. Cargo tricycle	+	0	+ +	+ +	0
2. Gyro bike	- -	+	0	0	-
3. Assisted cycling	- -	+ +	0	- -	+ +
4. Support bags	+ +	- -	- -	0	+
5. Emergency support	+	- -	- -	0	+
6. Smart saddle	0	+	- -	-	+ +

figure 35: The design directions were evaluated on different criteria to make a choice

Recreational e-bike tour

Phase	01. Preparation						
Activities	planning route	charging battery	checking weather forecast	packing bag	getting bike out of shed	checking tyre pressure	attaching bag(s)
Problem areas		forgetting to charge the battery			difficult to maneuver bike out of shed		bike unstable when attaching bag(s)

Phase				03. At the destination					04. Cycling back
Activities	riding away	checking route	climbing a hill	braking	getting off the bike	parking the bike	locking the bike	taking bag(s) off	attaching bag(s)
Problem areas		not knowing the route	climbing up hill costs effort		difficulties getting off the bike			instability when taking the bag(s) off	

Doing groceries with e-bike

Phase	01. Preparation				02. Cycling to supermarket			
Activities	charging battery	packing bag	getting bike out of shed	attaching bag(s)	getting on the bike	riding away	braking	giving signs
Problem areas	forgetting to charge the battery		difficult to maneuver bike out of shed	bike unstable when attaching bag(s)	instability when getting on the bike	difficulties with getting up to speed	unfore-seen situa-tions	feeling unsafe when giving signs

Phase	05. Cycling back					06. Back home	
Activities	attaching bag(s)	unlocking the bike	moving bike to bicycle lane	getting on the bike	riding away	braking	getting off the bike
Problem areas	instability when attaching bags	difficulties getting off the bike	bike is heavy because of the groceries	instability when getting on the bike	difficulties with getting up to speed		difficulties getting off the bike
	lifting bags is heavy						

3.4 Use scenarios

Two use scenarios for the 'cargo tricycle' were chosen based on the motives of e-bike users (figure 36). Numbers show that the majority of e-bike users are people aged 65 years and older, thus this gives a good indication which activities elderly use their e-bike for. Even though literature shows that the next generation elderly is likely to do voluntary work, it is assumed that elderly will be using the e-bike less to travel to work.

Doing groceries and recreational tours are therefore chosen as use scenarios. These are both situations in which the user is likely to transport goods, for example groceries or a backpack.

Percentage of cycled kilometres by e-bike per motive in 2016

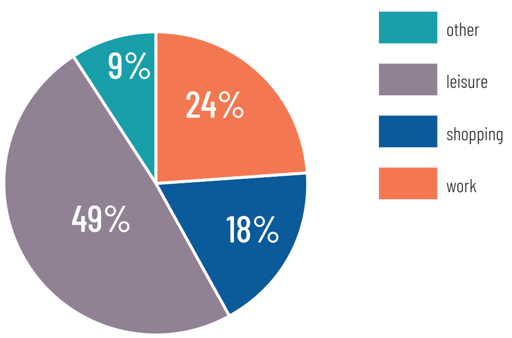


figure 36: Percentage of cycled kilometres by e-bike per motive in 2016

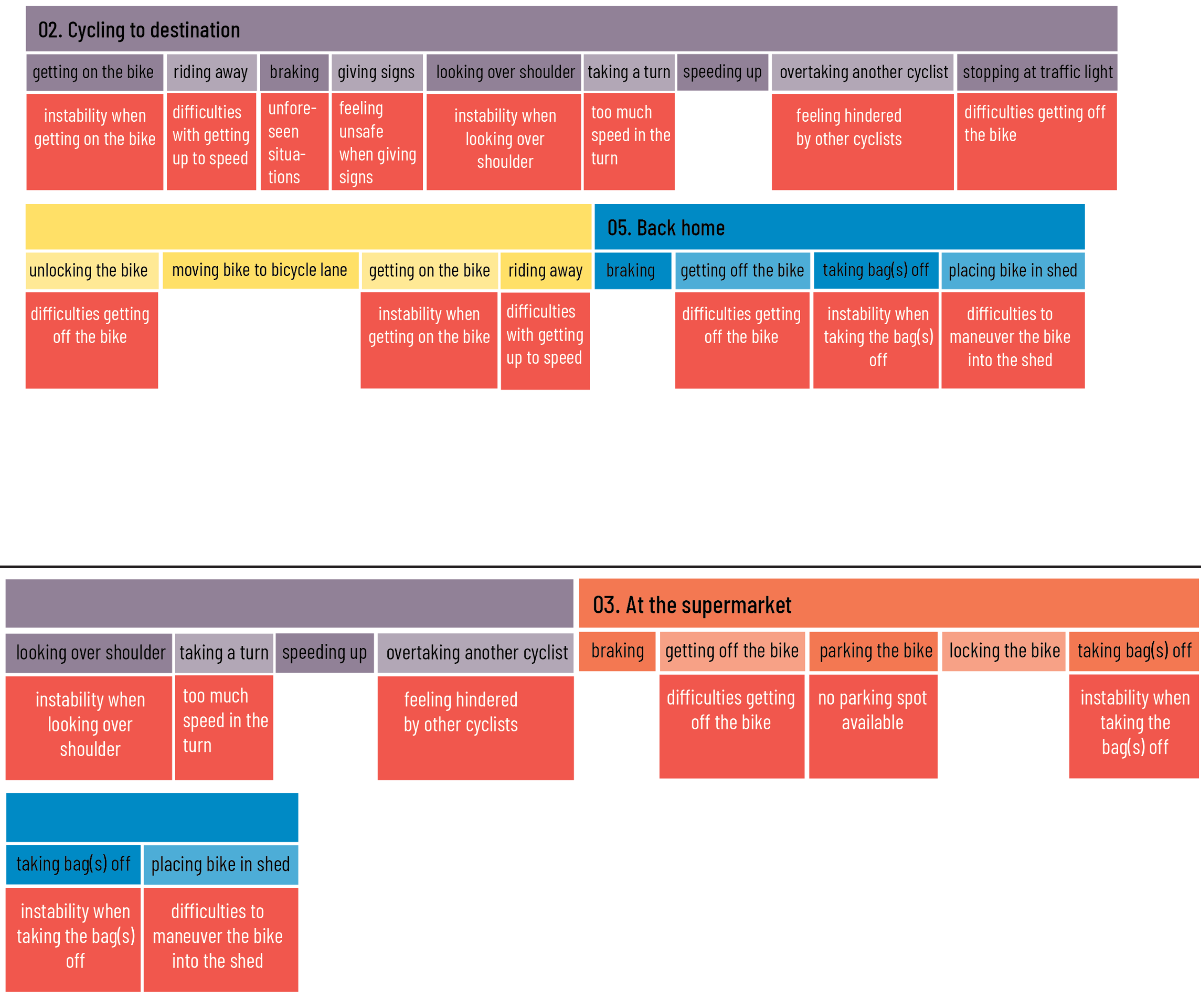


figure 37: Use scenarios of making a recreational tour by e-bike and doing groceries with an e-bike

The use scenarios were specified in a brainstorm session with Beixo. As preparation for the brainstorm two posters with steps in the user's journey of making a recreational tour with the e-bike and doing groceries with an e-bike were made. During the brainstorm additional steps were added and problem areas were identified. In figure 37 the result of the brainstorm, the two use scenario's, is shown. The problem areas provide possibilities to improve with the design. For example, feeling unstable when looking over the shoulder, could be solved with tricycle.

Other aspects, such as finding a parking spot or a getting off the bike also need to be considered in the design and may pose challenges.

During the design process these use scenarios must be considered, because the product is likely to be used for both activities. Thus, these use scenario's will be used as guidelines during the design process.

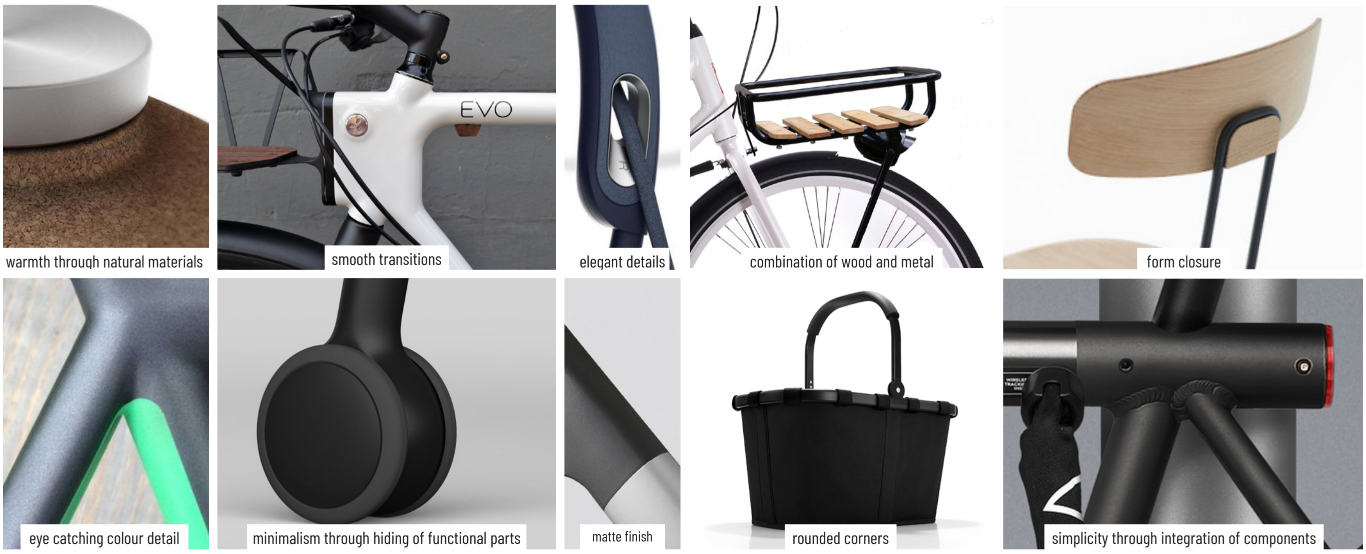


figure 38: Design DNA for design

3.5 Design DNA

Based on the brand personality and design DNA of Beixo, a design DNA for the design was created (figure 38). Examples of form transitions, materials and details are given to provide inspiration for the design. The brand personality traits 'honest', 'reliable' and 'wholesome' could be achieved by creating smooth transitions, rounded corners, matte finish, hiding functional parts and integrating components, because it gives the design a pure and simple appearance. 'Cheerful' could be achieved by using colour details and a combination of metal and warm materials, such as wood or cork. 'Spirited' can be achieved by applying elegant details and form closure. This will make the design more elegant, which fits the spirited character of Beixo, which refers to offering cool bikes for elderly.

3.6 Cargo bikes

The decision for the design direction 'cargo tricycle' means that the product will compete with the product category three wheel cargo bikes. Cargo bikes are bicycles with a cargo area for transporting goods. To understand how cargo bikes work and to identify possibilities to differentiate the design from existing products, competing cargo bikes were analysed and cargo bike steering and cycling behaviour was researched.

Competitors
To get an understanding of the features of three wheel cargo bikes, a selection of three wheel cargo bikes was analysed (see figure 39 to figure 45). The competitors seem quite similar. All of them have a container in between the front wheels and electric pedal support. All, except the Veleon Family e-Motion have 20 inch front wheels and a 26 inch rear wheel. The rear wheel of the Veleon cargo tricycle has a 28 inch rear wheel. The Babboe Carve Mountain, Butchers and Bicycles and Veleon Family e-Motion have a tilting steering mechanism. This allows the user to lean into a turn. The dimensions, shape and load capacity of the cargo area differs per competitor. The components, such as gears, motor and battery also differ.

figure 39: Babboe Big

figure 40: Babboe Carve Mountain

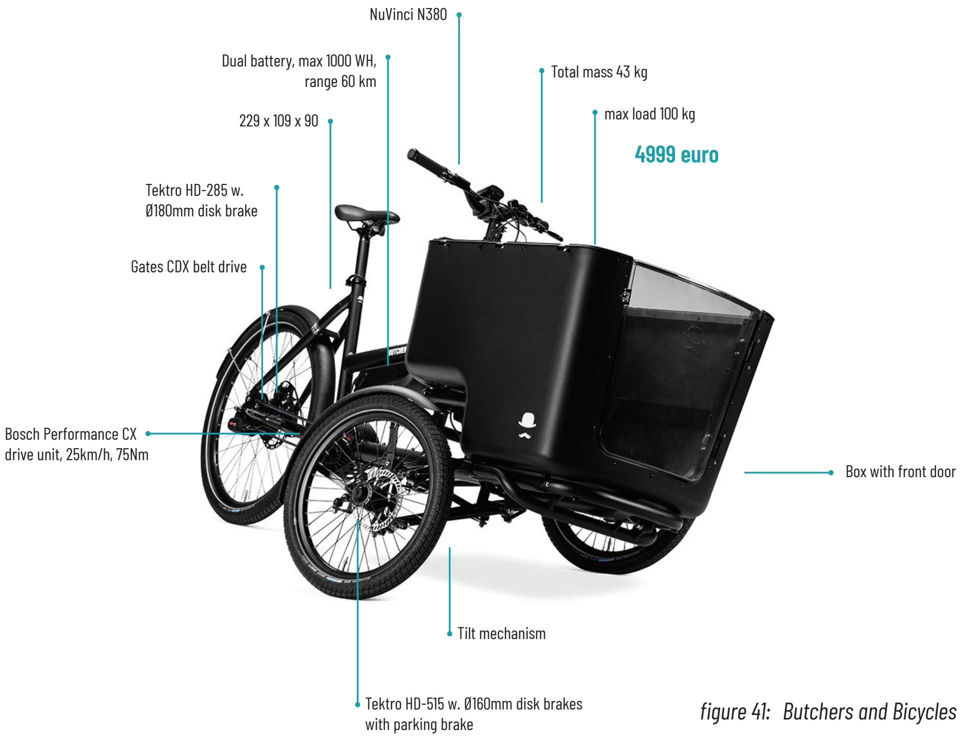


figure 41: Butchers and Bicycles MK1 E

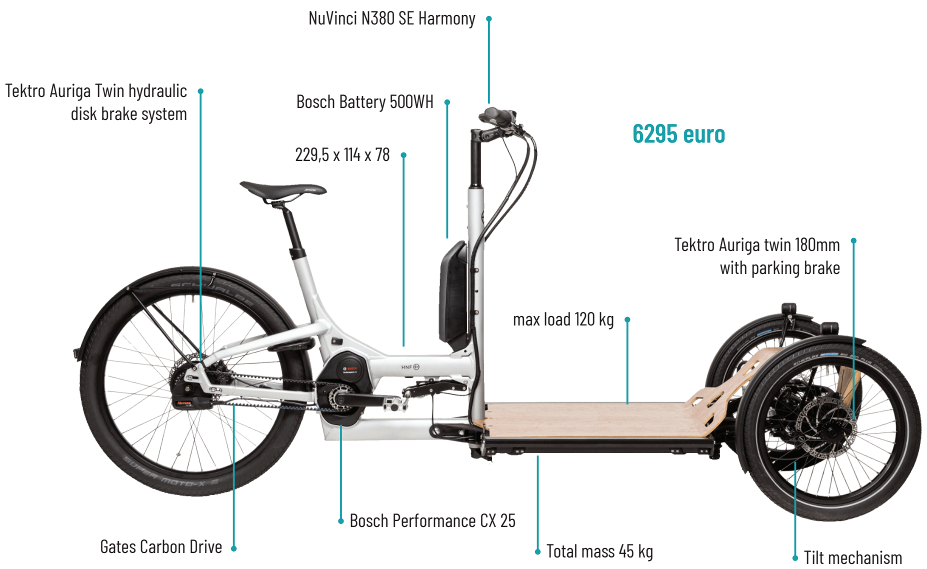


figure 42: HNF Nicolai CD1 Cargo

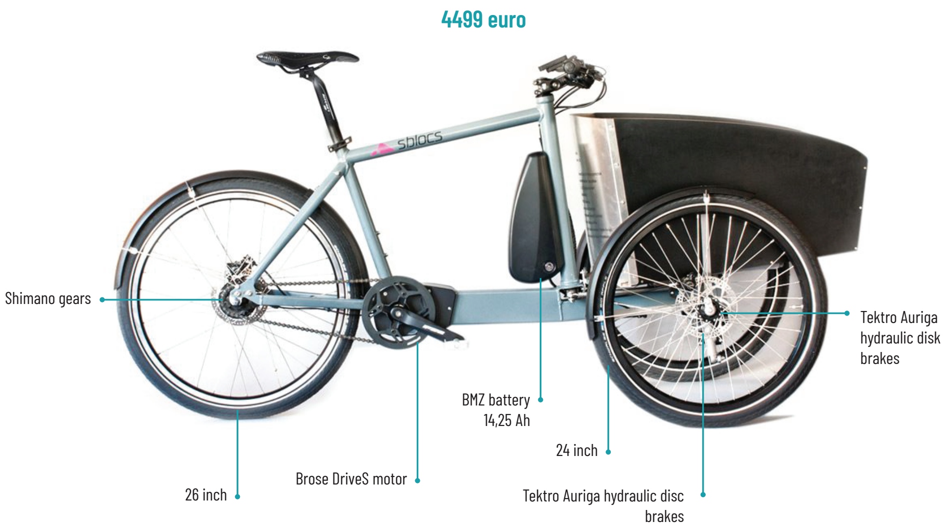


figure 43: Sblocs E Kurier

figure 44: Triobike Mono

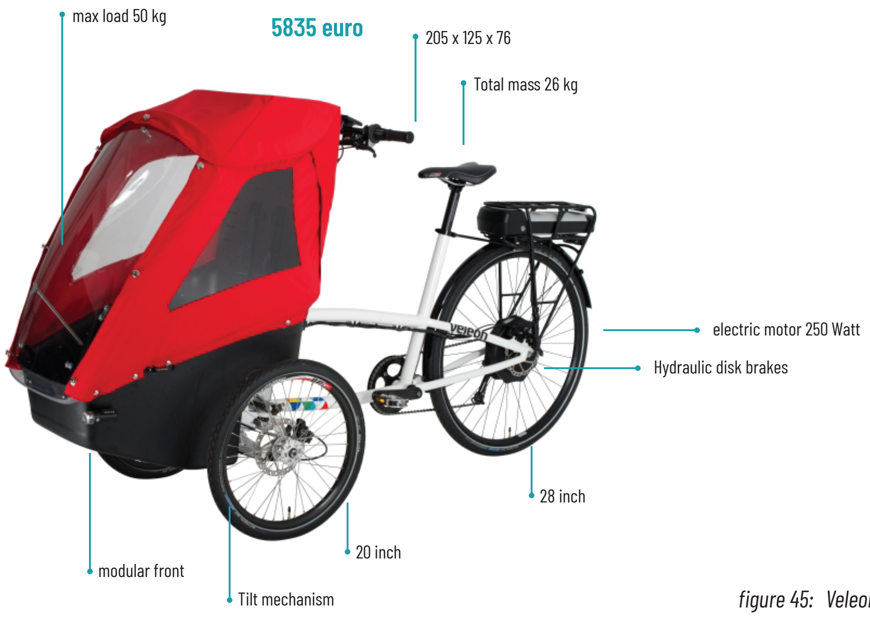


figure 45: Veleon

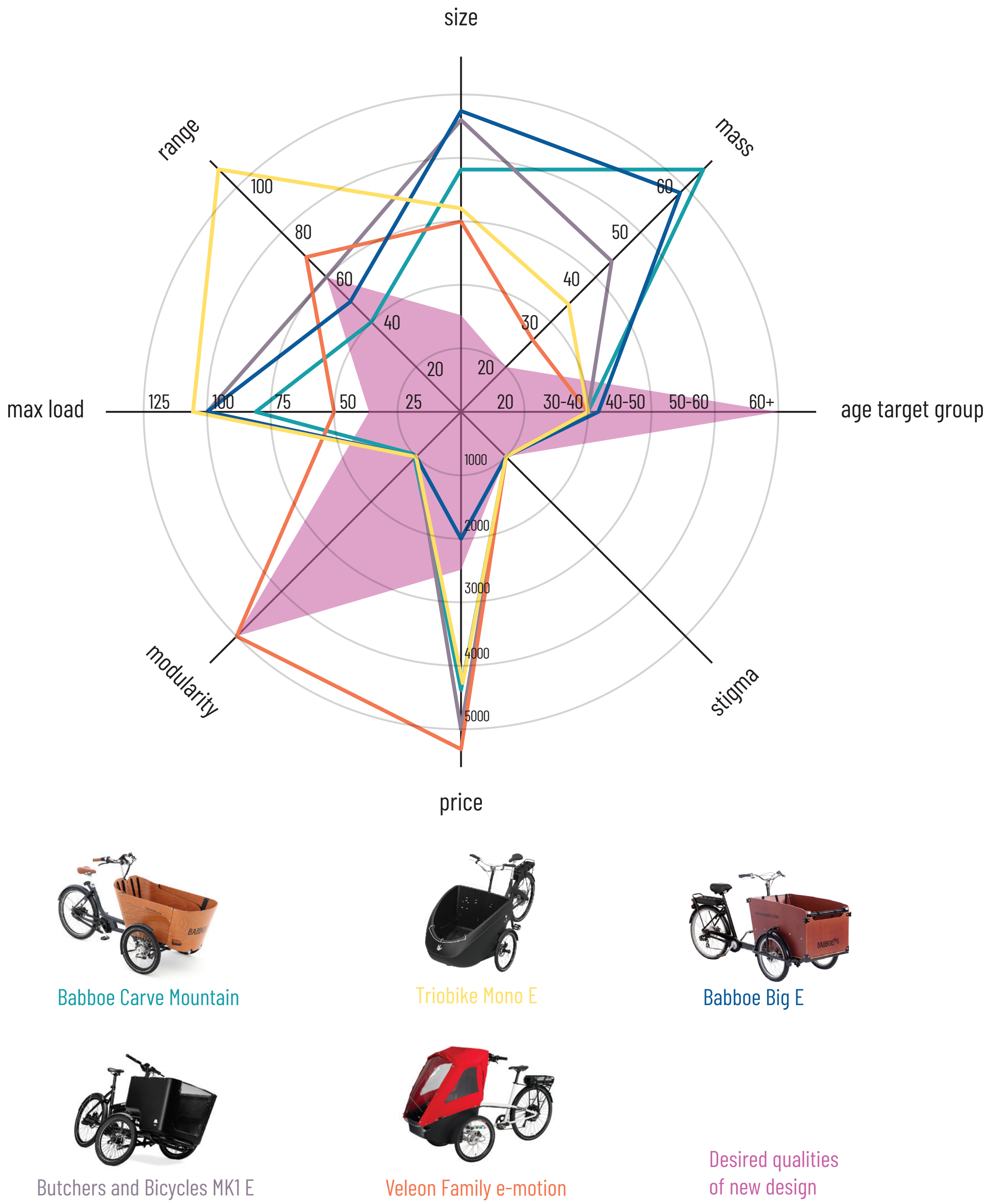


figure 46: The new design could differentiate from the competitors on several aspects

The competitors have been ranked on the criteria size, mass, age of the target group, stigma, price, modularity, maximum load of the cargo area and range to get an understanding of how the design could differentiate from the competition (figure 46). The desired qualities of the design have also been mapped.

Conclusion

The competing products have been designed for a younger target group. The new design will differentiate on the age of the target group. This requires reducing the mass and size of the product to allow for easier handling. The load capacity could be reduced, because the target group is likely to transport smaller cargo, like groceries. The new design could differentiate from these competitors by offering a modular cargo solution. Ideally the price of the new design is lower than that of the competitors. It should be sold for around the price of an e-bike, so it can also compete with e-bikes. This is important, because it is the solution that the target group currently uses. In order to avoid stigma, the new design should be close to the design of the competitors, so it is associated with a cargo tricycle.

<u>Steering</u>

Having two front wheels poses a challenge for steering. To find out about options for tackling this challenge, existing three wheel cargo bikes were analysed to learn about their steering. Three wheel cargo bikes can have different types of steering (figure 47). With the type 1 steering the front wheels stay parallel and the cargo area is attached to the wheel base, causing it to rotate as the bike is being steered. Type 2 steering has a steering rear wheel. With the type 3 steering the wheels steer around the cargo area. Type 4 is similar to type 3. The wheels also steer around the cargo area. However, the wheels also tilt in a turn.

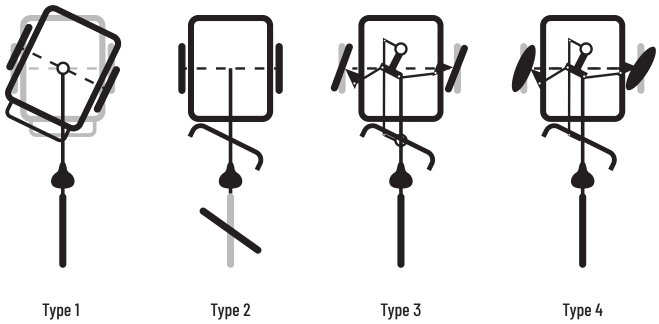


figure 47: Types of steering of three wheel cargo bikes

<u>Cargo bike cycling behaviour</u>

To get a feeling for the different types of steering and to be able to decide on the best steering for the design, the type 1, 3 and 4 were tested at a retail store for cargo bikes.

As an example of the type 1 steering mechanism the Babboe Curve was tested. The Babboe Curve was not very comfortable to steer. As can be seen in (figure 48) steering requires to push the handlebars away from the body. This results in an uncomfortable position and requires strength. Additionally, the turning radius is quite large, making it difficult to make sharp turns.

figure 48: The Babboe Curve is uncomfortable to steer

For type 4 two cargo tricycles were tested; Babboe Carve E (figure 50) and MK1-E of Butchers and Bicycles (figure 49). Riding the Babboe Carve E was very difficult, because it took a lot of effort to balance the cargo bike. Once the container is completely tilted, cycling is no longer possible. The Butchers and Bicycles MK1-E was also not easy to ride, because it requires a lot of balancing. However, the MK1-E was easier to steer than the Carve E. According to the retailer this is due to reduced weight of the container and stronger springs in the tilting mechanism.

figure 50: Babboe Carve E (source: https://www.babboe.nl/bakfietsen/carve-elektrisch)

figure 49: Butchers and Bicycles MK1 E

The Babboe Carve has a 'carve lock', which when activated turns the steering into a type 3 (figure 51). When activating the "carve lock" of the Carve E, cycling and steering becomes easy. The cargo bike then does not tilt and steering can be done by simply turning the handlebars, like with a normal bicycle.

figure 51: Babboe carve on 'carve lock'

Type 2 was not available at the shop, but online there are plenty of video's that show the cycling behaviour of cargo tricycles with a rear wheel steering. An example of a cargo tricycle that uses the type 2 steering mechanism is the Bellabike (figure 52). From what can be evaluated from videos of the Bellabike, the steering is very different from a normal bicycle. The assumption is that it requires quite some practice to feel comfortable steering the Bellabike.

figure 52: Taking a turn on Bellabike (source: https://www.youtube.com/watch?v=8h8ce1Uj2nQ&t=12s)

Rear wheel motor | Front wheel motor | Middle motor

figure 53: Possible positions of e-bike motors

3.7 E-bikes

The new design should be a safer alternative for an e-bike, therefore it is crucial to understand the advantages and disadvantages of e-bikes. To learn about e-bikes, retailers were visited, e-bike users were observed and test rides with e-bikes were made. Reporting of these activities can be found in appendix G. These activities gave insights about the differences in cycling behaviour between the e-bike motor types and motor position.

E-bike motor position
The electric motor of an e-bike can be positioned in the front wheel, rear wheel or at the pedals (figure 53). The latter will be referred to as 'middle motor'. A front wheel motor makes steering heavier, because of the additional weight in the front wheel.

E-bike cycling behaviour
The motor only gives support when the user cycles. There are two types of sensors that register this; a torque sensor and a rotational sensor. Test rides with both types of motors resulted in the insight that the e-bikes that have a motor with a torque sensor are more intuitive, because the motor immediately reacts to the force that the user applies to the pedals. This also means that the user has to put force onto the pedals to move forward. The e-bikes with a motor with a rotational speed sensor are less intuitive, because the motor provides support as long as the user is turning the pedals. This means that if the user forgets to stop pedaling in a turn, the motor would continue giving support. This could lead to a dangerous situation, because of high speed in a turn.
This suggests that a motor with a torque sensor is the better choice for the cargo tricycle, because the user is more likely to have the feeling of being in control, because the speed is related to the force he/she puts on the pedals.

3.8 Stability

The design direction 'cargo tricycle' was chosen, because it could solve both the problem of stigma and the problem of stability. The test rides with three wheel cargo bikes already showed that the third wheel provides stability. In order to understand how the stability is achieved and what to consider in the design to maintain stability, stability of a tricycle was explored mathematically. The product must be stable when getting on and off the bike and while cycling. Therefore, stability at zero speed and stability in a turn were approached mathematically.

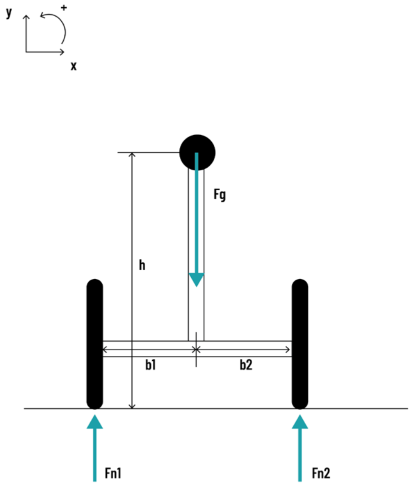


figure 54: The centre of mass is located in the middle of the front wheels

<u>Stability at zero speed</u>
The user should be able to get on and off the tricycle without it tilting. While getting on and off the tricycle the user's centre of mass is not always located at the centre of the bike. The question is how far the user can lean over before the tricycle will start to tilt.

In figure 54 the tricycle is shown in the situation that the centre of mass of the cyclist is located in the centre of the tricycle, in the middle between the wheels. In this situation b1 = b2. To counter the force Fg, the gravitational force generated by the mass of the tricycle and the cyclist, a normal force Fn1 acts upon the left wheel and a normal force Fn2 acts upon the right wheel. In this situation Fn1 equals Fn2.

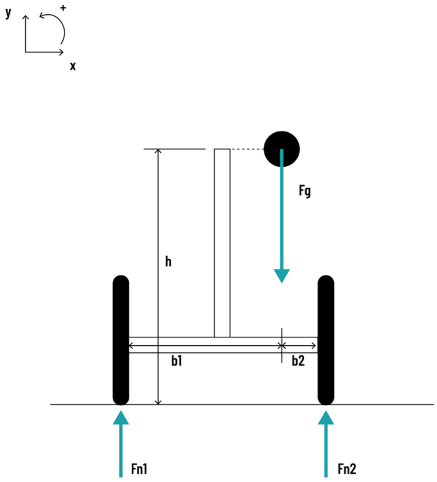


figure 55: The combined centre of mass moves towards the right wheel

At zero speed the equilibrium of forces is dependent on the position of the combined centre of mass of the tricycle and the cyclist. When it is located in the middle between the front wheels (figure 54), the normal forces Fn1 and Fn2 are equal and there is no resulting moment.

$$Fn1 + Fn2 = Fg$$

$$Fn1b1 - Fgb2 = 0$$

If the combined centre of mass of the tricycle and the cyclist moves towards the right wheel (figure 55), the normal force on the right wheel increases to compensate for this. Still, there is no resulting momentum, because

$$Fn1b1 - Fgb2 = 0$$

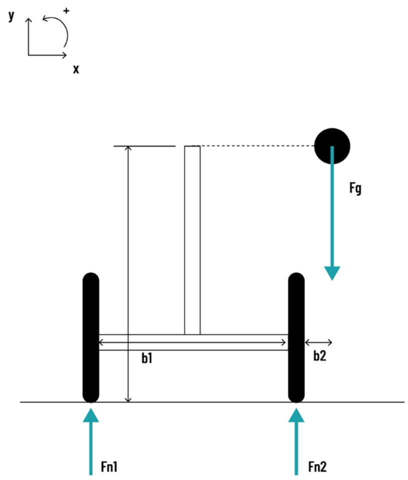


figure 56: The combined centre of mass is located outside the wheels

If the combined centre of mass of the tricycle and the cyclist moves outside the wheels (figure 56), for example to the right side of the right wheel, the direction of the arm of Fn2 changes. It is now in the same direction as the arm of Fn1. This results in a momentum, because

$$Fn1b1 + Fgb2 \neq 0$$

A resulting momentum means motion. Thus, the bike will tilt around the right wheel.

From this calculation can be concluded that as long as the centre of mass of the cyclist and tricycle stays within the front wheels, the tricycle will not tilt. A situation in which the centre of mass of both does come outside the wheels is one of extreme use. This would mean that the cyclist hangs extremely to one side while having the feet on the pedals and holding the handlebars. This situation could be avoided by making a frame with a low entry that allows the user to easily get on and off the bike.

Stability while turning

While taking a turn with the tricycle, a centripetal force acts upon the tricycle. If unbalanced, this force can make the tricycle tilt around its outer wheel. The centripetal force Fr is dependent on the total mass of the bicycle and cyclist m, the velocity of the tricycle v and the radius of the turn the tricycle is making r.

$$Fr = \frac{mv^2}{r}$$

The centripetal force Fr and the height at which the combined centre of mass of the tricycle and cyclist is located, h create a momentum around outer wheel.

$$Mr = Fr * h$$

A counter momentum Mc is created by the gravitational force generated by the total mass of the tricycle and cyclist and the distance of the centre of mass of the tricycle and cyclist to the outer wheel (figure 57).

As long as both momentums are equal, or the momentum Mc is larger, the tricycle will not tilt in a turn.

Assuming the cyclists weighs 100 kg (M) and the centre of mass is located at a height of 1 meter (h1), the mass of the tricycle is 15 kg (m) and its centre of mass is located at 0,3 m (h2), we can calculate h, the height of the centre of mass of the tricycle and cyclist.

$$h = \frac{(M * h1 + m * h2)}{M + m}$$
$$h = 0.91$$

The momentums Mr and Mc should be equal, therefore:

$$Mr = h * \frac{mv^2}{r} = Mc = M * g * \frac{w}{2}$$

This gives for velocity v:

$$v = \sqrt{\frac{0.5r * g * w}{h}}$$

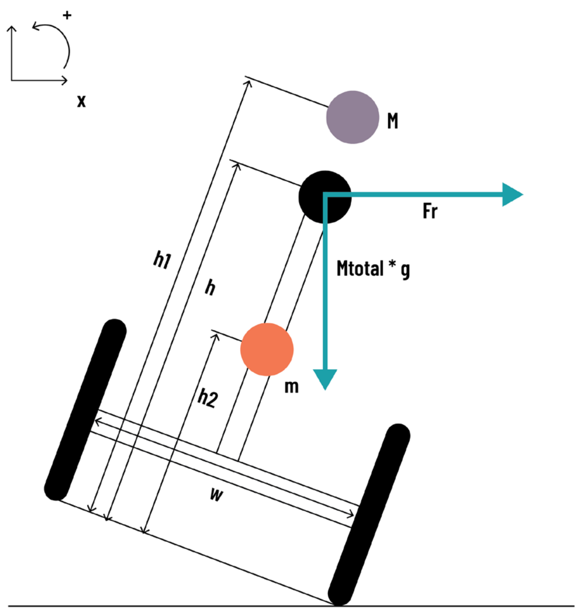


figure 57: A centripetal force acts upon the tricycle when taking a turn

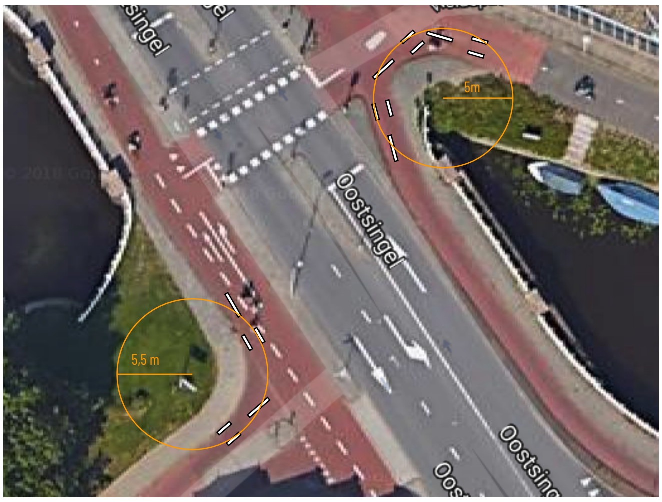


figure 58: Turning radius of right-angled corners on bikelanes in Delft

Assuming the distance between the wheels w is 0,6 m and the turning radius r is 5m, this gives a velocity v of 4,02 m/s or 14,47 km/h.

In this calculation is was assumed that the cyclist does not naturally lean in when taking the turn, as is normal while cycling. A turning radius of 5 m would imply a right-angled sharp turn (figure 58). Taking such a turn with a speed of 14,47 km/h is extreme. In normal cycling situations the cyclist would lower the speed before taking the turn.

From this calculation we can conclude that at normal use, the bike will not tilt while taking turns. Extreme situations would need to be tested to make a statement about the stability in those situations.

3.9 Concept direction

The starting point for the development of the concepts was that the bike should have two front wheels with a cargo area in between, a frame with a low entry, a middle motor and a shaft drive. The bike should also be compact, ideally not exceed the dimensions of a normal bicycle. Taking a 28 inch city bike as a reference, this gives a length of approximately 1,85m and a width of 0,65m. While creating concepts for the 'cargo tricycle' these aspects were taken as a given and the focus was on interaction with the cargo area. Thus all concepts have the same frame, but a different design for the cargo area. This was done, because the cargo area is important for avoiding stigma as well as for the functionality. The design of the frame and technical details was done in a later stage.

Concept direction 1

The first concept is a cargo tricycle with a shopping trolley figure 59). The shopping trolley is an accessory designed for the cargo tricycle. It consists of a basket and a backpack that can be separated for flexible use. The shopping trolley allows for easy transport of cargo, for example groceries, on the bicycle and at the destination. The cargo does not need to be lifted, because the trolley can be easily attached to the front of the bike by tilting and pushing the trolley. To use the shopping trolley the user folds out the bar, which is used for pulling the trolley.

Concept direction 2

Concept 2 (figure 60) allows for transporting a rollator. The lightweight cargo canvas can be easily attached to the basket. The folded rollator can then be inserted from the front of the bike.

Concept direction 3

Concept 3 (figure 61) contains a shopping trolley which is designed to provide walking support to the user. The user pushes it forwards and can lean on it to get support while walking. The top part of the trolley can be taken off and used as a bag. Like in concept 1, the trolley can be easily attached to the front of the bike by tilting and pushing the trolley.

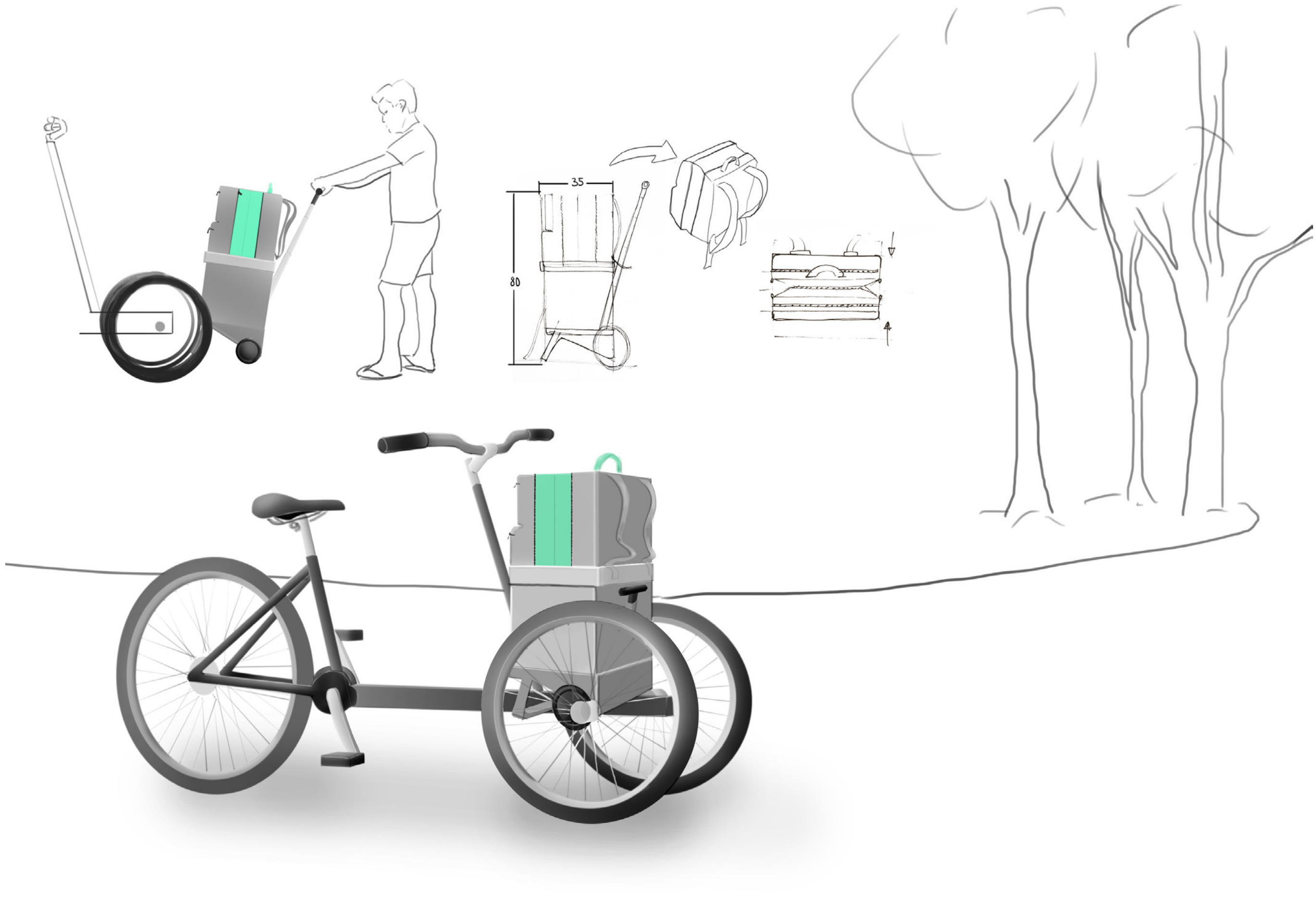


figure 59: Concept 1

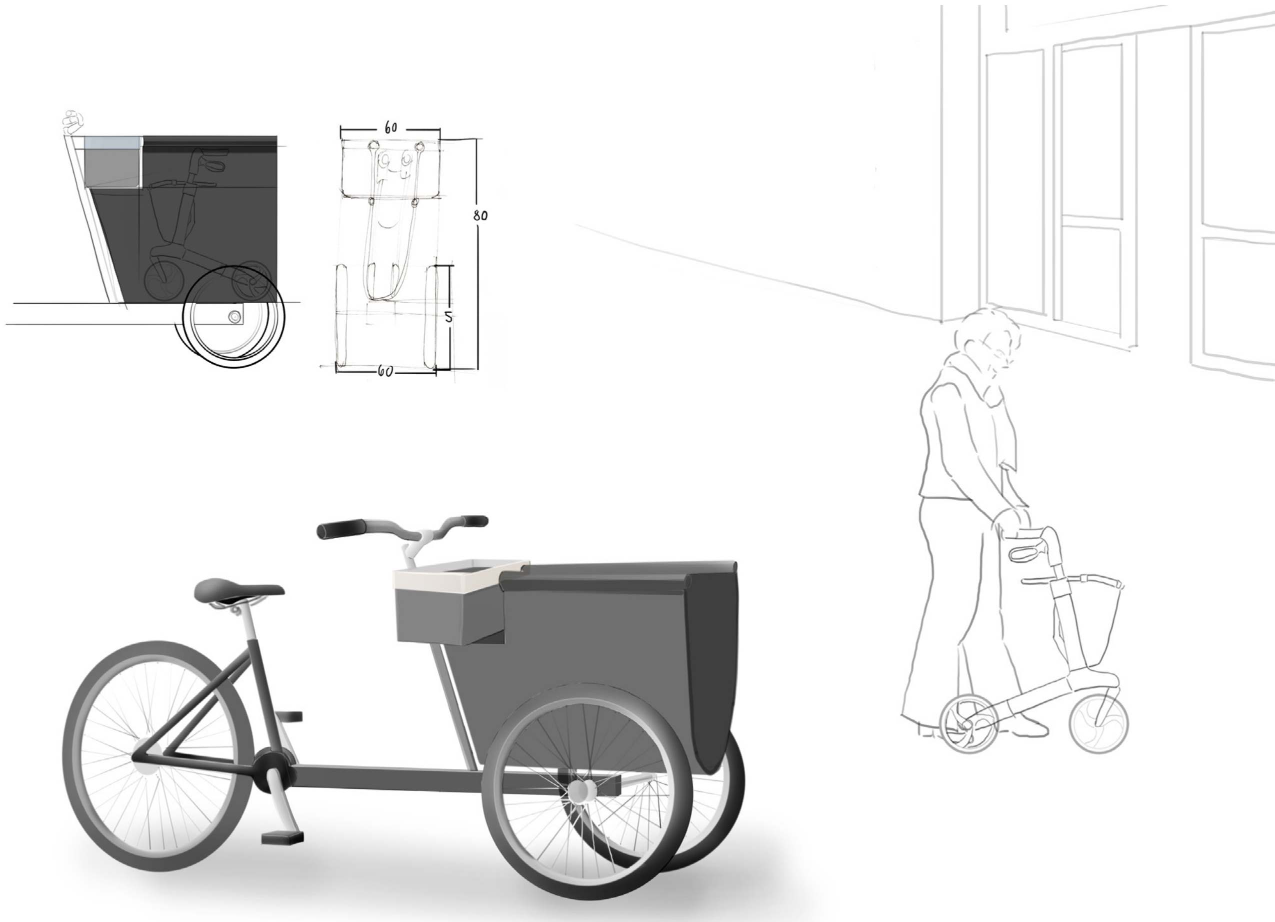


figure 60: Concept 2

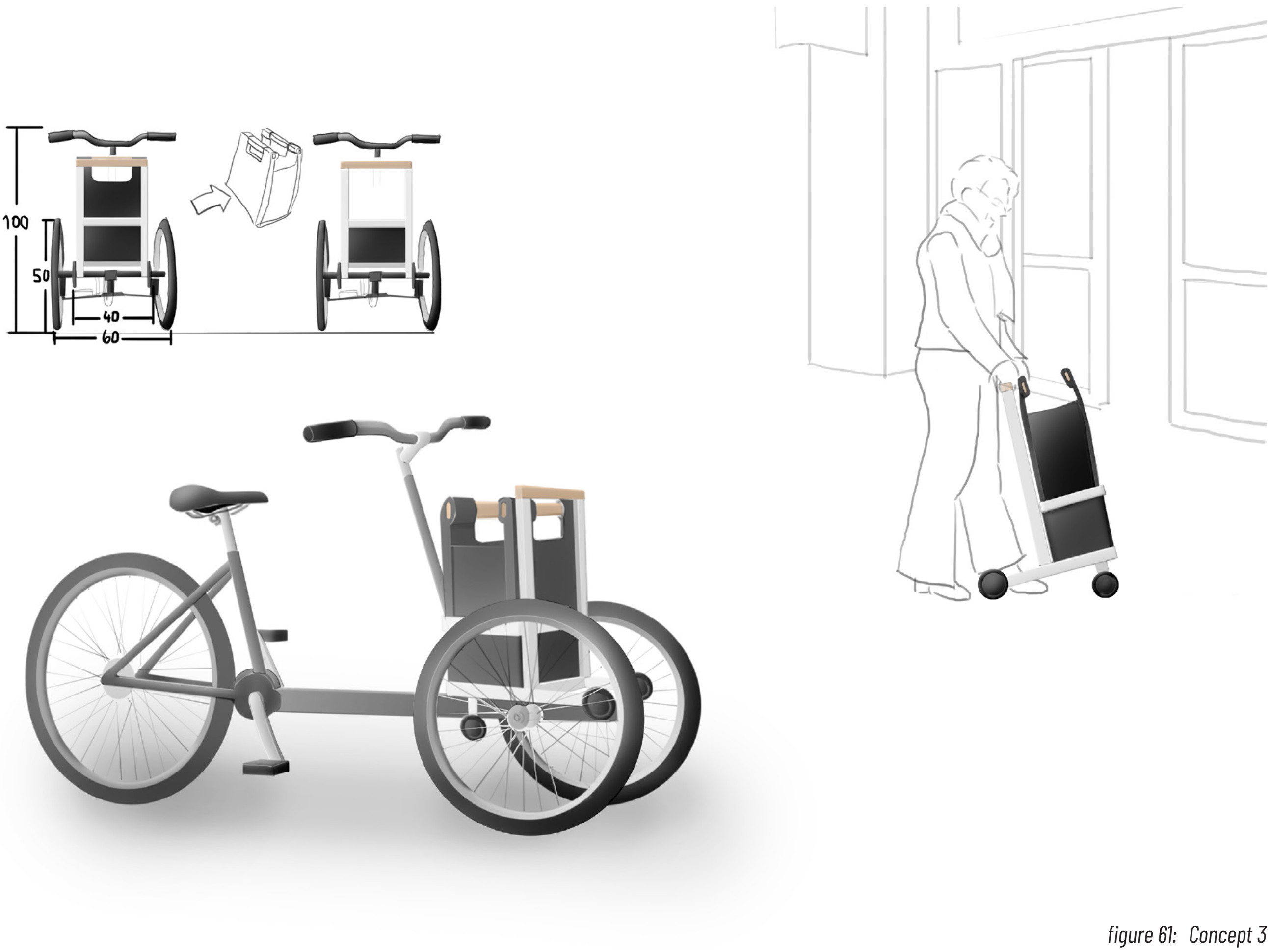


figure 61: Concept 3

3.10 Chosen concept direction

To make a choice for one of the concepts presented in the previous chapter, the concept were evaluated on the criteria stigma, stability, complexity, age dependency and handling. These criteria have been set as a result from the analysis.

When evaluating the concepts on stigma, stability, complexity, age dependency and handling, concept direction 1 is preferred (figure 62). Concept direction 1 is considered less simple than concept 2. The design of the shopping trolley can be similar to existing shopping trolleys and is therefore quite simple, but the design of the attachment system may be quite complex. It is not very stigmatising, because the shopping trolley does not imply that the user has a disability. It is age independent, because it can be used by different age groups. The three wheels make concept direction 1 stable. Concept direction 1 is compact and the shopping trolley can be easily attached, making the handling easy.

Concept direction 2 is considered simpler than concept direction 1, because the attachment of the canvas can be quite simple. However, concept direction 2 is considered somewhat stigmatising, because bystanders can see that the user is transporting a rollator. The cargo canvas is designed to transport a rollator, making the design more age dependent. The dimensions of the folded rollator dictate the dimensions of the cargo canvas. This makes it less flexible in use and less compact than concept direction 1 and concept direction 3. The additional length makes the handling of the cargo tricycle more difficult. Inserting the rollator in the cargo canvas may also require more effort than attaching the trolleys in concept direction 1 and 3.

Concept direction 3 is considered somewhat stigmatising too, because the shopping trolley can be used as a walking aid. Though the design is similar to a shopping trolley, the product architecture must be similar to that of a rollator to provide proper support while walking. When bystanders can make the reference to a walking aid, the product becomes stigmatising. The walking support function makes this concept more age dependent. The stability is similar to the other concepts. The handling of concept direction 3 is slightly more difficult than of concept direction 1, because the product architecture of the trolley with walking support makes tilting the trolley more difficult.

Concept direction 1 will be taken as a starting point for the final concept. However, the shopping trolley that is designed for the cargo tricycle limits the flexibility of use. It would be interesting to look into how other products could be attached to the front of the bike. This modularity would broaden the use scenarios and the target group, which contributes to avoiding stigma. The bike could be seen as a platform that can be used to transport all kinds of cargo. To differentiate from competitors and be suitable for elderly, the product should stay compact and allow for easy handling.

	Simple	Non-stigmatizing	Age independent	Stable	Easy handling
Concept direction 1	0	+ +	+ +	+ +	+ +
Concept direction 2	+	-	- -	+ +	0
Concept direction 3	0	-	- -	+ +	+ +

figure 62: The concepts have been evaluated on criteria

4

Concept development

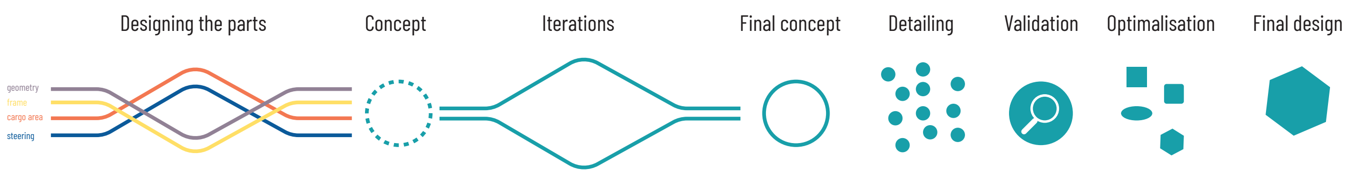


figure 64: Design process from first concept to final concept

Using concept direction 1 as a starting point, the design was further developed. Several aspects needed to be elaborated on, namely the architecture, wheel size, geometry, the frame design, the design of the cargo area and the steering. On the following pages the process from the first concept to the detailing of the final concept is presented for each of these aspects. The development of these aspects ran in parallel and influenced each other (figure 64), but for better understanding of the design decisions made, the process will be presented separately per aspect.

4.1 Architecture

The design will consist of several parts and components. As can be seen in figure 63 the design will consist of the five main parts frame, cargo area, drive, steering and standard components. The frame is built up of the downtube, headtube, seattube, seatstay, chainstay and carrier. The cargo area is the part between the wheels that is used for transporting cargo. To the drive train belong the motor, shaft drive, gears, battery and display. The steering consists of the steering mechanism and handlebars. To the standard components belong the headset, seatpost, saddle, lights, bell, tires, rims, brakes, etc.

The position of the motor, battery and cargo area relative to the rest of the parts is not fixed and is determined by the design.

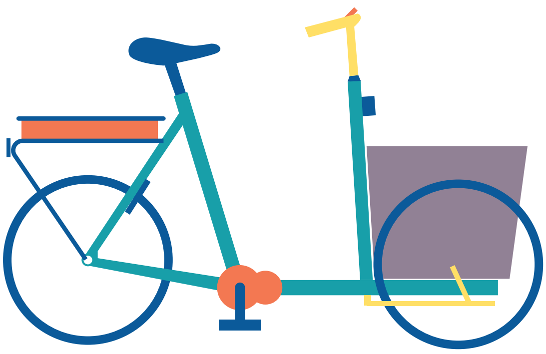


figure 63: Architecture of 'cargo tricycle'

4.2 Requirements

The concept choice was based on the criteria stigma, stability, complexity, age dependency and handling. For the embodiment of the chosen concept, more specific requirements are needed. The requirements have been organized for each of the main parts.

<u>1. Frame</u>
1.1 The geometry must allow for adjustability.
1.2 The wheelbase must be no longer than that of a 28 inch bicycle.
1.3 The frame must have a low entry of maximum 25 cm.
1.4 The Bafang E-shaft motor must be integrated in the frame.
1.5 The frame must be strong enough for holding a cyclist of up to 100 kg and a cargo load of maximum 40 kg.
1.6 The shaft drive must be integrated in the frame.
1.7 The frame design must fit Beixo's brand personality and design DNA.

<u>2. Cargo area</u>
2.1 The cargo area must be located between the front wheels.
2.2 The minimum volume of the cargo area is 400 x 300 mm.
2.3 The cargo area must allow for safe transportation of goods.
2.4 The cargo area must be resistant to weather impact.
2.5 The minimum load capacity of the cargo area is 40 kg.
2.6 The cargo area is accessible from the front.
2.7 The design of the cargo area must communicate its transport function.

<u>3. Drive train</u>
3.1 The bike uses the Bafang E-shaft motor.
3.2 The battery provides power for at least 30 kilometers.
3.3 The battery is easily accessible.

<u>4. Steering</u>
4.1 The turning radius is not larger than 3 m.
4.2 The steering mechanism is suitable for a bike with a width of approximately 0.6 m.
4.3 The bike can be steered solely by moving the handlebars.
4.4 The steering mechanism allows for effortless steering.
4.5 The steering mechanism ensures stability.

<u>5. Standard components</u>
5.1 The front wheels must have one-sided suspension.
5.2 The handlebars must be adjustable.
5.3 The grips must be ergonomic.
5.4 The bike must have a brake on each wheels.
5.5 The bike must have a front and rear light.
5.6 The saddle must be comfortable and unisex.
5.7 Each wheel must have a mudguard.
5.8 The pedals must have grip.
5.9 The pedals do not touch the ground.

4.3 The wheel size

There are many possibilities for the wheel size of the cargo tricycle. For the concept a 26 inch rear wheel and 20 inch front wheels were chosen, because those are mostly used by three wheel cargo bikes. The aim was to stay as close as possible to the archetype of a three wheel cargo bike, in order to avoid stigma. However, other wheel sizes may have other advantages, such as reduced size, therefore different combinations of wheel sizes were explored.

Not only three wheel cargo bikes, but also other tricycles were used as inspiration, for example 'Kiffy' (figure 65) and the vanRaam 'Viktoria' (figure 66). Changing the wheel size changes the look, character and association of the bike. Where a 26 inch rear wheel and 20 inch front wheels are associated with a cargo bike, a 24 inch rear wheel and 18 inch front wheels (figure 66) may be associated with a tricycle for people with a handicap. With a larger front wheel a tricycle, the front part may look like a normal bicycle. An example is the Huka Country (figure 67), which has a 24 inch front wheel and 20 inch rear wheels. The 20 inch wheels of 'Kiffy' make the tricycle compact and gives it a sporty look.

The steering mechanism prototype was used to test some of the wheelsize combinations in 3D. The advantage was that the result could be seen from all sides. In figure 68 the combination of 20 inch front wheels and 28 inch rear wheel is shown.
The big difference in wheel size makes the bike look out of proportion and the cargo area very small. In figure 69 the combination of 16 inch front wheels with 20 inch rear wheel is shown. The bike looks better in proportion and also compact.
For the final design 20 inch front wheels and a 20 inch rear wheel were chosen, because they make the bike compact and give it a sporty look. Additionally, the small wheels allow for a smaller frame which can be used to create larger adjustability.

figure 65: Kiffy (source: Designboom.com)

figure 66: vanRaam Viktoria (source: vanraam.com)

figure 67: Huka country (source: huka.nl)

figure 68: 20 inch front wheels and 28 inch rear wheel

figure 69: 16 inch front wheels and 20 inch rear wheel

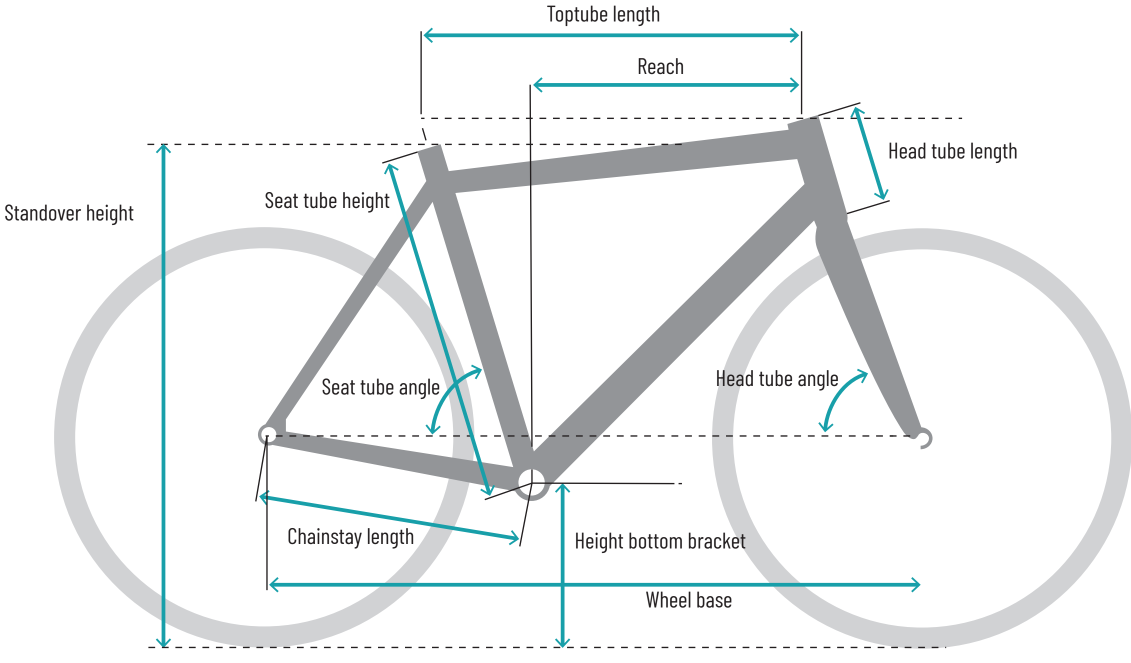


figure 70: Geometry of a bicycle frame

4.4 The geometry

The geometry of the bicycle has a great influence on the cycling behaviour and ergonomics of the bicycle and is thus very important. To understand how bicycle geometries differ, existing geometries were analysed. In this section the considerations for the final geometry and iterations are presented.

Frame geometry

The geometry of a bicycle is made up of several dimensions (figure 70). Important for the geometry of the 'cargo tricycle' are the head tube and seat tube angle and length, the toptube length, the wheelbase and the distance from the ground to the downtube. The size of bike is determined by the toptube length and the seat tube height. Taller cyclists will need a larger seat tube height and toptube length. The angle of the head tube and seat tube influence the position of the cyclist. They are also important for adjustability. As the saddle or handlebars are adjusted in height, the distance between the saddle and handlebars changes. The wheelbase determines the total length of the bike and influences the steering. How this influences the steering is explained in the section 'Steering'. The distance from the ground to the downtube is important for a low entry.

Existing geometries

When looking at different archetypes of bicycles, it becomes clear that their geometry differs. As can be seen in figure 71, the headtube angle of a racing bike is much steeper than that of a city bike (figure 72). Most e-bikes have a headtube angle and seat tube angle of approximately 70 degrees. In most cases the seat tube is slightly steeper than the head tube. Some cargo bikes have a very upright head tube (figure 73). Bicycles with a low entry frame measure a distance from the ground to the downtube of approximately 25 cm (figure 74). Some cargo bikes have a large wheelbase to create space for a cargo area (figure 75).

figure 71: A racing bike has a steep head tube

figure 72: The head angle of a city bike is smaller than that of a racing bike

figure 73: This cargo bike has a head angle of 90 degreed

figure 74: The height of a low entry frame is around 26 cm

figure 75: This cargo bike has a wheelbase that is longer than that of a normal bicycle

Considerations
While designing the geometry, several aspects were considered. To enable the users to easily get on and off the bike, the frame must have a low entry. To provide an ergonomic cycling position for users of different sizes, the geometry must allow for maximum adjustability. The cyclist should have a comfortable cycling position, similar to on a city bike. Additionally, the frame should be compact. Another consideration was the position of the cargo area. If the cargo area stays in between the wheels, there would not be a risk of crashing it into an obstacle. Additionally, the turning radius could be reduced.

Requirements
The considerations have led to the following requirements for the geometry:

1.1 The geometry must allow for adjustability.
1.2 The wheelbase must be no longer than that of a 28 inch bicycle.
1.3 The frame must have a low entry of maximum 25 cm.

Iterations
There were many iterations needed before the final geometry was found. Changes in wheelsize, position of the pedals, entry height and position and size of the cargo area greatly influenced the geometry. Some of the iterations are shown in figure 76 to figure 80.

In figure 76 one of the first geometries is shown. The rear wheel is 26 inch and the front wheels are 20 inch. The bottom bracket is positioned at 260 mm from the ground. The length of the shaft drive has not been taken into account. There is space for a cargo area of a length of 400 mm.

In figure 77 the bottom bracket has been brought down to 220 mm. The angle of the seat and head tube have been reduced to 75 degrees, they are now parallel.

In figure 78 the length of the shaft drive is considered. The wheelsize is again 26 inch in the rear and 20 inch in the front. The angle of the seat tube and head tube has become steeper.

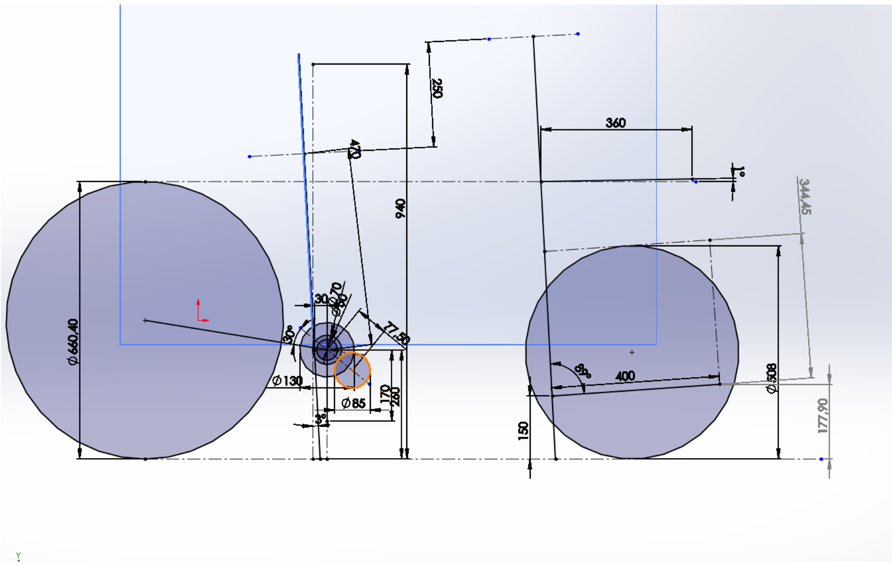


figure 76: 26 and 20 inch wheels

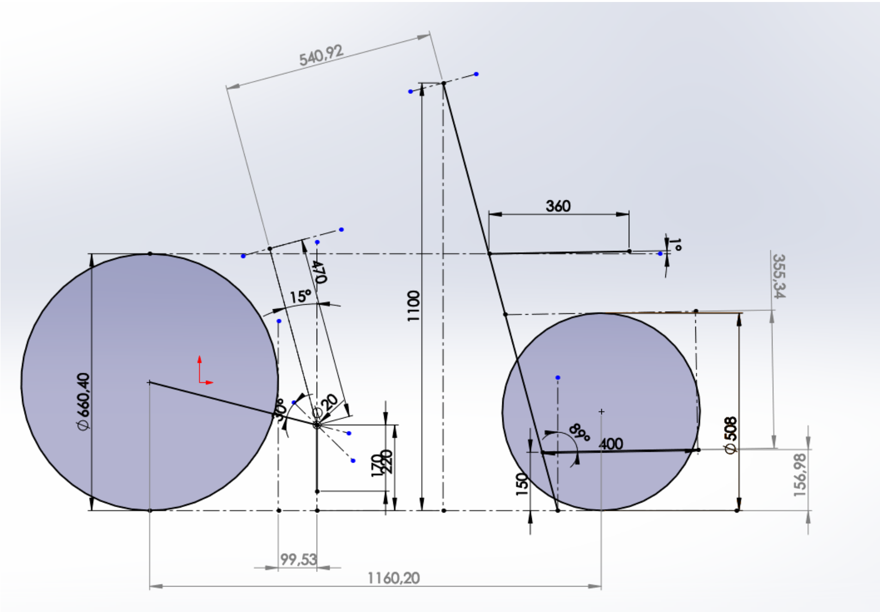


figure 77: lower bottom bracket

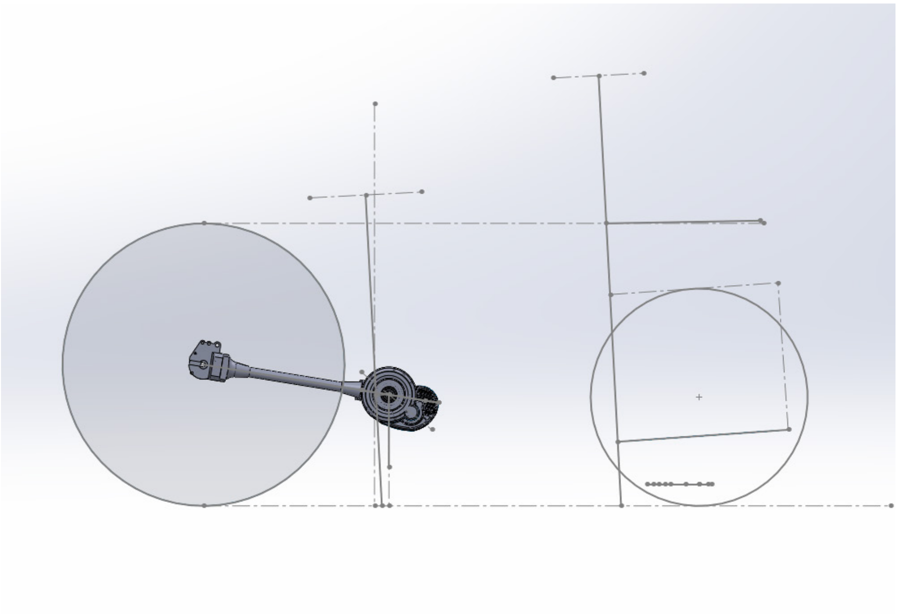


figure 78: geometry with shaft drive considered

In figure 79 the geometry in a later stage is shown. The rear and front wheels are all 20 inch. The shaft drive is positioned almost horizontal. The head tube and seat tube are still parallel.

In figure 80 the shaft drive has been positioned in line with the down tube, slightly pointing downwards. The head tube starts right after the front wheels and is now at a steeper angle than the seat tube.

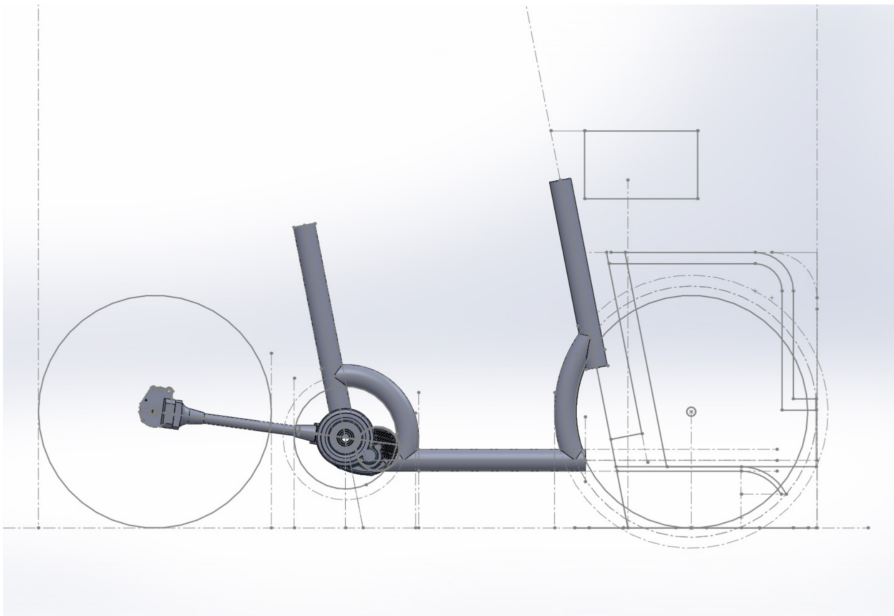


figure 79: 20 inch rear and front wheels

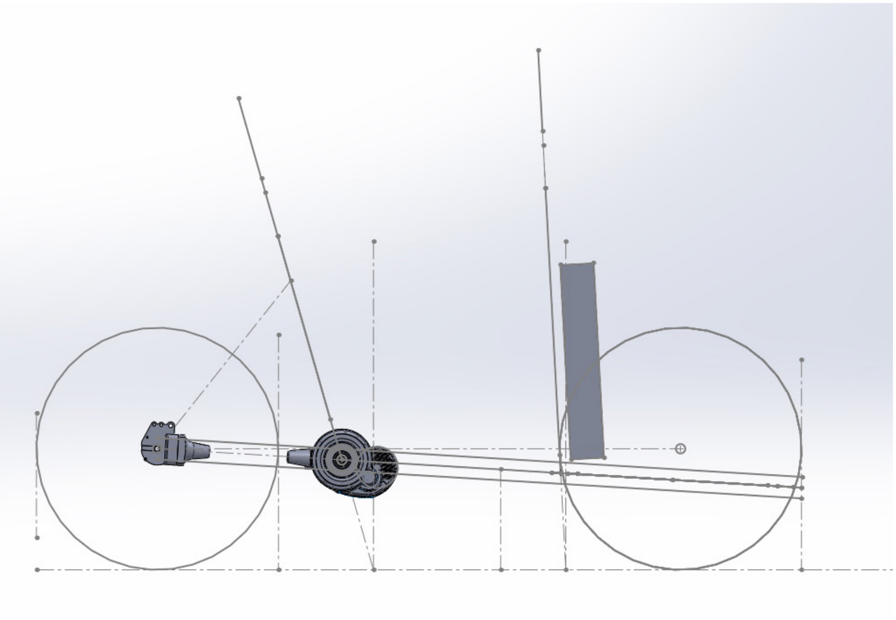
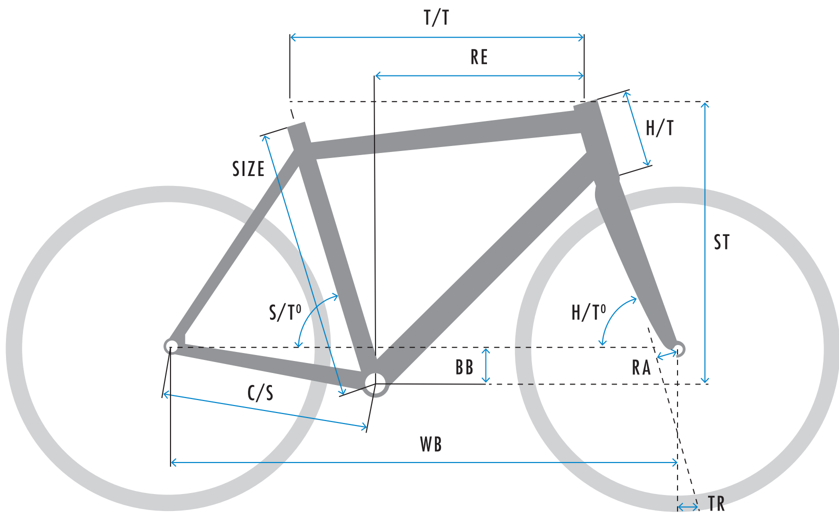


figure 80: shaft drive in line with downtube

figure 81: Popal Subway F201 (source: https://www.premium-bikes.nl/subway-f201-mat-zwart-20-inch-vouwfiets.html)

figure 82: Koga Venya 5.0 (source: https://www.koga.com/nl/stads-en-toerfietsen/collectie/venya-50_



GEOMETRY

GENTS

SIZE	T/T	C/S	WB	BB	RA	H/T⁰	S/T⁰	TR	H/T	RE	ST
54	572	457	1078	55	45	69,5	72,0	85	120	384	579
57	584	457	1069	55	45	70,5	71,0	79	140	377	602
60	596	457	1081	55	45	70,5	71,0	79	165	381	625
63	608	457	1080	55	45	70,5	70,0	79	195	370	654
66	620	457	1092	55	45	70,5	70,0	79	230	370	687

LADIES

SIZE	T/T	C/S	WB	BB	RA	H/T⁰	S/T⁰	TR	H/T	RE	ST
47	562	457	1064	69	45	69,5	72,0	85	160	357	630
50	569	457	1071	69	45	69,5	72,0	85	170	361	640
53	576	457	1079	69	45	69,5	72,0	85	180	365	649
56	583	457	1061	69	45	70,5	71,0	79	190	355	663
59	590	457	1068	69	45	70,5	71,0	79	200	359	672

figure 83: Geometry of Koga Venya 5.0 (source: https://www.koga.com/files/5/2/1/4/KGV5.pdf)

Achieving maximum adjustability

In order to provide an ergonomical position for a wide range of users with different sizes, the aim was to design the frame such that it would provide great adjustability. Frame sizes are based on the height of the saddle measured from the bottom bracket and the length of the (imaginary) toptube. Both will increase in a larger frame size, as generally taller people also have longer arms. A longer toptube length at increased height of the saddle cannot be achieved if the head tube and seat tube are parallel. But if the angles are chosen carefully, the correct toptube length for the corresponding saddle height can be achieved and thus several frame size could be covered with one frame. Exactly this is done with the geometry of the final design.

To determine the head tube and seat tube angles needed to achieve the different frame sizes, two existing geometries were used as reference. A geometry overview of a the Koga Venya 5.0 ladies city bike (figure 82 and figure 83) was used as reference for the toptube lengths and saddle heights corresponding to different frame sizes. The geometry of the Popal Subway F201 (figure 81) was used as a reference for the angles of the head and seat tube, because it is a bike with 20 inch wheels and low entry. Based on these two geometries the angle of the seat tube was chosen x degrees and the angle of the head tube was chosen x degrees. With these angles a ladies frame size 47 to 59 can be achieved with the frame design.

The geometry of the final concept

In the final geometry (figure 84) the bottom bracket is located at 23 cm. The shaft drive is put in line with the downtube and points slightly downwards. This results in an entry of about 20 cm. The seat tube has an angle of 74 degrees and the head tube has an angle of 87 degrees. This results in an adjustability from ladies frame size 47 to 59. The wheelbase is 1.1m, which results in a total length of 1.6m.

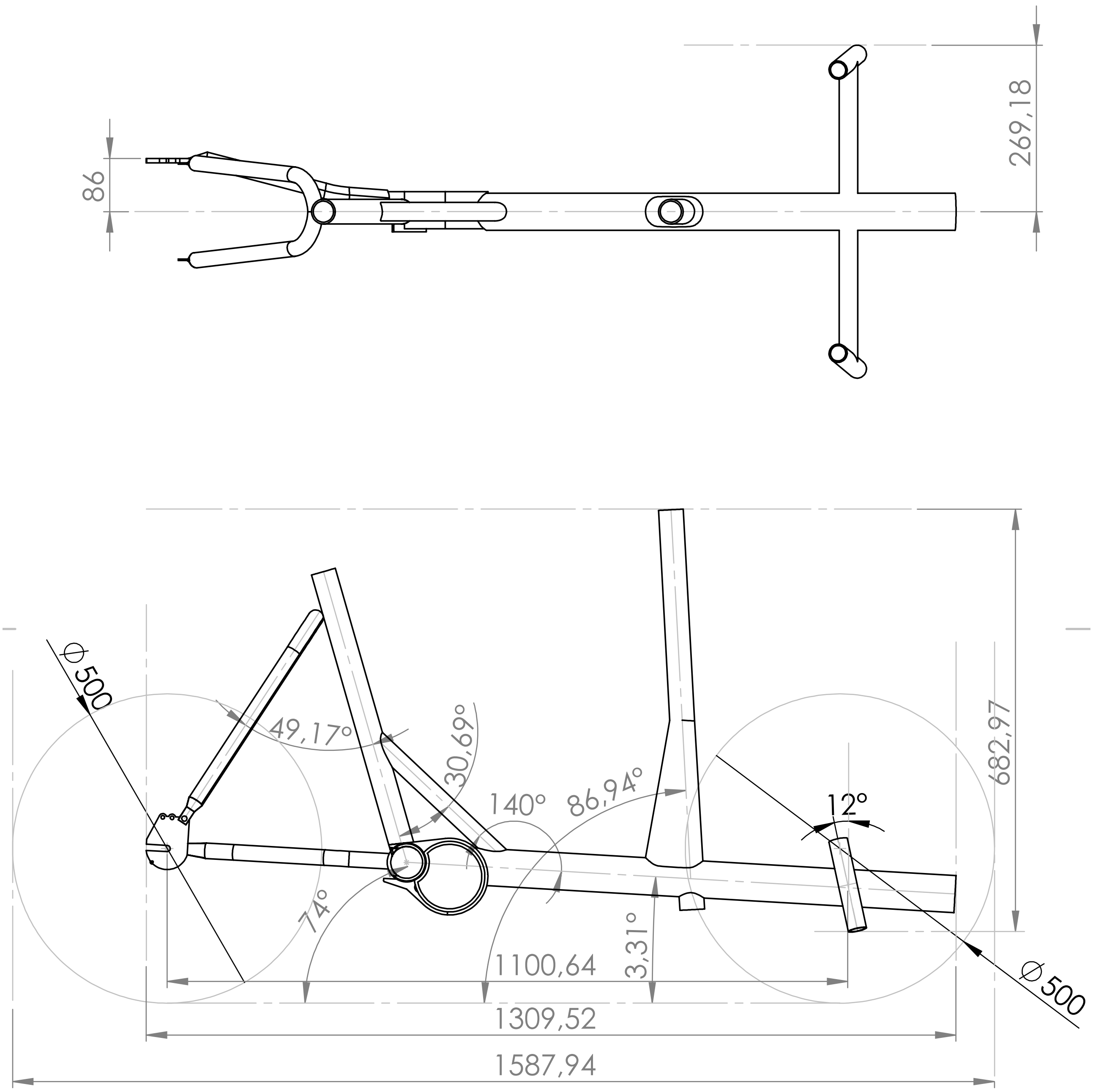


figure 84: The geometry of the final concept

4.5 The frame

The frame is the most important part of the bike, because it holds all parts together and determines the look and strength of the bike. This section focuses on the development of the frame design.

Requirements
The frame must fulfill several requirements in order to be suitable for the situation of use.

1.3 The frame must have a low entry of maximum 25 cm.
1.4 The Bafang E-shaft motor must be integrated in the frame.
1.5 The frame must be strong enough for holding a cyclist of up to 100 kg and a cargo load of maximum 40 kg.
1.6 The shaft drive must be integrated in the frame.
1.7 The frame design must fit Beixo's brand personality and design DNA.

Motor integration
Integrating the motor in the frame was the first challenge of designing the frame. This was done prior to the styling, because the way of integrating the motor largely influences the design of the frame. Three options to integrate the frame were explored (figure 85). The motor could be positioned in between the seat tube, downtube and chainstay. The motor could be surrounded by the frame or be placed between a double downtube.

Positioning the motor between the seat tube, downtube and chainstay was considered most interesting, because it allows for achieving a low entry and a simplistic frame design. It could be achieved without having to hydroform tubes, as is the case when the motor is surrounded by the frame. However, creating a strong connection is a challenge. Due to the shape of the motor the downtube cannot be welded directly to the bottom bracket. This is solved with a motorblock that surrounds the motor (figure 86). The motor block integrates the bottom bracket and provides additional material to connect the downtube.

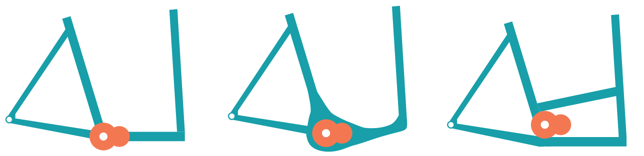


figure 85: Three possibilities for integrating the motor in the frame

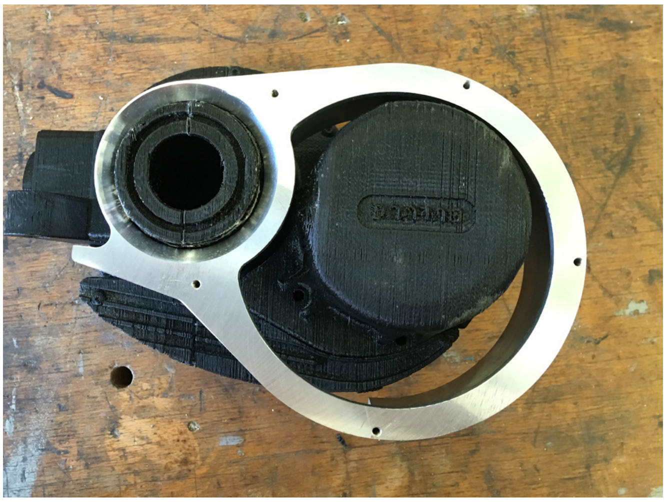
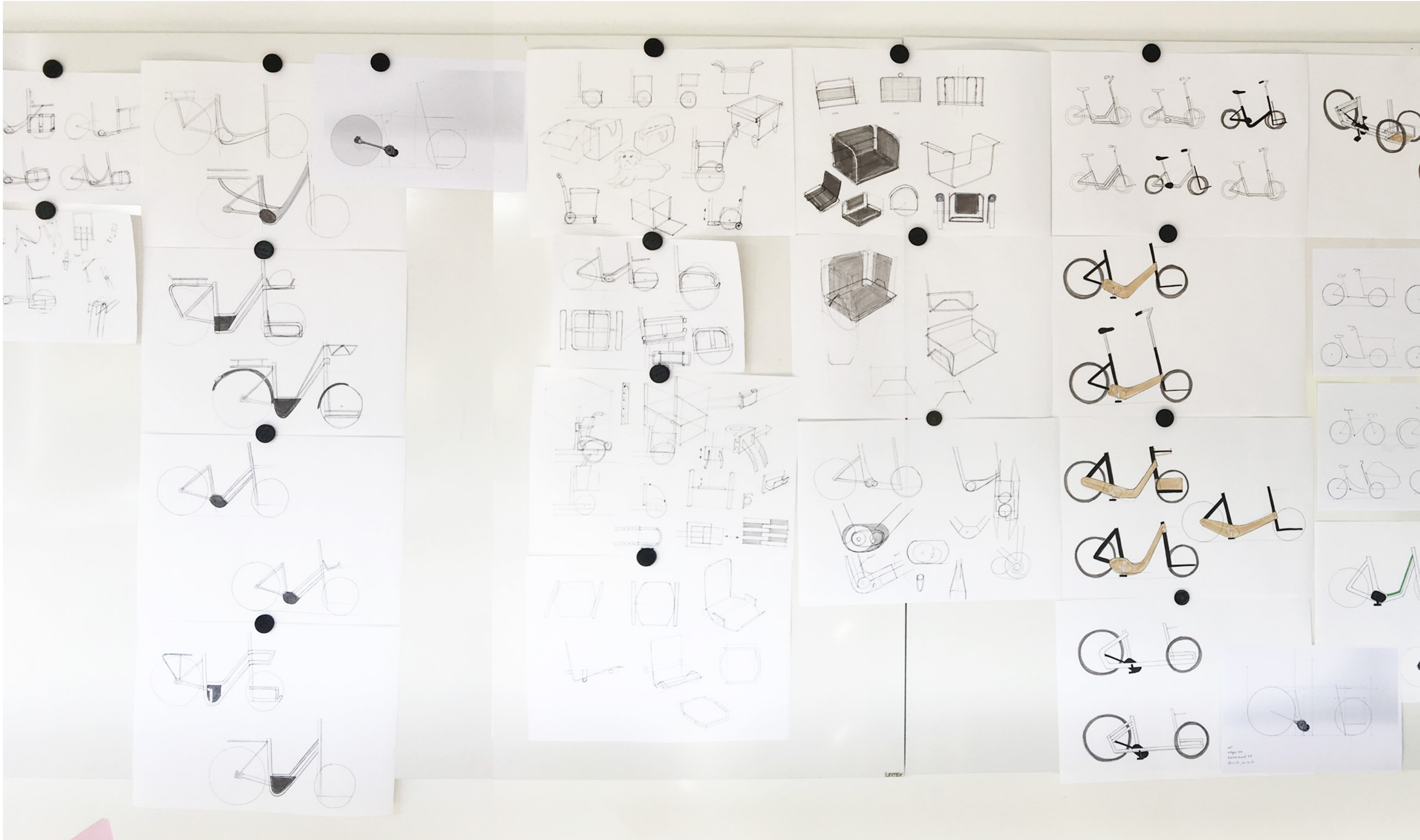


figure 86: Motor block surrounding the motor and offering surfaces for welding the seat and downtube



Styling
Creating the styling of the frame took many iterations. The evolution of the frame design can be seen in figure 88, where a selection of frame sketches is hang to the wall to create an overview of the design choices that have been made.

In one of the earlier sketches a reference was tried to make to the Beixo Share (figure 87). The characteristics of the bicycle are the parallel top and down tube. The design is geometric and very simplistic. The idea of two parallel tubes was left behind, because it was not possible to achieve a low entry, but the geometric form language was explored in different ways. One way was trying to create one strong visual line. Another design strategy was to empathize the frame itself and to subordinate the other components.

To get more inspiration, three designers of VanBerlo were invited to sketch ideas for the frame in a creative session. An introduction into the design DNA and an overview of the requirements was given. The results were hang to the wall and by voting by each placing four sticker dots, the best ideas were selected. The selected ideas are presented in figure 89 to figure 94. Some of the aspects in those sketches were used during the next ideation. Interesting aspects were the continuation of the shape (figure 89 and figure 90), repetition of elements (figure 91), integration (figure 92) and using colour to accentuate a shape (figure 93 and figure 94).

figure 87: Beixo Share

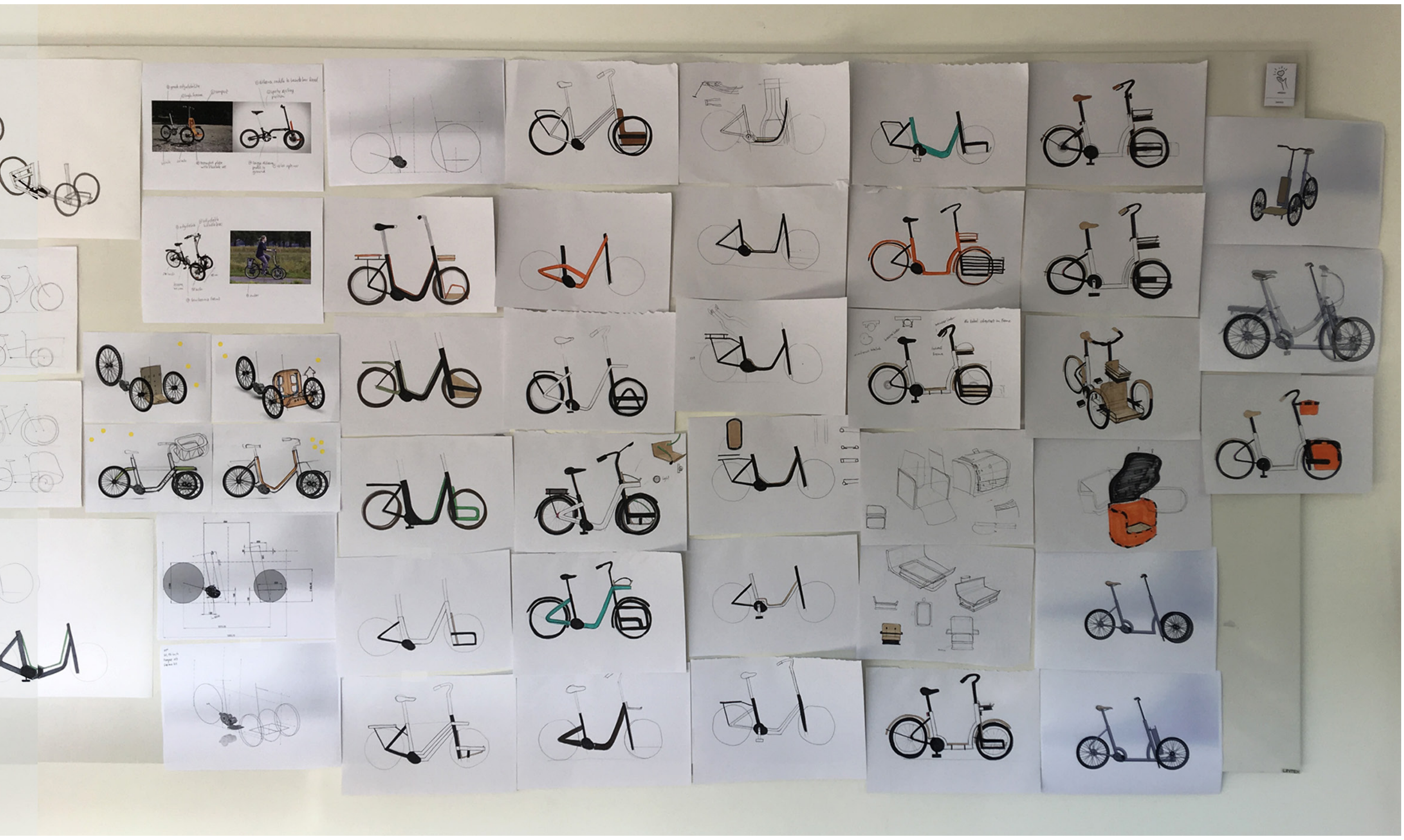


figure 88: Sketches on wall showing the evolution of the frame design

figure 89: Continuation of the shape 1

figure 90: Continuation of the shape 2

figure 91: Repetition of elements

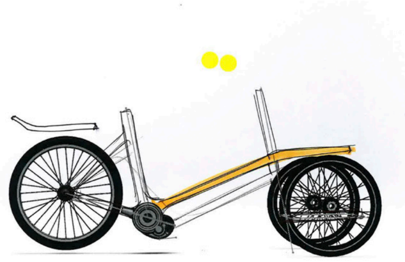


figure 92: Integration

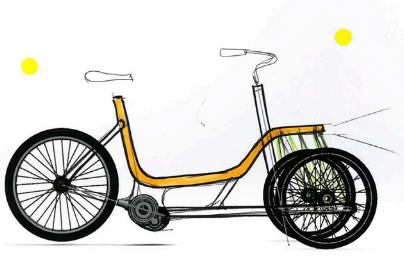


figure 93: using colour to accentuate a shape 1

figure 94: using colour to accentuate a shape 1

figure 95: Frame concept sideview

figure 96: Frame concept perspective

figure 97: Frame concept in CAD

figure 98: Adjustments to frame concept

The iterations led to the frame design shown in figure 95 and figure 96. This frame uses geometric shapes, repetition and accentuation of the frame by the means of colour. Iterations on this frame were made, because its simplistic and friendly appearance made it promising. Unfortunately, the idea as sketched did not work out in CAD (figure 97). The radii that are a repetition of the wheels needed to have a different size as sketched. The result is quite bulky.
Iterations, like changing the angle of the seat stay, extending the downtube and colour difference, were made to improve the frame design (figure 98). However, the result did not satisfy the requirements of a simple and pure design and thus more frame designs were explored.

Additional iterations led to the idea of continuing one visual line from the shaft drive to the cargo area. It was found that by creating a slight downward slope, a low entry as well as low cargo area could be achieved. The slope creates a forward movement, making the bike look fast. This idea was explored by drawing with tape on the wall (figure 99). In this way it was easier to get a feeling for the size, because the bike could be drawn on a 1:1 scale. A gentleman's city bike was placed next to it to compare the dimensions to an existing bicycle (figure 100). This helped to optimise the sketch and create a realistic looking frame.

Once the boundaries for the side view of the frame were set, the shape of the three dimensional frame was explored. Some of the explorations are shown in figure 100 to figure 103 . Different profiles were explored. In some of the sketches the cargo area was tried to be integrated into the shape of the frame. By splitting the frame up into two tubes that go around the cargo area (figure 103), the line is still visible from the side, but not from the other views. Trying to keep the line visible led to the frame design in figure 104.

figure 99: 1:1 scale drawing on wall of frame idea

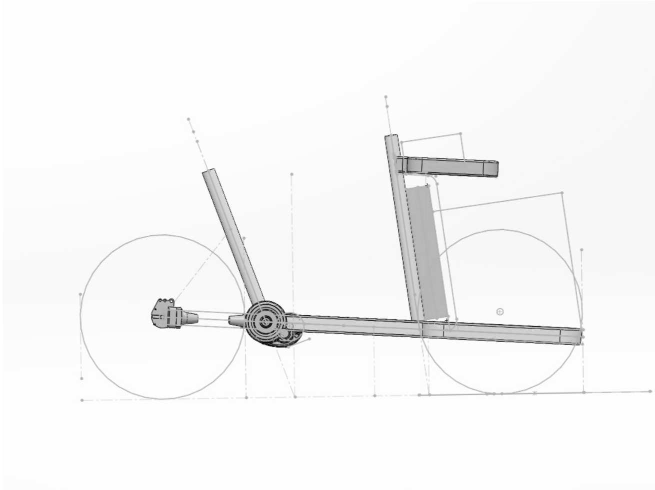


figure 100: Frame iteration with rounded rectangular profile

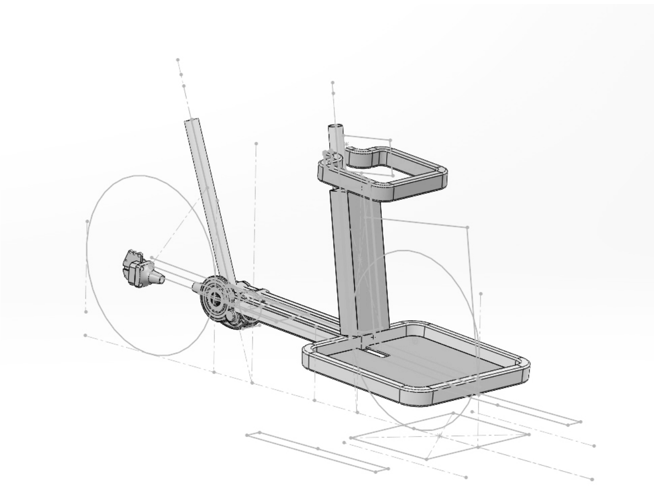


figure 101: Frame iteration with rounded rectangular profile in perspective

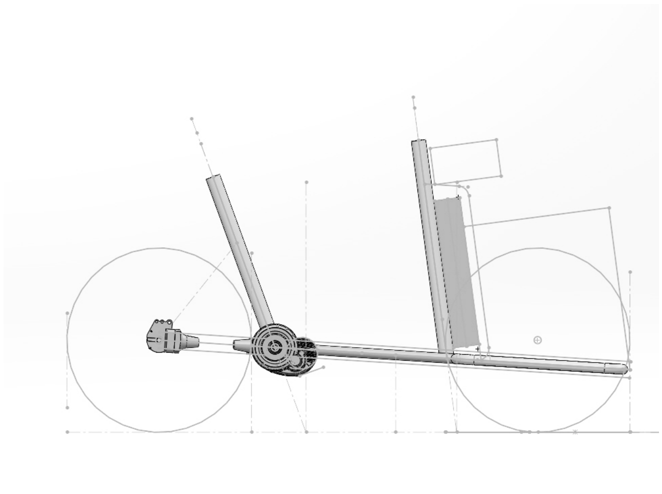


figure 102: Frame iteration with tubes

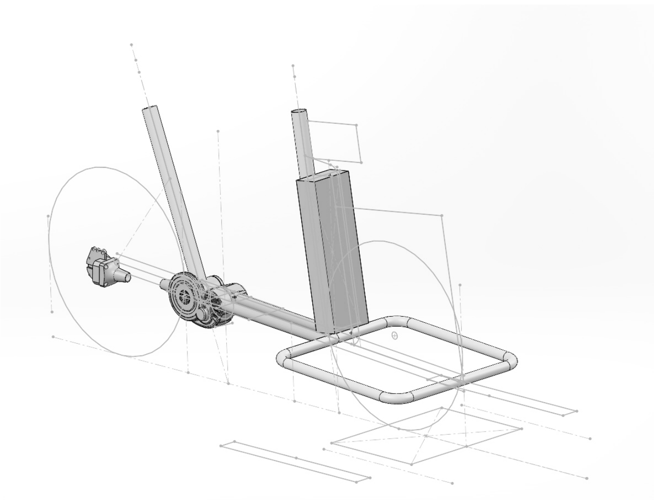


figure 103: Frame iteration with tubes in perspective

figure 104: Final frame design concept

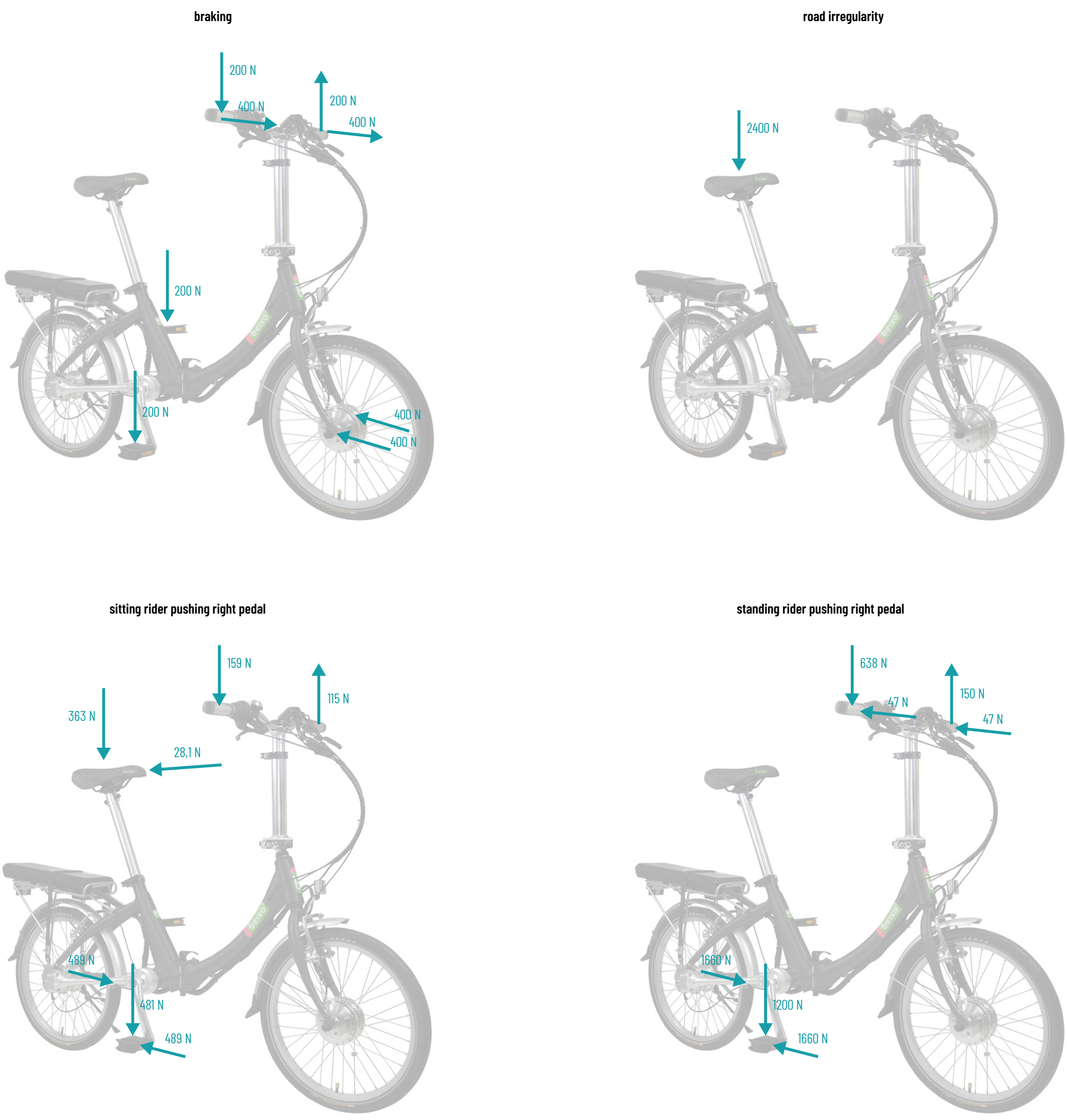


figure 105: Load conditions as proposed by Maestrelli and Falsini (2008)

Structural mechanics

During use the frame is exposed to static and dynamic forces. The static forces are the weight of the components, the rider and the cargo. The dynamic forces occur when the rider brakes, pushes the pedals or when there are irregularities in the road. These dynamic load situations are illustrated in figure 105.

Both the frame stiffness and strength need to be considered in the design of the frame. It is outside the scope of this project to simulate or calculate the forces in the frame. However, based on the load situations as proposed by Maestrelli and Falsini (2008) an estimation of the critical parts of the frame can be made.

It is assumed that there will be deflection in the seat tube, head tube and downtube and torsion in the downtube.

To make an estimation of a frame with sufficient stiffness and strength, existing bicycle frames are used as examples and the

figure 106: Smooth transitions between the tubes make the frame stronger

frame design is discussed with Beixo's engineer in Taiwan to get feedback from an experienced frame designer. Additionally, a mechanical engineering teacher from TU Delft was asked for advice. From this it was concluded that the welding connections are critical points. To avoid stresses in the material it is best if the form of the tubes follows the load and if abrupt transitions are avoided. Ideally, this would result in organic shapes that exactly follow the load distribution. In practice it would create expensive frame parts and is not always aesthetically pleasing. Thus, an example would be to achieve a transition with tubes. An example for this is the transition from the seat tube to the downtube in Beixo's 'Compact low' created with a trumpet shaped tube (figure 106).

Optimisation

The initial frame design solely consisted of a downtube, chainstay, seatstay, seat tube and head tube. This gave the frame a very minimalistic appearance, but appeared not to fulfill the needs for stiffness and strength.

Based on the feedback received from the engineers in Taiwan, iterations were made to add reinforcement to the seat tube and head tube. The first iteration was to add a plate between the seat tube and head tube that follows the form of the motor (figure 107). This plate could be hidden in the motor cover and would not be visible. However, a plate is not very resistant to deflection and torsion. Therefore, a tube was added between the seat tube and the downtube. Iterations were made to explore how this tube could become an aesthetic element in the frame (figure 108). The head tube also required reinforcement. The first step was to add a small tube on the front of the head tube (figure 109). This was done to keep the entry of the frame as large as possible. The frame of the final concept is presented in figure 110.

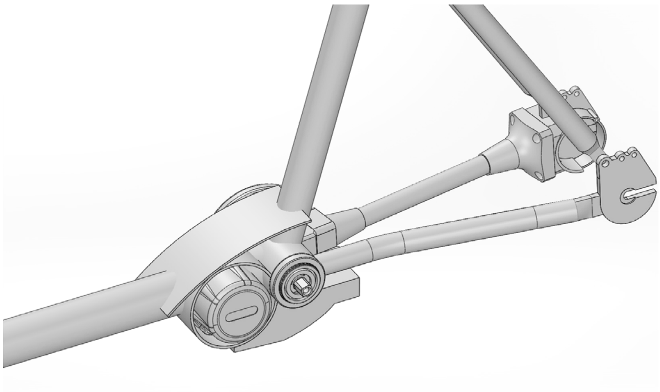


figure 107: Reinforcement plate

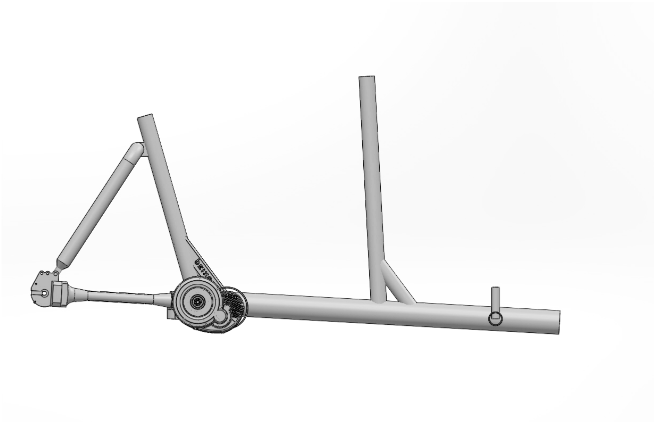


figure 108: Reinforcement tube with rectangular profile and Beixo logo

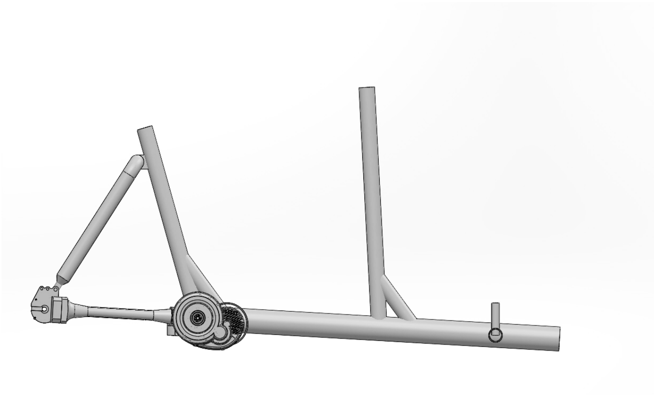


figure 109: Reinforcement tubes between seattube and downtube and headtube and downtube

figure 110: Frame design of final concept

figure 111: Original colour scheme idea

figure 112: Iteration on use of colour

figure 113: black frame

figure 114: orange frame

Colour study

The colour combination of the frame and other components greatly influences the look of the bike. By the use of colour certain aspects can be empathized, whereas others are pushed to the background. The use of colour is also tricky, because colour is very subjective. Some people may really like it and others dislike it. Colour can also indicate the gender or age of the target group.

The aim is to create an age and gender neutral bike that could appeal to anyone. Beixo indicated to prefer minimal use of colour. Neutral colours like white, black and aluminum also come back in Beixo's design DNA.

In the sketches the frame was coloured white and black. To put emphasis on the sloped line formed by the chainstay and downtube, the seatstay was coloured black. The motor cover was also coloured black, in order to create a contrast between the frame and the technical parts.

A colour study was performed to see how a different use of colours changes the bikes appearance. The original colour scheme is used in figure 111. In figure 112 the seat stay and reinforcement tube above the motor were also coloured white. This made the frame look more in balance and also more simple.

Additionally, a complete black frame (figure 113) and a coloured frame (figure 114) were explored. The black frame does not have preference, because there is no longer a contrast between the frame and the functional parts. It is more difficult to read the shape of the frame, which makes it appear more complex. The simplicity of the frame remains in the orange version. Like in the white version, there is a high contrast between the frame and functional parts. The warm orange additionally gives the bike a friendlier appearance and goes well with the warmth of the bamboo wood. However, orange is a very saturated colour that may not appeal to some people. The white frame is a better fit with Beixo's design DNA, therefore it will be used in the final design.

4.6 The cargo area

The cargo area is an important part of the design, because it differentiates the design from a tricycle. It is what disguises the third wheel and creates the association with a cargo bike. Thus, it is important for avoiding stigma. Designing the cargo area gives the possibility to adjust it to the needs of the target group. The aim is to create a three wheel bike with cargo function that better fulfills the needs of elderly than existing tricycle and cargo bikes do.

Considerations
For the design of the cargo area two aspects are equally important. The first aspect is creating an association with cargo bikes in order to avoid stigma and the second aspect is ease of use.

Next to a reduced balance the target group may also have reduced muscle strength. To enable the user to place the cargo without great effort, heavy lifting of cargo must be avoided.
The size of the cargo area influences the total width and length of the bike and must therefore be considered carefully. A balance between functional cargo space and acceptable width must be found. The volume of a beer crate (400x300 mm) is considered the minimal functional space. The length of the cargo area is determined by the wheel size, as the cargo area must stay within the wheels to minimize the turning radius.
Also the load direction and position of the cargo must be considered when designing the cargo area.
To allow for flexibility in use the design of the cargo area must allow the transportation for all kinds of cargo, ranging from grocery bags to dogs and flower pots (figure 115).
The bike may be stored outside where weather and vandalism impacts the product. To increase the durability vulnerable components, such as moving parts, should be avoided.

Requirements
The cargo area must fulfill a set of requirements:

2.1 The cargo area must be located between the front wheels.
2.2 The minimum volume of the cargo area is 400 x 300 mm.
2.3 The cargo area must allow for safe transportation of goods.
2.4 The cargo area must be resistant to weather impact.
2.5 The minimum load capacity of the cargo area is 40 kg.
2.6 The cargo area is accessible from the front.
2.7 The design of the cargo area must communicate its transport function.

figure 115: Products that the user might want to transport

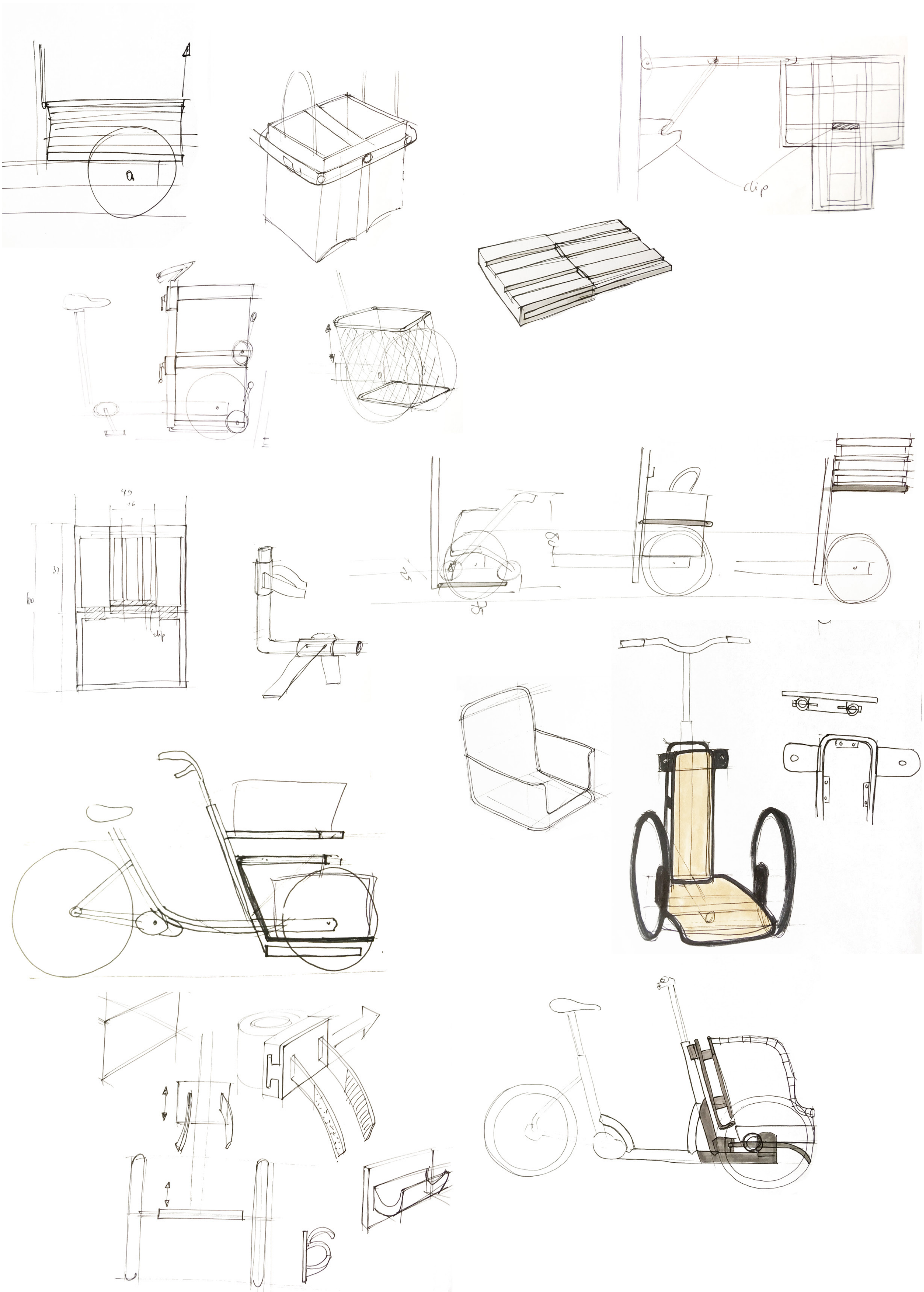


figure 116: Exploration on modularity of cargo area and fastening solutions

Modularity
Different designs for achieving modularity and maximum flexibility in use of the cargo area were explored. Explorations include adjustable size of the cargo area and different types of fastening (figure 116).

Using one fastener type that could be used to fasten all kinds of cargo was prefered over a modular system with specific fasteners for specific cargo, because the additional parts are more expensive and require additional steps during use. For this reason, a fastener with elastics and hooks (figure 117) was chosen. This is a standard component that is used on many bikes carriers or racks. This provides the user with the advantage that it can be easily replaced.

A prototype was made to test the use of this fastener and explore different shapes for the holes (figure 118).

It was also chosen to use the platform archetype instead of a container, because a platform has open sides, which allows for easy access. The challenge, however, was to design the platform such that it allows for safe transportation of the cargo. In the design in figure 119, this was solved with a frame surrounding the sides of the platform and a small border on the front of the platform.

figure 117: Fastener (source: powerplustools.nl)

figure 118: Testing different shapes for the holes in the platform

figure 119: Platform and rack design

figure 120: Shopping trolley design

figure 121: The rack has the same form language as the platform

figure 122: Klickfix adapter for stem (source: www.eurocycles.com.au)

By combining the platform with a shopping trolley that is designed to easily attached to the platform, the transportation of groceries becomes even more convenient (figure 120). The shopping trolley allows for safely transporting small things and makes transportation from the shop to the bike and from the bike to home effortless.

A rack with the same form language as the platform was designed for the transportation of valuables and smaller items that are convenient to have in reach (figure 121). By using a 'Klickfix' adapter (figure 122) the rack can be easily attached and detached and be replaced with any other rack or basket.

4.7 The steering

The steering mechanism is crucial for the functionality and cycling behaviour of the bike. The design of the steering mechanism was based on the steering mechanism of the Babboe carve when the 'carve lock' is activated (figure 123), but had to be designed specifically for the dimensions of the design. In this section the principle behind the steering mechanism and the design process are presented.

Requirements
The steering mechanism must fulfill the following requirements:

4.1 The turning radius is not larger than 3 m.
4.2 The steering mechanism is suitable for a bike with a width of approximately 0.6 m.
4.3 The bike can be steered solely by moving the handlebars.
4.4 The steering mechanism allows for effortless steering.
4.5 The steering mechanism ensures stability.

The Ackerman principle
In order to allow easy turning, the Ackerman principle was applied. This principle is also used in most cars and ensures a small turning radius without slipping tires. When the Ackerman principle is applied, the inner wheel has a smaller turning radius than the outer wheel as to enable both wheels to turn around a common center point (figure 124). This is achieved with inwards pointing steering arms (figure 125). For perfect Ackerman steering, the following criteria must be fulfilled:

1. The angle of the steering arms causes and imaginary line from the kingpins to pass through the rear wheel axle (figure 125).

2. The common center point of the turning radii of the front wheels lies on a horizontal line from the rear wheel axle (figure 124).

(Koladia, 2014)

figure 123: Steering mechanism of Babboe Carve when on 'carve lock'

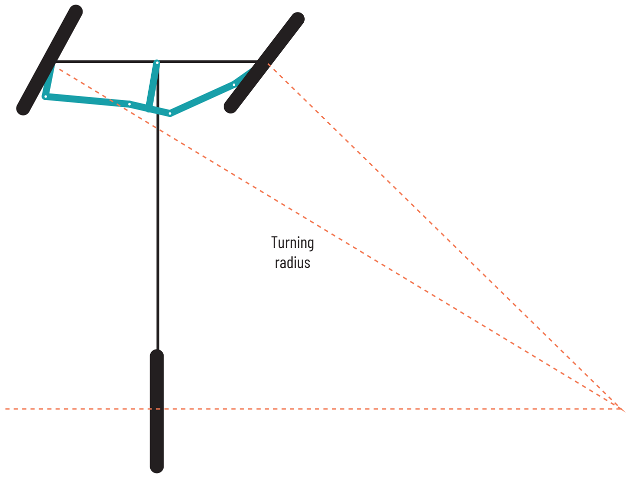


figure 124: Ackermann criteria 2

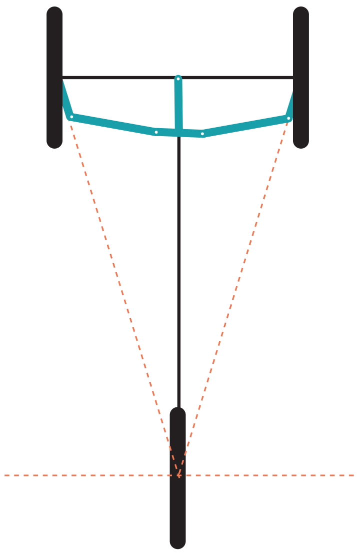


figure 125: Ackermann criteria 1

The steering model

Different types of steering mechanisms exist. The type used in the Babboe Carve was chosen, because its cycling behaviour was experienced as comfortable. The mechanism uses two rods that push the steering pivots. The rods are connected to a T-shaped part that rotates around a point as the handlebars are turned. Because the steering mechanism lies in front of the head tube, an additional rod is used to translate the turning motion of the handlebars into a rotation of the T-shaped part (figure 126).

The steering mechanism was built as a line sketch in Solidworks. The advantage of using this tool is that relationships between the lines can be set, which allows to move the line sketch as a rod mechanism would.

Trial-and-error approach

Initially a trial-and-error approach was used to create a steering mechanism that fulfills the Ackerman criteria. After many trials the model came very close to a perfect Ackermann, but a perfect solutions was very difficult to achieve.

Steering prototype

To get a feeling for how the steering mechanism would work in reality, a 1:1 prototype was made. The prototype was made from a combination of standard components and wooden parts, because that speeded up the process and allowed for quick adjustments (figure 127). The prototype did not fulfill criteria 2. As can be seen in figure 128 the wheels are not parallel when in a straight steering position. A learning from the prototype was that the position of the linkages needs to be carefully designed, since they overlap. Also, the arm of the steering extensions must be long enough to create a momentum large enough to turn the T-shaped crank. But the prototype showed that principally the steering mechanism could work.

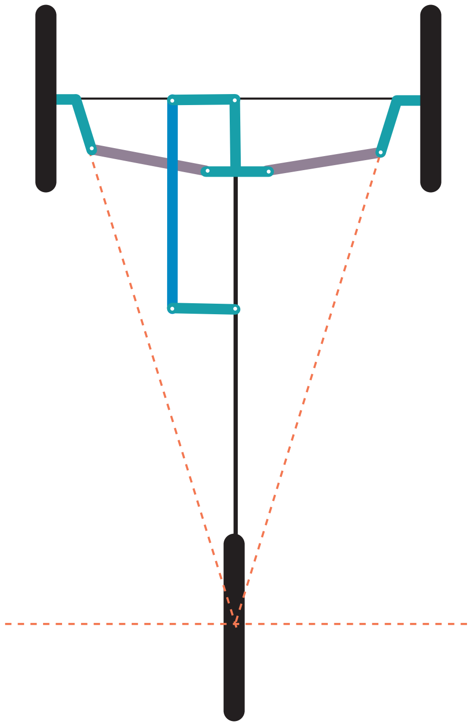


figure 126: The steering mechanism used

figure 127: The steering prototype

figure 128: The steering prototype does not fulfill all Ackermann criteria

Mathematical model of steering

To strive to find the correct lengths and angles of the linkages for a perfect Ackerman steering, a mathematical model was created and solved in Matlab. The idea for the mathematical model was taken from a similar model for a slightly different steering mechanism (Koladia, 2014) and assistance was received from a mechanical engineering student. The mathematical model is described below.

As it is strived to achieve perfect Ackerman steering, it is important to understand the principles of a perfect Ackerman steering. The first Ackerman principle is illustrated in figure 129. The angles of the steering arms are chosen such that when collinear lines are drawn from them these intersect at the axle of the rear wheel.

The second Ackerman principle is that as the bike is steered, the outer wheel angle θ and inner wheel angle φ are such that two lines perpendicular to the wheel intersect on the horizontal through the rear wheel axle (figure 130).

With perfect Ackerman steering the turning radius R can be determined with:

$$R = \frac{L}{\sin\theta} + w$$

The maximum angle of the outer wheel φmax is dependent on the size of the basket and the distance from the wheels to the basket and can be determined with:

$$\varphi\max = \sin^{-1}\left(\frac{2w}{Dbasket}\right)$$

The relationship between the el angle θ and inner wheel angle φ is:

$$\frac{L}{\tan\theta} = \frac{L}{\tan\varphi} + Wbike$$

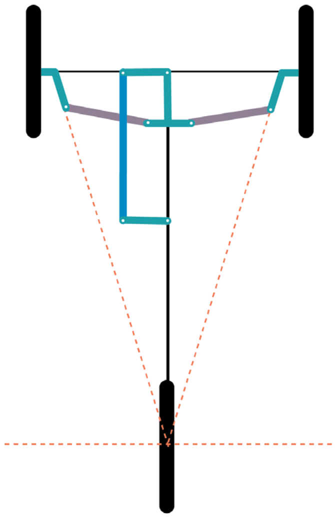


figure 129: The first Ackerman principle

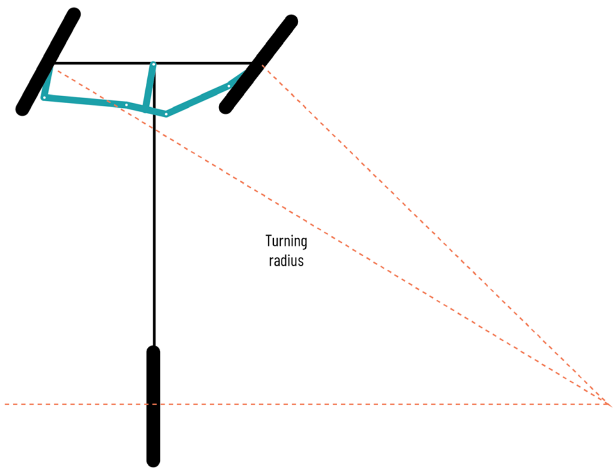


figure 130: The second Ackerman steering principle

The aim of this mathematical model is to find the parameters for the steering geometry as is illustrated in figure 131.

The geometry of the steering mechanism consists of two identical tie rods with the length l, two steering arms with length x at an angle β and a T-shaped crank with a horizontal arm 0.5p and a vertical arm d (figure 131). The front wheels are connected at either side of the basket with a distance w from the wheel axle. The axles of the front wheels are located at a distance L from the rear wheel axle.

From the bike geometry it can be determined that:

$$\beta = \tan^{-1}(\frac{2L}{Wbike})$$

$$l = (\frac{(Wbasket - p)}{2} - x\sin\beta)^2 + (d - x\cos\beta)^2$$

The function of l is true when the bike is steering straight ahead. This equation however still contains a lot of undetermined parameters (p, d, x).

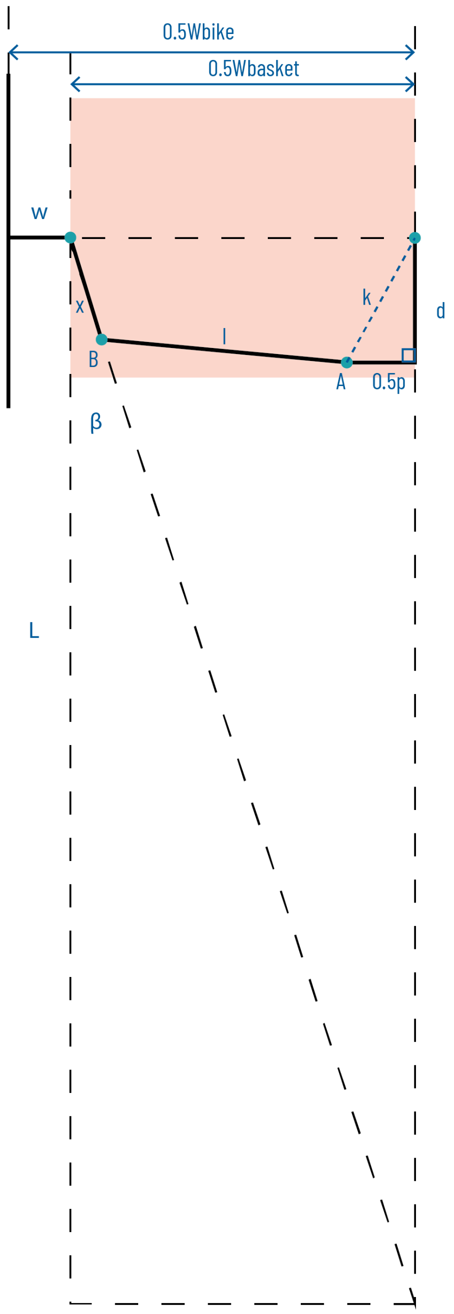


figure 131: Steering geometry

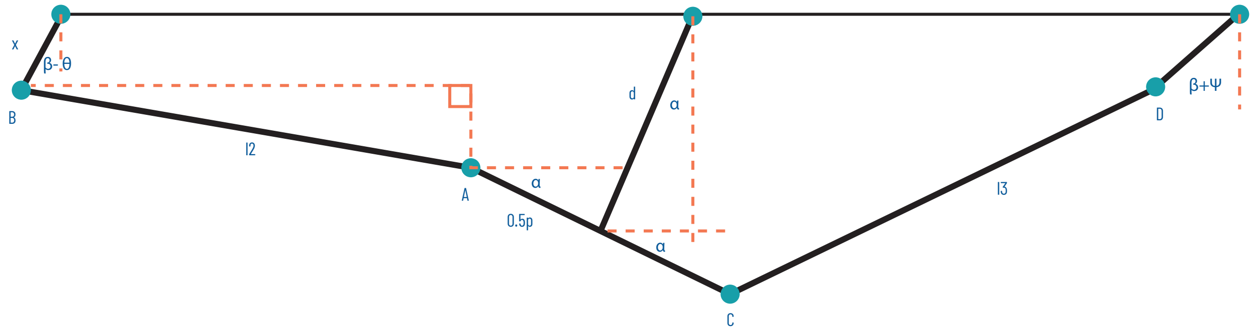


figure 132: The length of the tie rod does not change during steering

The length of the tie rod, l, does not change as the bike steers to the right or to the left. This is shown in figure 132. As the T-shaped crank is turned at an angle *α* the length of the tie rods l2 and l3 do not change. The position of the connection points A, B and C, D changes. Using pythagoras the x and y coordinates of the points A, B, C and D can be determined. Using these coordinates, l2 and l3 can be calculated.

Therefore, the length of the tie rod can also be described based on the rotation of the inner wheel or on the rotation of the outer wheel. This gives three equations for the length of the tie rod, l1, l2 and l3:

$$l1 = (\frac{(Wbasket - p)}{2} - x\sin\beta)^2 + (d - x\cos\beta)^2$$
$$l2 = ((\frac{Wbasket - p}{2}) + d\sin\alpha - 0.5p\cos\alpha - x\sin(\varphi+\beta))^2 + (d\cos\alpha + 0.5p\sin\alpha - x\cos(\varphi+\beta))^2$$
$$l3 = ((\frac{Wbasket - p}{2}) - d\sin\alpha - 0.5p\cos\alpha + x\sin(\theta-\beta))^2 + (d\cos\alpha - 0.5p\sin\alpha - x\cos(\theta-\beta))^2$$

Through optimization using Matlab, the best solution for the three defined lengths of the tie rod can be approximated.

The model gives the following lengths:

l1 = y0 = 231.7547
l2 = y1 = 231.1913
l3 = y2 = 231.1898

p = 0
d = 48.4740
x = 50.0000

The length of the tie rod given for steering straight (l1) is the length that is chosen for the design of the tie rod, because when steering straight the wheels should be parallel in order to avoid wear of the tires and to ensure a comfortable steering. It should be noted that solving this will yield a l2 and l3. l2 and l3 are equal and differ very slightly from l1. This means that with the maximum steering angle perfect Ackerman steering is almost achieved. p equals zero, which means that the distance between the two ends of the tierods A and C is zero.

The Matlab code was created by Diederik Stikvoort and can be found in Appendix H.

component	description	example product
saddle	ergonomic gel saddle, black	
seat post	with suspension, black anodized aluminum, minimum length 400 mm	
handlebars	black anodized aluminum	
stem	adjustable, black anodized aluminum	

component	description	example product
grips	ergonomic, black	
gear shifter	black	
hand brake	black	
bell	black, small	
integrated light	cylindrical light with diameter 55 mm	as used in Mobike 

4.8 Standard components

The bike uses several standard components. These components do not need to be designed. The standard components involve technical parts, such as the brakes, gears, display, motor, shaft drive, lights and battery. Also the saddle, handlebars, grips, mudguards, tires and rims are standard components. A wide variety of standard bicycle components and suppliers exist. This makes the choice for specific products difficult.

Beixo suggested to let their engineers in Taiwan order the parts, because they are closely to connected to a vast network of suppliers and can arrange a good price.

To make sure that the standard components fulfill the technical and aesthetic needs, guidelines were established (figure 133).

component	description	example product
front wheels	20 inch, one-sided suspension, black anodized aluminum rim	
rear wheel	20 inch, black anodized aluminum rim	
mudguards front	one-sided suspension, matte black plastic	
mudguard rear	matte black plastic	
disk brakes	two hydraulic brakes with one cable	Bengal 
drum brake	suitable for 20 inch rear wheel	
gears cable	black, minimum 2.5 m	

component	description	example product
electric motor	electric motor for shaftdrive, black	Bafang E-shaft 
battery	box shaped battery with connector, black	Bafang BT C01.304.UART 
component	**description**	**example product**
shaft drive	20 inch	
display	to be attached to handlebars, shows speed, battery power and support level.	Bafang DP C15.UART 

figure 133: List of standard components

figure 134: Concept

4.9 Concept

The many iterations on the geometry, frame, cargo area and steering led to the design presented in figure 134.

The Unique Selling Points of the final concept are:

- Trendy design
- The low entry makes getting on an off the bike easy
- The third wheel provides stability at any time
- The compact frame allows for easy handling
- Large adjustability from ladies frame size 47 to 59
- Pedalling support increases the cycling range
- Small turning radius of 3 m makes bike very agile
- The convenient transportation platform allows for easily transporting cargo
- The battery is easily accessible

The bike allows elderly with balance problems to cycle with confidence. The bike is stable at all times, is ideal for transporting groceries or taking a recreational tour and very trendy.

The bike is very compact. It's length and width do not exceed that of a normal city bike. The bike fits through any door and takes up little space on the bike lane.

The frame has been designed to provide maximum comfort to users of different sizes.

The transport platform is durable and very flexible in use. The elastic fasteners allow for quick and easy fastening of cargo of any size and shape.

5

Validation of concept

figure 135: First image used for validation

figure 136: Second image used for validation

5.1 Validation with bystanders

The final concept was validated with bystanders to test if it has been succeeded to design out stigma. Two images of the design (figure 135 and figure 136) were shown to people on the streets. Nine conversations with in total 14 bystanders were held. The bystanders were asked to answer the following three questions:

- What type of bike do you think this is?
- Who would use this bike, why?
- Would you use this bike, why?

Some quotes from the bystanders are presented in figure 137. The results are presented in appendix I.

In general the reactions to the bike were positive. Not everyone liked the design, but the associations that people made with the design indicate that the design is not stigmatising. The bystanders described the bike as a transport bike, bike for transporting a handicapped child, tricycle. Only one bystander, an elderly woman descibed the bike as a bike for elderly.

Even though many bystanders were positive about the design of the bike, not many bystanders said that they would use the bike. Reasons given for not using it were that they prefer a bike with two wheels, because it is more convenient or more comfortable and not having the need to transport cargo.

Two of the bystanders associated the platform with a chair that can be used for transporting a handicapped child. This association is not desired, because even though it is unrelated to elderly, it does create the connection with disabilities and mobility aid.

Conclusion
From the reactions of the bystanders it can be concluded that the design succeeds quite well at avoiding stigma. However, the design of the platform could be improved so it more clearly communicates that its function is to transport cargo.

"It does not look like a bike for grandma's!"

"It is a modern design"

"The low entry is very good"

"Nice design"

"Anyone could use this"

"It is not old fashioned"

"It looks cool!"

figure 137: Quotes from bystanders

5.2 Validation with target group

The final concept was also validated with 4 people who were thought to belong to the target group. In addition to the image in figure 135 and figure 136 they were shown three side views (figure 138 and figure 139).

The interview with the target group consisted of two parts. In the first part the participant was asked to talk about his/her own bicycle. In the second part questions about the design were asked:

- What is your first impression of the bike?
- What type of bike do you think this is?
- Who would use this bike, why?
- Would you use this bike, why?
- If you would cycle on this bike, would you be scared that people look at you?
- Would you prefer another colour?

Some quotes from the target group are presented in figure 140.

In general the participants liked the design of the frame. The participants who recognised the low entry mentioned it as an advantage. The frame was described as "sporty" and "modern". From this it can be concluded that the design of the frame is not stigmatising.

The design of the cargo area had more influence on people's associations and opinions. One of the participants associated the platform with a wheelchair that can be used to transport a handicapped person.

Two participants indicated that they would prefer a container instead of a platform. The main reason given was that they are afraid that things they put on it could roll off.

When asking the participants if they like the white colour, most indicated they would prefer a colour, like orange, red or blue.

One of the participants owns a tricycle from the brand vanRaam. Even though he prefers the design of the bike presented to him, he would not be able to use it himself. He needs a saddle with backrest and a possibility for transporting his rollator.

Of the four participants two indicated they would use the bike. The first participant to say this is a man who has balance problems due to an accident and has fallen several times with his e-bike. He would be glad to have a stabilised bicycle that he feels more secure with. The second participant who indicated wanting to use the bike is a woman who has lost her balance as a consequence being deaf. She would like to use the bike to cycle with her grandchildren. She now feels too insecure on her normal bike to cycle next to them, let alone taking one of them on the bike.

From the validation with the target group it can be concluded that in general the target group likes the design, but there are aspects that can be improved to better fulfill their needs.

The design of the cargo area could be improved to better communicate its function and avoid the association with a chair. Additionally, the sides of the platform should be closed to improve the feeling of safety.

5.3 Conclusion

From the validation with bystanders and the target group it can be concluded that the design succeeds quite well at avoiding stigma, because most participants did not associate the bike with elderly. In general, the reactions to the design were positive. Most participants liked the design, thought it looked sporty, modern, simple and not old fashioned. Most participants also recognised that the bike can be used to transport cargo.
However, an iteration on the cargo area is needed to better communicate its function and to increase the feeling of safety.

figure 138: Orange frame

figure 139: Black frame

"The front of the bike looks like a wheelchair but the back is very sporty."

"It looks sporty"

"Is the distance between the saddle and handlebars correct? That is important."

"You have kept it simple, I see that."

figure 140: quotes from validation with the target group

6

Iterating on concept

figure 141: The platform is associated with a chair

6.1 Iteration on cargo area

Based on the feedback received from the target group and bystanders, the design of the cargo area was changed. The aim was to get rid of the association with a chair and to reassure users that their cargo will be secure in the cargo area. First, the elements of the design that cause the association with a chair were identified. The shape as well as the materials of the platform create a strong reference to a chair (figure 141). The back and bottom plate could provide support, just like a chair does. The transport frame at the sides of the platform remind of armrests and the combination of wood and metal is very common for chairs. However, participants and bystanders liked the wooden material. The form of the platform also caused some worries. Some of the participants were worried that their cargo would roll off the platform or that it could touch the wheels.

The cargo area is an important element in avoiding stigma, because with its transport function it disguises the third wheel and creates reference to the product category cargo bikes. Therefore, it is important that it communicates its function well and that users feel confident to use it to transport their cargo. It seemed promising to solve both issues by closing the sides of the cargo area. It would get rid of the association with a chair, because one cannot sit on it when the front and sides are closed. Closing the sides would also create a closed container, which avoids that items can roll out.

The question was how and with what material to close the sides. Different options were explored, from textile to plexiglas, plastics and wood (figure 144, figure 145, figure 147). Existing cargo bikes were used as inspiration, for example the Gazelle Cabby (figure 142) which has a container from textile and a metal frame and the Urban Arrow Family, which has a container from polystyrene and metal frame (figure 143). Different shapes were explored that would allow for easy loading and at the same time avoid the cargo from falling out (figure 146, figure 148, figure 149). The materials of the container should fit the simple and pure appearance of the bike and be durable, affordable and lightweight. Also different ways of bringing in the Beixo brand were explored, for example by applying colour details with the colour used in the Beixo logo.

figure 142: Gazelle cabby (source: https://fietsenconcurrent.nl/populaire-series/gazelle-cabby/)

figure 143: Urban Arrow Family (source: https://www.ibike.be/fietsen/bakfietsen/urban-arrow-family-bakfiets/)

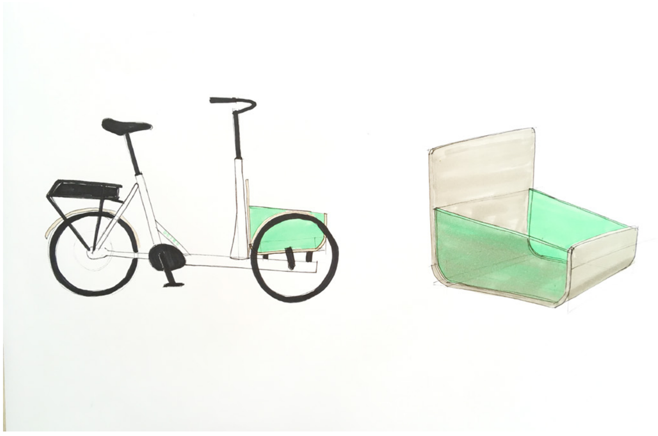


figure 144: container idea with bamboo and green plexiglas

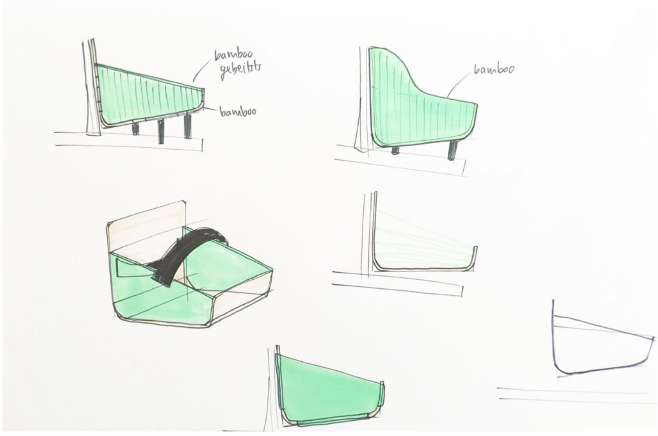


figure 145: container from bamboo

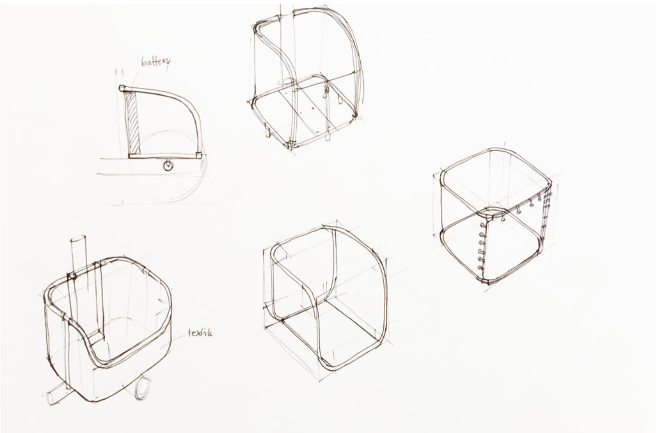


figure 146: Container shapes

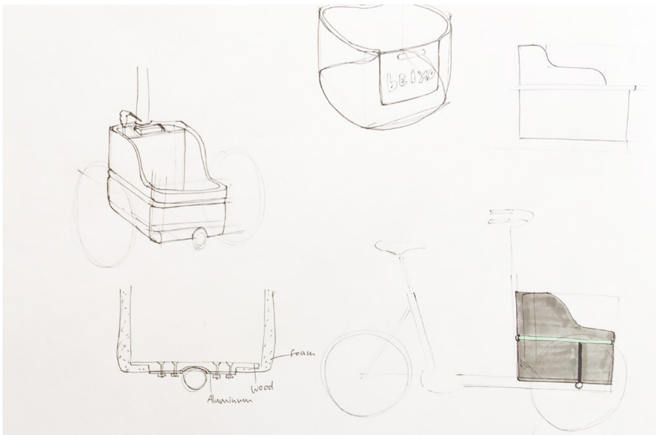


figure 147: idea for container of polystyrene

figure 148: Shape exploration for bamboo container

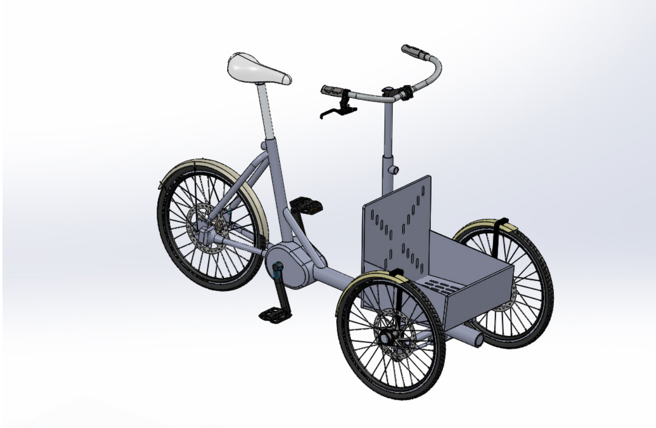


figure 149: Idea for bamboo container

Based on the criteria appearance, durability, price and weight, a bamboo container with slanted sides was chosen. The bamboo material gives the bike a luxury, yet pure and simple appearance. At the same time the wood creates an association with cargo bikes, which very often have a wooden container. Bamboo is a cheaper alternative to hardwood, while having comparable material qualitities (bambooxl, 2018). If treated correctly, bamboo can be used for outdoor applications. By impregnating the bamboo directly after harvest its durability can be increased from 2 years to more than 50 years (Bambooimport, 2016). Like every type of wood, weather will impact the material. After some time the colour of bamboo will change to grey (figure 150). The colour change is considered acceptable in this context. The price of a bamboo container is expected to be higher than the price for a textile or plastic container, but the luxury appearance and sustainability of the material are considered to compensate for this. Compared to textile or polystyrene, bamboo is heavy, but to achieve the same strength and stiffness a textile or polystyrene container is likely to need a metal frame or plastic base, which would also add up to the weight.

The choice was made to use the purity and colour of the bamboo and add a colour detail in the elastic band that was designed for additional fastening of the cargo (figure 151).

The designed container has slanted sides. The slant creates a 'fast' appearance, because like an arrow it points forwards. The lines in the bamboo created by the direction of the fibres are placed parallel to the slanted side to accentuate the direction (figure 152). The slanted sides also create a low front side, which allows the user to easily load cargo. The back side is kept higher to provide support for larger cargo. It is parallel to the head tube. The bottom of the container is perpendicular to the back side, which causes it to be slightly slanted. This slant is desired, because the items in the cargo will slide towards the back side, where they can be fastened using the elastic band.

figure 150: Weather impact causes bamboo to turn grey (source: https://www.bambooimport.com/nl/blog/bamboe-eigenschappen-en-onderhoud)

figure 151: With the elastic band cargo can be secured

figure 152: The slanted sides accentuate the direction and allow for easy loading of cargo

6.2 Iteration on frame

Upon advice from a former mechanical engineering teacher from TU Delft, changes have been made to the reinforcement of the head tube. To better cope with the forces by distributing the forces in the material, a trumpet shaped tube was added at the connection of the head tube and down tube (figure 153). This parts was taken from a Beixo compact frame and adjusted to fit the frame of the design.

figure 153: trumpet shaped reinforcement for headtube

6.3 Iteration on steering

The steering mechanism in the concept has straight kingpins. To improve the steering qualities and increase stability, a caster angle of 12 degrees and a kingpin inclination of 10 degrees to achieve centerpoint steering and neutral camber was applied.

<u>Caster angle</u>

Every front steered bicycle, including tricycles have trail, which is achieved by the caster angle. In figure 154 is illustrated how trail is achieved in a bicycle. Trail is the distance between the contact point of the wheel and the imaginary contact point of the steering axis. The effect that the caster creates is comparable to the wheel of a shopping cart. The caster angle helps to self-center the wheel, which causes the bike to steer straight and makes steering easier, especially at higher speeds (Eland, n.d., Gernaat, 2001.).
Caster is also applied in the steering design of tricycles, as can be seen in the trike of Huka (figure 155) and the Babboe Carve (figure 157).
Little publications can be found on the caster angle in tricycle steering geometry, but on Peter Eland's website he advices a caster angle of 10-14 degrees and the recumbent bike "Thunderbolt" uses a caster angle of 12 degrees (Horwitz, 2010). No literature on methods for calculating the caster angle has been found and it is very likely a parameter that needs to be determined through trial. As a starting point the caster angle of 12 degrees is chosen for the design (figure 156).

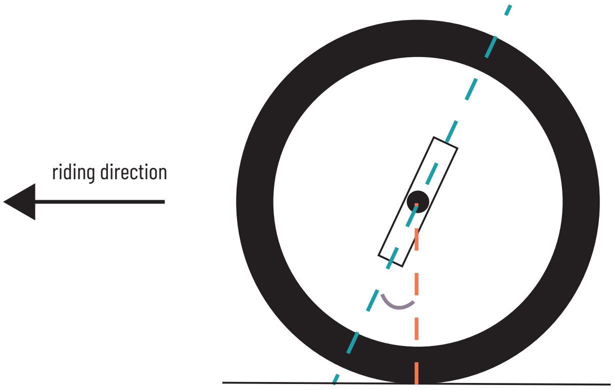


figure 154: Caster angle

figure 155: The Huka trike applies caster (source: https://www.huka.nl/product/driewieler-trike/)

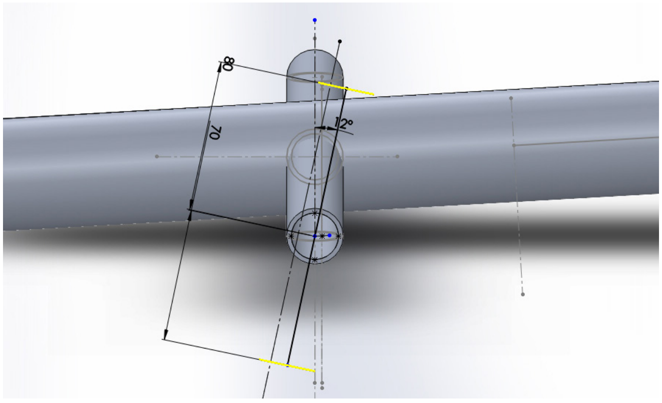


figure 156: The caster angle of the design is 12 degrees

figure 157: The Babboe Carve also applies a caster angle

Centrepoint steering
When looking at the Huka trike from the front it can be seen that the kingpin is tilted inwards (figure 158). In some steering the designs this angle is chosen such that an imaginary line would meet the contact point of the tyre (figure 159). This so-called "centrepoint steering" is applied to protect the steering from impact forces and torque that is created by bumps in the road. With centrepoint steering the forces are passed through the kingpin axes. The kingpin inclination should be kept at a minimum, in order to avoid the steering from becoming heavy (Eland, n.d.). In the design a kingpin inclination of 10 degrees was chosen to achieve centrepoint steering (figure 160).

Camber
In some designs positive camber (figure 161) is chosen to compensate for the slack in the bearing and other designs use negative camber to compensate for the forces on the outer wheel that push the wheel to a positive camber in a turn. By applying a negative camber one can make sure that in a turn only the flat part of the tyre has contact with the road. The disadvantages of applying camber are wear of the tires when riding straight and greater forces on the wheels (Gernaat, 2001). For these reasons it has been chosen to apply neutral camber to the design. As can be seen in figure 159, the Huka trike also applies neutral camber.

Scale factor
Due to the angles of the kingpin, the location of the connection point of the tie rod changes. The kingpin axis inclination is expected to have the biggest effect on the change of location. The changes caused by the caster angle are neglected. Because of the kingpin inclination, the length of the tie rods change. Thus, the lengths and distances retrieved from the mathematical model for the steering geometry cannot be used.

It is assumed that the relation between the lengths and distances stays the same, thus the new values can be calculated by scaling the complete mechanism.

The scaling factor was calculated by dividing the difference between the new and old length by the old length. This resulting scale factor was used to calculate the new values.

The new values are:

p = 0
d = 50,85
x = 52,45
l = 243,16

figure 158: The Huka trike applies kingpin axis inclination and neutral camber (source: https://www.huka.nl/en/products/)

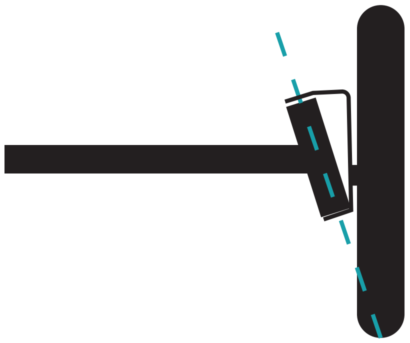


figure 159: centrepoint steering

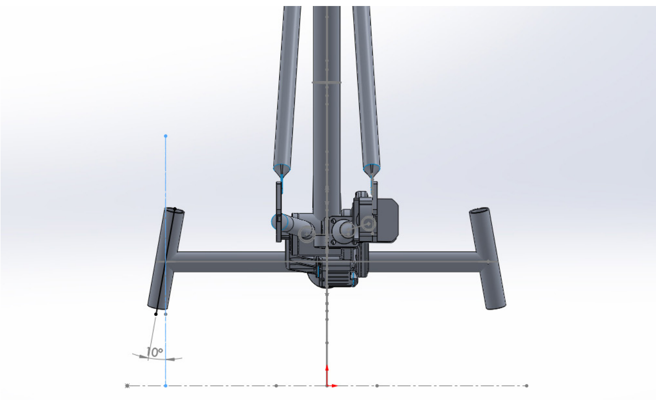


figure 160: centrepoint steering is applied in the design

figure 161: negative and positive camber

7

Design proposal

figure 162: The low container makes loading the cargo effortless

figure 163: With the elastic band the cargo can easily be secured

figure 164: The low entry and three wheels make getting on and off the bike easy

figure 165: Simple and pure design

The final design proposal is a stabilised bike with cargo function designed for people who do not dare or cannot cycle on a normal bicycle anymore out of fear of falling due to reduced balance. The design elements have been chosen carefully to create a bike that is not associated with a handicap. At the same time, it has been designed to fulfill the needs of its user, who may next to reduced balance also experience reduced strength, reduced sight or hearing and a slower reaction speed.

7.1 Functionality

The bike has three wheels, providing stability during cycling, especially during getting on and off the bike. The compact container between the front wheels allows for transporting cargo like groceries, luggage, a pet or a beer crate, etc. The container is located close to the ground and its front side is low to enable easy placing of cargo (figure 162). The elastic band can be used to fasten larger items and thus provides additional security (figure 163). The low entry makes getting on and off the bike comfortable and easy (figure 164). The electric shaft drive motor located at the pedal axis provides pedaling support, making cycling effortless and extending the range of its user. A light has been integrated in the frame to light up the bike path for better sight in the dark.

To provide additional options for transporting, a carrier has been added which can be used for panniers. The combination of aluminum and bamboo give the bike a contemporary look. The clear lines and purity of materials give the bike a simple and pure appearance, fitting Beixo's design DNA and portfolio (figure 165).

7.2 Design strategy

It has been tried to design out stigma by camouflaging the third wheel and adding additional benefits. Camouflage or disguise is a design intervention proposed by Vaes (2014a) to avoid stigma in design. This has been done by adding the container for transporting cargo between the front wheels. The transporting function disguises the third wheel and creates an association with three wheel cargo bikes, a product category primarily used by young people to transport goods or children. Next to the camouflage, the transporting function also adds the benefit of being able to safely transport heavy or large items. Adding benefits or experiences is another design intervention for avoiding stigma (Vaes, 2014a).

Design elements often used in bikes for people with disabilities, like a 'U'-shape frame to achieve a low entry, a messy frame and

figure 166: Prototype of the proposed design

functional design has been avoided to avoid an association with handicap.

By applying design elements specific for cargo bikes and avoiding attention to adjustments made to make this bike suitable for people with disabilities, this stabilised bicycle falls in the product category cargo bikes and is less likely to be associated with a tricycle for people with a handicap. This strategy is similar to Vaes' design intervention of reflecting on meaningful interactions with other products (Vaes, 2014a), because the typology of an accepted product is mimicked.

7.3 Specifications

The bike has the following specifications:

- Low entry of 0.25 m
- 32 kg
- Width is 0.7m
- Turning radius is 3 m
- Aluminum frame
- 20 inch wheels with Continental tires
- 7 gears
- Shaft drive
- Electric pedalling support
- 25 km/h top speed
- Estimated range 40 km
- Cargo area 0.3 x 0.4m
- Maximum cargo load 40 kg

7.4 Dimensions

The main parts and their global dimensions are presented in figure 167. The technical drawings of each part can be found in appendix J.

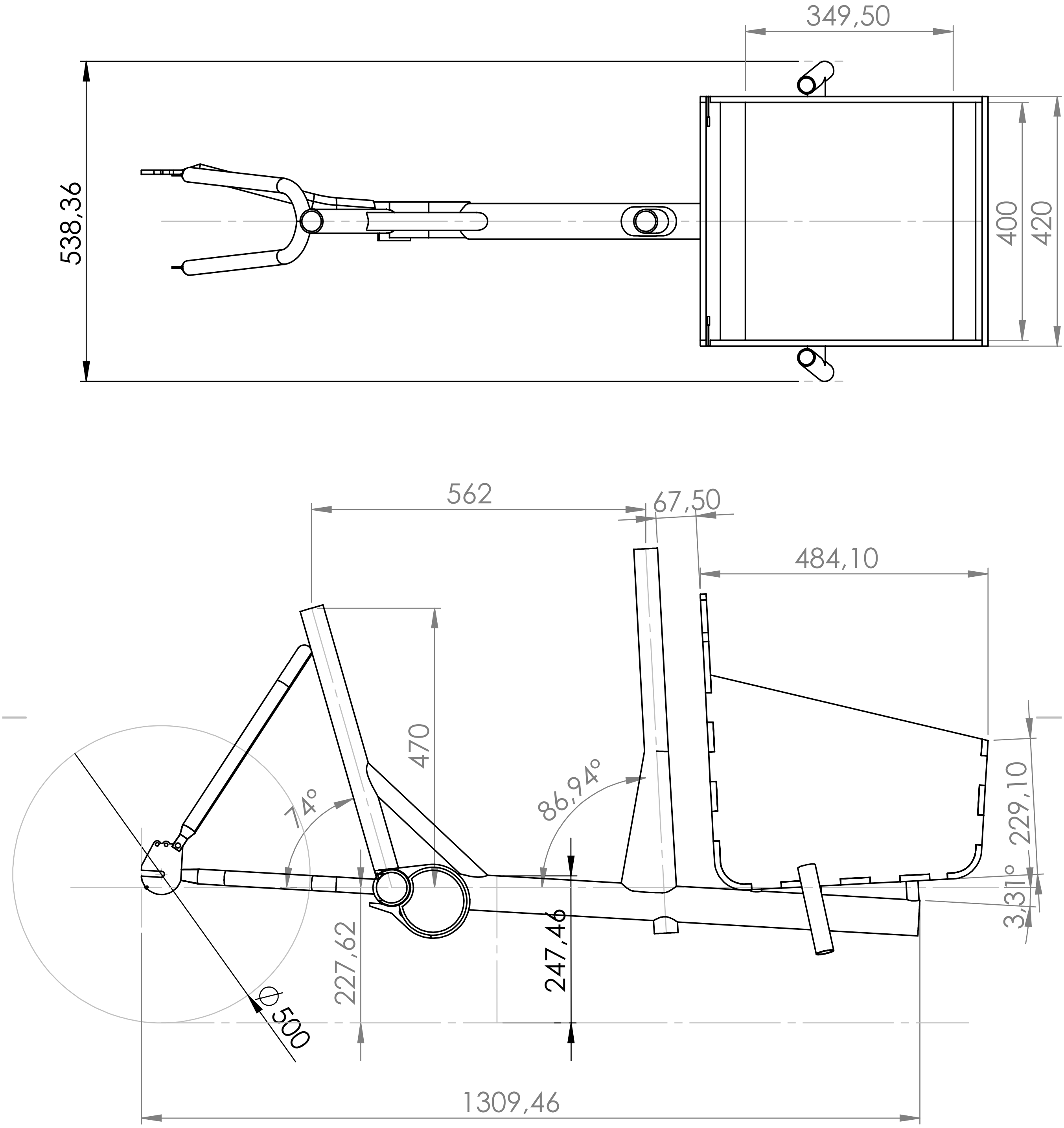


figure 167: Global dimensions of the design proposal

7.5 Positioning

The positioning of the product is challenging and if not done right it can cause the product to be stigmatising after all. What makes the positioning a challenge is that it is a mobility aid in disguise. The main target group are people with reduced balance, reduced mobility and thus a disability. However, in order to avoid stigma, the product must be perceived as a normal bike that can be used by anyone.

The product certainly should not be positioned as bike for elderly or disabled people, because that puts a stigma on it. People without a disability will not buy it, resulting in an association with a disability.

Positioning the product as a cargobike will avoid stigma, because cargobikes are a product category widely accepted by society and not associated with a disability. There is however a risk that the main target group is not reached when the product is presented as a cargobike, because the main target group is looking for a tricycle or other adjusted bikes.

From the user research it was concluded that people find it difficult to imagine being less mobile in the future. This may mean that people do not buy a mobility aid a few years ahead. This must also be considered for positioning the product. This product is an investment. If people have already invested in another bike, for example an e-bike, because they did think to have mobility problems in the future, they may not be willing to make a second investment. This could be solved by presenting the advantages the bike has for people without mobility problems and the possibilities it offers for future mobility decline.

The art is to present this bike in a way that it becomes clear that this is a bike that can be used by anyone, but that it could also provide a solution for people who have reduced balance.

7.6 Production

Beixo has contracts with production facilities in Taiwan where they produce their bicycles. At these facilities skills and machines are available for manufacturing bicycle frames. It is very likely that the same suppliers are able to produce the frame of the new design. Therefore, the manufacturing process of the frame is not discussed here. However, the new design incorporates a motorblock, steering mechanism and cargo container, which are parts that the other Beixo models do not have. This section looks into the production techniques that can be applied to manufacture these parts.

<u>Motorblock</u>
The motorblock is a part made from solid aluminum that integrates the Bafang E-shaft motor in the frame. Strength and small tolerances are crucial for this part, because large forces are applied to it during use and the motor must have a good fit. The part must also have welding quality, because the downtube and headtube are welded to it.

For the prototype the motorblock has been manufactured using CNC milling to achieve the tolerances. For this an aluminum quality which is suitable for welding and milling is required. The alloys with a suitable quality are EN AW-5005, EN AW-5005A, EN AW-6026 and EN AW-7021 cast (Alumeco, n.d.). The disadvantage of using CNC milling are the high material costs. To create the part, a solid aluminum block is needed from which material is removed by the milling machine. Thus, a lot of material is wasted. For the motorblock in the prototype a slice of diameter 200 mm and a thickness of 75 mm was used. The price of the material was 34,18 euros. Additional costs for the machine were 25 euros.

An alternative production technique for the motorblock is closed-die forging. Forging is a technique which shapes the material by pressing it in a mold with high pressure. Closed-die forging results in a product with high strength and complex shapes. Closed-die forging produces closer tolerances than open-die forging (The Aluminum Association, n.d.). With this technique no material is wasted. However, a die is needed and thus the investment costs of the die also need to be calculated in the price per piece. For a series of at least 150 it is assumed that a forged motorblock will be less costly than making it with CNC milling. Price calculations for each of these options based on up to date information from Beixo's suppliers or new suppliers in Taiwan are needed to make final decisions.

<u>Steering mechanism</u>
The steering mechanism is built up from steel tubes, ball bearings and aluminum or steel plate parts. The manufacturing can be done using the conventional production techniques turning, milling and welding. Therefore it is assumed that the steering mechanism can be produced in the same manufacturing facilities where the Beixo frames are produced. However, a new production and assembly line must be set up.

<u>Cargo container</u>

The cargo container is made from a base part and two side parts. The base part is bent in two places to create corners with a radius. The cargo container should have a bamboo look and have a high strength and durability. There are different options for manufacturing the cargo container. The options are discussed in this section.

Methods for bending the base part

In the prototype the bent corners are achieved using a lasercutting technique. A line pattern is cut into the wood to remove material, in order to allow the material to bend (figure 168). This is done with a two layers of plywood material of 5 mm. The side parts, which are attached with a finger joint and glue, keep the base part in its bent shape. After assembly, the container was covered with bamboo veneer to give it the bamboo look and to cover the lasercut pattern. This method is cost-saving, because manufacturing and material costs are low. The disadvantage of this technique is that the material looses strength where it is cut. Also, plywood is softer than bamboo, which makes the product more sensitive to high impact. The thin layer of glued bamboo veneer is also less resistant to force and weather impact.

An alternative, yet similar way to the lasercutting method is creating bends by removing material through saw cuts (figure 169). The material is not cut through, a thin layer is kept intact. This method is called kerf bending. The kerf cuts remove material, making the sheet flexible in this area (Hiziroglu, n.d.). Kerf bending can be done with plywood and would also be possible with bamboo plywood. The advantage of using bamboo plywood is that the material properties of the bamboo, for example its strength and hardness are within all of the product. The disadvantage of the kerf bending method is that the cuts will be visible on the inside of the bend. This could be covered up with bamboo veneer, but would require additional material and production steps.

Another method for bending wood is steam bending, where steam is applied to the wood before bending it. Steam bending does not work well for softwoods, but can be applied to hardwoods. As the example of the Faraday steam-bent fender (figure 170) shows, bamboo can also be bent by applying steam. Steam bending is a time consuming process. The wood sheets are steamed in a steam box (figure 171) for several hours. The steaming time depends on the thickness and moisture level of the material. To achieve the shape, the steamed wood needs to be bent within seconds and then clamped for at least 24 hours to cool down completely. So far no examples of steam-bent bamboo with a small radius has been found, which might indicate that the radius as in the design of the cargo container cannot be achieved with steam bending.

figure 168: Bending plywood using a lasercut pattern

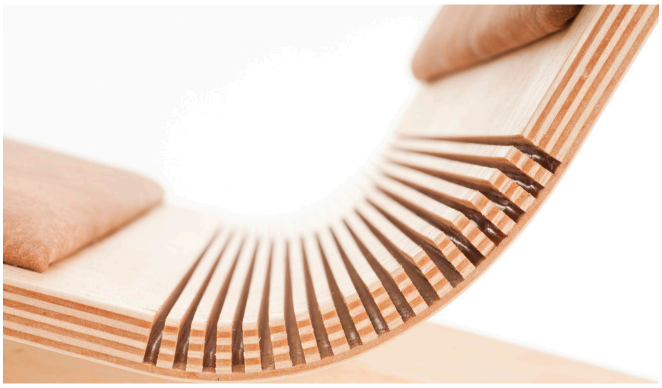


figure 169: Kerf bend applied to plywood (source: https://www.thebasicwood-working.com/how-to-bend-plywood/)

figure 170: Steam-bent bamboo fender (source: https://www.oregon-ebikes.com/faraday-faraday-steam-bent-bamboo-fenders.html)

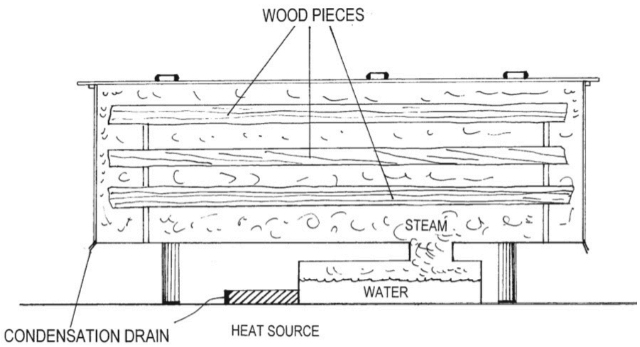


figure 171: Steam box (source: Hiziroglu, S. (n.d.) Bending wood for hobbyists.)

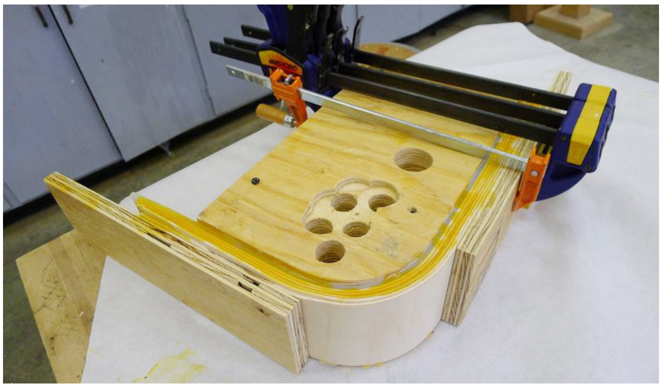


figure 172: Bending flexible plywood around a mold (source: https://www.instructables.com/id/Ramified-Armchair-bending-plywood/)

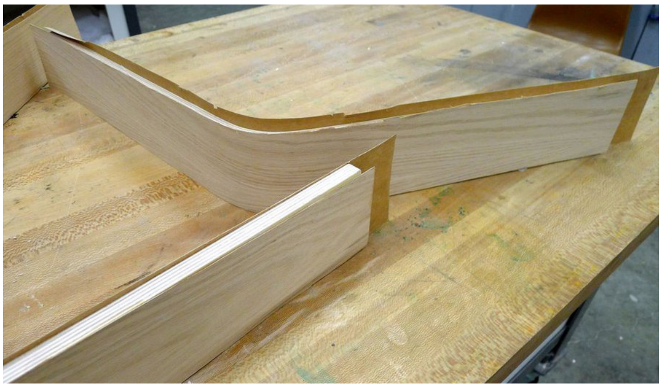


figure 173: Adding a layer of veneer to the bent laminated plywood (source: https://www.instructables.com/id/Ramified-Armchair-bending-plywood/)

figure 174: MOSO flexbamboo (source: https://materialdistrict.com/material/moso-flexbamboo/)

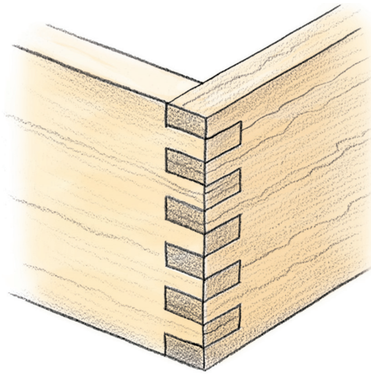


figure 175: finger joint (source: http://www.startwoodworking.com/post/finger-joint-basics)

Some types of plywood are sold as 'flexible plywood' and are especially designed for bending. The thin layers are easily bent around a mold (figure 172). By adding glue in between the layers and clamping them to the mold, a bended piece of laminated wood can be created. Bending the flexible plywood does not require special skills or equipment and is therefore not very labour or cost intensive. By adding one layer of bamboo veneer on the inside and one on the outside, similar to how is done in figure 173 with another type of veneer, a laminated bend with bamboo-look could be created. Alternatively to bamboo veneer, which has a thickness of less than 1 mm, 'Flexbamboo' by MOSO ((MOSO, 2018) can be used for the inner and outer layer. This material has a thickness of 2 mm and is therefore more resistant against impact. This material is bent perpendicular to the grain direction (figure 174) and the strips are 7 mm. This may cause the surface to be not as smooth as when veneer is used.

Fastening methods for connecting the sides to the base part

There are different ways to connect the side parts to the base part. Metal fasteners like bolts or screws are avoided, because of aesthetics reasons. A wood joint is less visible and is therefore preferred. There are different types of wood joints of which a few have been considered suitable for the design of the cargo container.

figure 176: In the prototype the sides are covered with bamboo veneer to hide the finger joint

One possibility is to connect the sides and base using a finger joint (figure 175). This connection is easy to make and creates a flush surface. By adding glue between the finger joints, the parts are held in place. This method was applied in the prototype. If not covered up by a layer of veneer, the finger connection remains visible. A possibility is to cover the sides with a layer of bamboo veneer after assembly, as was done in the prototype (figure 176). A finger joint can be made using lasercutting as was done in the prototype or with a box joint jig (figure 177). Alternatively a milling machine could be used. The fingers in the base need to be made after the bending process, to avoid deformation.

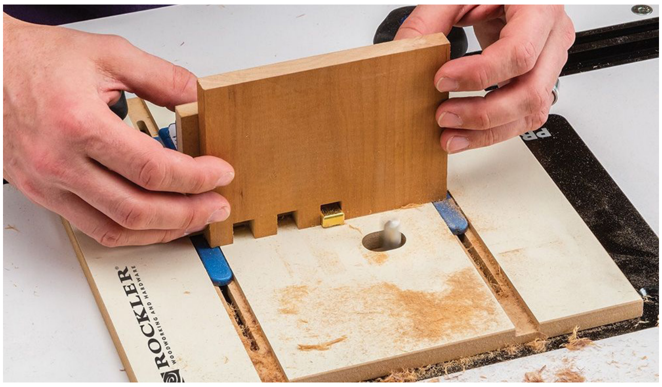


figure 177: box joint jig (source: https://www.rockler.com/router-table-box-joint-jig)

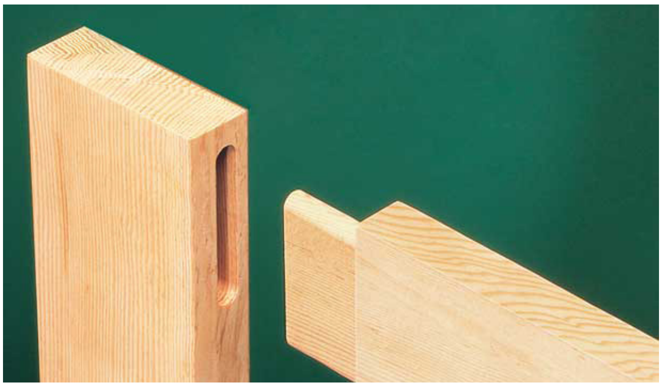


figure 178: mortise and tenon joint (source: http://www.woodworkersjournal.com/mortise-tenon-joints/)

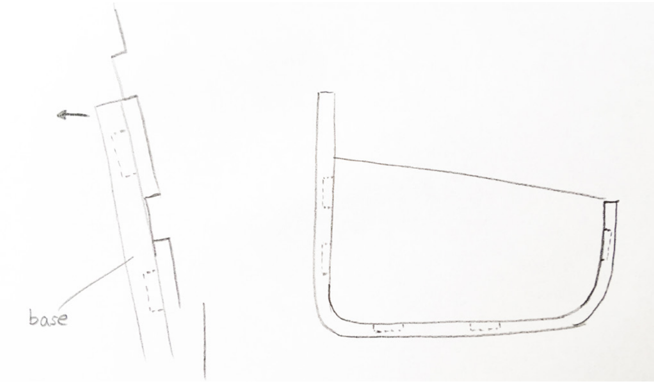


figure 179: mortise and tenon joint with tenon on the side part

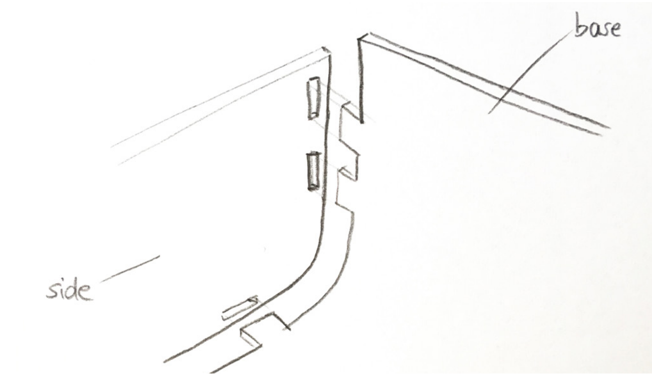


figure 180: mortise and tenon joint with tenon on the base part

Another wood joint that can be applied is the mortise and tenon joint (figure 178). This joint can be applied in two ways. One way is by applying the tenon to the side parts (figure 179). The base part is assumed to be slightly flexible, allowing it to bend open enough to connect the side parts with the tenon. The mortise and tenon joint is a strong connection, because it has a large glue area and the form closure prevents the sides from moving inwards or outwards. The thickness of the base is 10 mm, hence the tenon will be no longer than 8 mm. It needs to be tested if this length is long enough corresponding to the flexibility of the base. It must be avoided that if the base bends open the connection is broken. Optimizing this production technique might require more development costs.
Another way is to apply the tenon to the base part (figure 180). This way the base cannot bend inwards or outwards, but the sides can move outwards if the glue is not strong enough.
The mortise and tenon joint can be created using a milling machine.

Advice for production of the cargo container

The combination of flexible plywood, finger joint and a top layer of bamboo veneer seems to be most promising for the production of the cargo container. Creating the base part using flexible plywood does not require specific skills or machines and thus is cheaper to make than steam bending. The result is assumed to have greater strength than bending with lasercutting or kerf bending, because no material needs to be removed. To give the base part a bamboo look, bamboo veneer can be used as a top layer. Because of the use of the bamboo veneer on the base part, the side parts can also be made from plywood and covered with bamboo veneer. In that case, the finger joint can be used, because it will be covered by the veneer and thus will not be visible. The finger joint seems promising, because it is simple to manufacture. By combining these two methods the cargo container can be produced in a simple and cost efficient way.

7.7 Retail price estimation

The retail price for the bike were estimated by Beixo to be 3500 euros. This estimation is based on experience of the company. A quick check if this estimated retail price is realistic, has been done by estimating the retail price using different methods.

Methods for estimating retail price
There are different ways to estimate the cost price and retail price of the product. One way is to use existing information about production costs or estimate the costs for machine investment, labour, machine and material costs to calculate the cost price and apply a margin of profit to determine the retail price. For this method very detailed information is required, which cannot be easily attained. Even if the cost price can be attained with this method, the retail price is not necessarily a result of the cost price and profit margin, because the retail price can also be dictated by the market and competition. Another method is to estimate the cost price based on the prototyping costs. This does not incorporate labour costs and investment costs for machines. Also the material costs might differ, because for production the quantities will be larger and thus material prices may drop. The retail price could also be determined based on competing products. In this case the retail price could be based on the retail prices of cargo bikes and tricycles.

It is outside the scope of this project to retrieve all this information from Beixo's suppliers to calculate the production costs and estimate the cost price. A check of the retail price as estimated by Beixo has been done on the basis the prototyping costs and retail prices of competing products.

Approximate price for the prototype
The prototype cost approximately 1182,26 euros to make (Table 1). These costs are made up of the material costs for the frame, container, steering and standard components. Except for the motorblock, there were no machine or labour costs for the prototype. The frame costs are approximately 103,13 euros and the most costly part is the motorblock, which cost 35 euros for the material and 25 euros for using the CNC milling machine. The costs for the container of approximately 112,72 euros are made up of 90 euros for the bamboo veneer and the rest for the plywood. The costs for the steering were approximately 113,35 euros. The most expensive parts are the ball joints, which cost more than 10 euros each. The price for the standard components were taken from a datasheet of a Beixo folding bike and are based on large series. The motor with shaft drive were estimated by Beixo to cost around 500 U.S. Dollars, so 440 euros, the battery about 180 euros and the three wheels inclusively the tires about 120 euros. This results in a total of approximately 853,06 euros for the standard components. In total this gives a price of 1182,26 euros for the prototype.

For the final production prices differ due to larger series and machine and labour costs. Beixo produces in Taiwan, thus they need to also pay for transport and import. Too little data about these costs is available to make a precise calculation within the scope of this project. Let's assume that these differences will cancel out and the cost price of the bike is 1200 euros.

The estimated retail price of 3500 euros is inclusive BTW of 21%. This means Beixo receives 2765 euros for each bike they sell in their own shop. If they sell via a retailer, the retailer is likely to demand a margin of about 30% (A. Tummers, personal communication, November 12, 2018). This would result in 2126 euros per bike for Beixo. Taking off the production costs of 1200 euros, this leaves 926 euros per bike. Based on estimations this means that Beixo needs to sell about 400 bikes per year to break even.

The market for this product is assumed not to be large enough to sell 400 bikes per year, but Beixo also sells folding bikes and e-bikes for which the market is bigger. Thus, it seems plausible that Beixo can sell enough bikes to break even and the retail price of 3500 seems realistic.

Approximated retail price based on competing products
To check if customers would pay the 3500 euros for the bike, the retail price has been compared to the retail prices of competing products. Different product categories can be seen as competition. For this price estimation two tricycles with two front wheels and electric motor and two compact cargo bikes with electric motor are used as comparative material.

Huka Trike 26 inch with electric motor (figure 181): 4094 euros
vanRaam Viktoria with electric motor (figure 182): 4505 euros
Sblocs E Kurier (figure 183): 4499 euros
Triobike Mono e (figure 184): 4250 euros

This comparison shows that with a price of 3500 euros the bike can compete with electric tricycles and electric compact three wheel cargo bikes. Beixo could even consider increasing the retail price to 4000 euros to increase the margin and cover the insecurity about market share, especially in the first year after product launch.

Conclusion
The methods used for estimating the retail price show that a retail price of 3500 euros seems plausible. Based on the competition, Beixo could consider to increase the retail price to 4000 euros. To determine the precise profit margins and break even point a complete calculation with all production and transport costs, taxes and all other expenses needs to be made.

Table 1: Estimated costs for prototype

subassembly	part	material costs (Euro)	machine costs (Euro)	price (Euro)
frame	frame tubes	43,95	n.a.	43,95
frame	motorblock	34,18	25,00	59,18
frame total				*103,13*
container	multiplex inside	22,72	n.a.	22,72
container	bamboo veneer	90,00	n.a.	90,00
container total				*112,72*
steering	ball joints	75,54	n.a.	75,54
steering	tie rods *	5,00	n.a.	5,00
steering	bearings kingpins *	10,00	n.a.	10,00
steering	bearing rotation point *	5,00	n.a.	5,00
steering	pivot arms	13,95	n.a.	13,95
steering	other parts	3,86	n.a.	3,86
steering total				*113,35*
standard components	handlebar **		n.a.	1,68
standard components	handlebar stem **		n.a.	21,22
standard components	grip **		n.a.	1,00
standard components	saddle **		n.a.	6,13
standard components	seat post **		n.a.	6,98
standard components	pedal **		n.a.	2,73
standard components	crank **		n.a.	7,46
standard components	gear sets **		n.a.	8,36
standard components	disk brake *		n.a.	10,00
standard components	rear brake **		n.a.	2,76
standard components	brake lever **		n.a.	5,05
standard components	head parts **		n.a.	4,40
standard components	fender rear **		n.a.	4,63
standard components	fenders front ***		n.a.	10,00
standard components	seat clamp **		n.a.	1,21
standard components	carrier **		n.a.	8,62
standard components	logo **		n.a.	1,32
standard components	wheels incl tires ***		n.a.	120,00
standard components	Battery ***		n.a.	180,00
standard components	motor with shaft drive ***		n.a.	440,00
standard components	integrated front light *		n.a.	5,00
standard components	rear light *		n.a.	2,50
standard components	bell *		n.a.	2,00
Standard components total				*853,06*
Total				**1182,26**

* estimated
** price taken from datasheet of a Beixo folding bike
*** estimated by Beixo

figure 181: Huka trike 26 inch (source: Huka)

figure 182: vanRaam Viktoria (source: vanRaam)

figure 183: Sblocs E Kurier (source: Sblocs)

figure 184: Triobike Mono e (source: Triobike)

8

Prototyping

A fully functional, 'looks-like-real', 'works-like-real' prototype was built to validate and present the concept. This required manual production of all elements of the frame, steering and cargo container and integration of standard components, such as saddle, handlebars, carrier, motor, etc.

8.1 Aim of prototype

A prototype was made to test the stigma and stability of the bike and to be showcased at the Dutch Design Week. Different ways of prototyping have been considered. One option was to use an existing bike frame as the base. The consideration was made to create a functional prototype for testing the stability and an aesthetic prototype for testing stigma. Due to the ambition of showing a 'looks-like-real' and 'works-like-real' prototype at the Dutch Design Week, the choice was made to create one prototype that resembles the design as close as possible. The design of the frame is in many ways quite different to existing bike frames, thus the frame was built from scratch.

8.2 Prototyping process

The prototype was made in the PMB workshop of Industrial Design Engineering at the TU Delft with support from the employees of the PMB. The duration of the prototyping was approximately 7 weeks. The prototyping process consisted of several phases, which are summarized on the following pages.

<u>Prototyping steps</u>

1. the frame

In the first phase all parts for the frame have been produced and eventually welded together to create the frame of the bike. For this different production methods, including milling, turning, CNC milling and bending were utilized. In figure 185 to figure 194 some of the steps that were required to produce the frame are shown.

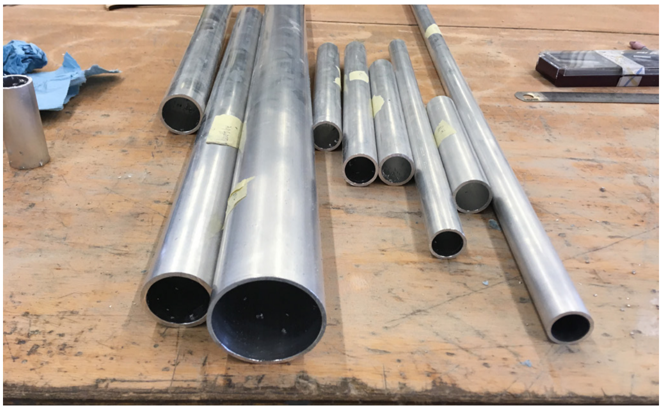


figure 185: The frame is build up of aluminum tubes with different diameters and similar thickness. The tubes are cut to length before bending or milling the part.

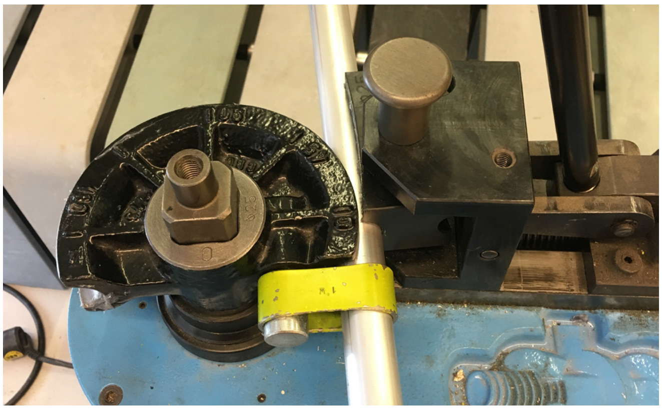


figure 186: The bending machine is used to bend the tubes for the seatstay and chainstay.

figure 187: The chainstay is made of a tube and a part used for connecting the rear wheel, mudguard and carrier. The seatstay consists of two bent tubes that are connected using a solid piece of aluminum which is welded in between.

figure 188: The ends of the head tube, seat tube and reinforcement tubes had to be milled at specific angles to easily fit onto the adjacent tube to form the frame. This was done by using a boring head and placing the tube under the correct angle.

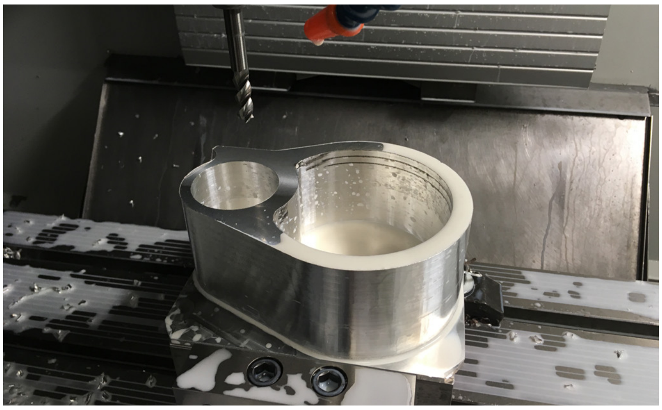


figure 189: The motorblock was manufactured from a solid disk of aluminum using CNC milling.

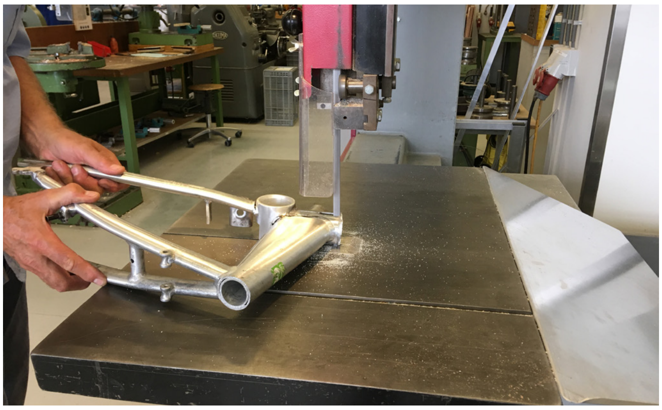


figure 190: The trompet shaped tube from the Beixo compact was removed from an old frame to be used as reinforcement of the head tube in the prototype.

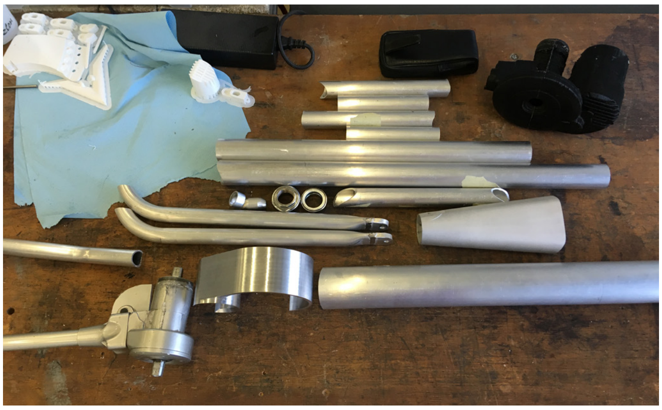


figure 191: When all parts for the frame were manufactured and cleaned, they were ready to be welded together.

figure 192: The welding process started with welding the chainstay to the motor-block. Correct positioning was crucial.

figure 193: The angles of the tubes were doublechecked after fastening the part with a spot weld. If the position was incorrect it could still be corrected using a plastic hammer. Only when the parts were in place they were welded together.

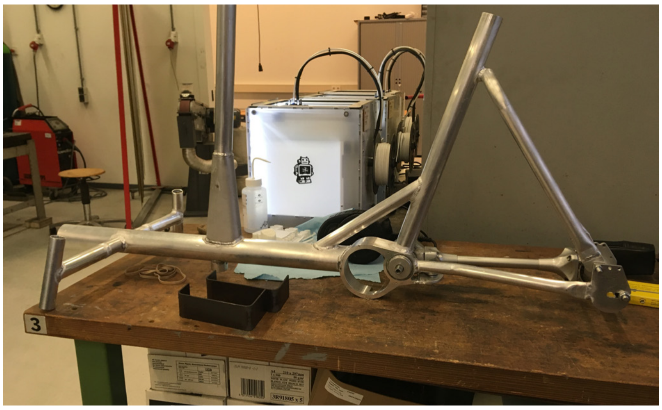


figure 194: All frame parts are welded together to create the frame.

2. the steering

All parts for the steering, excluding the wheels, have been manufactured. The prototyping steps are summarized in figure 195 to figure 199.

figure 195: The kingpin was created by pressing bearrings in the top and bottom of the tube. A tube with internal thread was placed through both bearrings and functions as axis. The pivot arms can be attached to the axis with two screws.

figure 196: The pivot arms were made by bending steel sheets and welding. The second plate, which functions as reinforcement touched the kingpin and thus part of it needed to be cut away.

figure 197: The connection to the steering tube was created by welding a plate to a tube. It is kept in place with a screw and form enclosure and guided by a headset bearring.

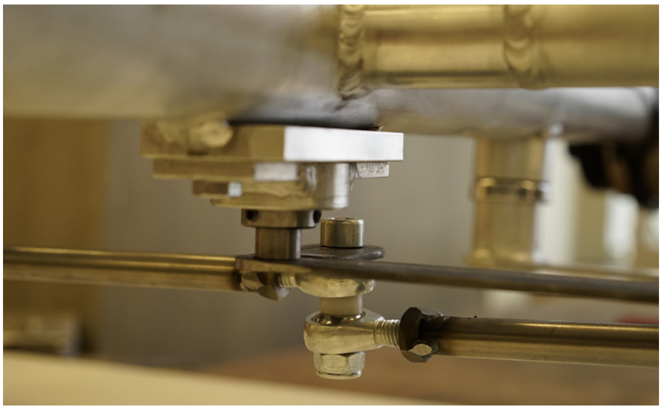


figure 198: The pivot point is created with a bearring that is fixated with a form enclosure created by milling an aluminum plate and an axis made from a tube with internal thread.

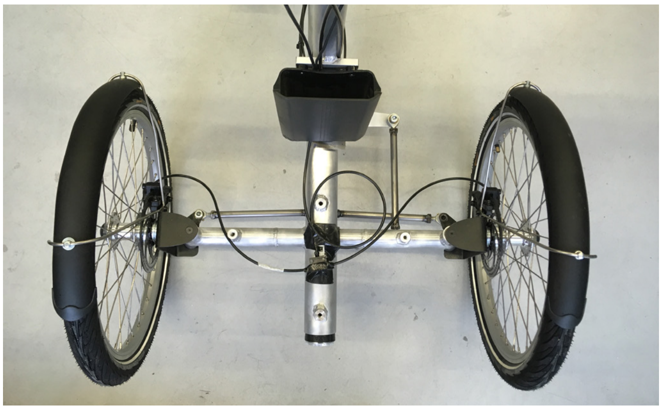


figure 199: The initial tie rods were replaced with steel tubes with internal thread to eliminate slack.

3. Assembly

After the completion of the welding of the frame and manufacturing of the steering parts, the bike could be assembled. Standard components such as the motor, battery, carrier, brakes, etc. were added. Some adjustments to the standard components were required prior to assembly. In figure 200 to figure 204 these steps are presented.

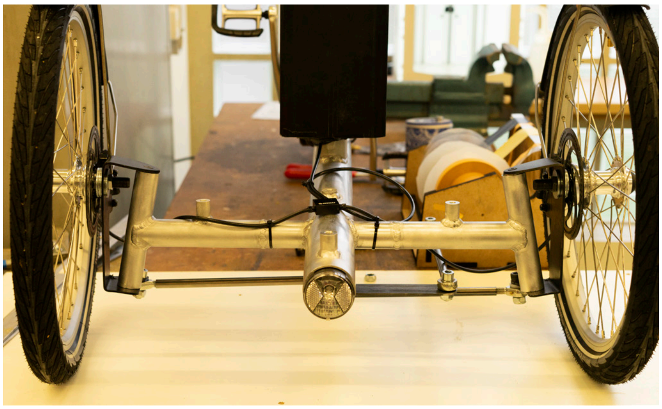


figure 200: The disk brakes were screwed to the attachment points on the pivot arm and the cables secured to the frame with tiewraps. Rubber sheet was attached to the side of the light to make it fit tight in the downtube. Attachment points for the container are welded to the frame.

figure 201: Four connector points to attach the battery were welded to the headtube.

figure 202: Attachment points with internal thread for the carrier and the lock were welded to the seatstay.

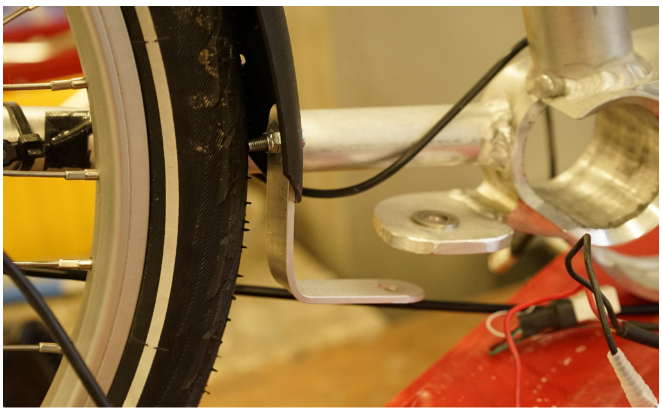


figure 203: The rear mudguard is fixated with a connector made from bent sheet that is attached with the same bolt that holds the shaft drive in place.

figure 204: The cables of the brakes, gears and motor were connected.

4. The cargo container

The cargo container for the prototype was manufactured using laser cutting techniques and bamboo veneer (figure 205 to figure 209).

figure 205: A pattern of linear cuts made with the laser cutter was used to create a hinge and achieve the bent corners. A teeth connection also created with a laser cutter was used to attach the sides to the base.

figure 206: The sides and base were traced on the bamboo veneer and cut with a stanley knife. The borders of the sides were covered with tape to avoid glue to stick. Wooden sticks were placed between the side part and the veneer to avoid that both will stick together at once. Then they were removed one by one.

figure 207: After gluing the veneer on the side, the borders were cut off to allow for a good connection between the sides and the base.

figure 208: Clamps were used to fixate the parts during the dryin process.

figure 209: In order to bend the veneer to be able to fit it on the base, it was made wet with warm water and clamped to the base. When it had taken on the shape, it was glued to the base and fixated with clamps.

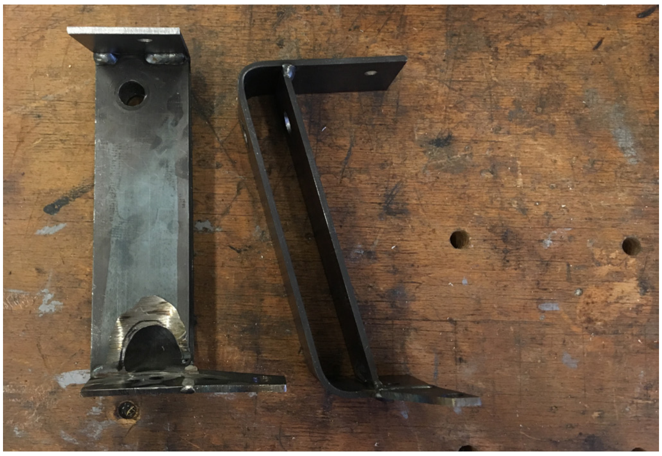


figure 210: The first pair of pivot arms had complications

figure 211: The incorrect angle of the pivot arms led to positive camber

figure 212: The new pivot arm has a connection for the disk brake

figure 213: To connect the steering arms a hole needed to be cut in the downtube

8.3 Prototyping complications

The prototyping process was a learning process in itself and required spontaneity and flexibility to find solutions for prototyping of specific parts. Not in every case the first version of the part worked. On the following pages the stories and learnings of some of the failures are told.

Pivot arms
Three trials were needed to correctly manufacture the pivot arms. The first pair touched the kingpin while steering and part of the reinforcement plate had to be cut out to resolve this (figure 210). Also, the first pair resulted in slightly positive camber (figure 211). This was due to tolerances in the bending. A second pair was created to create negative camber of 10 degrees. It was easy to manufacture this pair, because it required a 90 degrees bent, because the kingpin axis inclination is also 10 degrees. The negative camber was considered undesirable and the pivot arms were adjusted to create a third pair for neutral camber. To leave enough room for the kingpin, no reinforcement plate was used. Connectors for the disk brakes were created and welded to the pivot arms (figure 213).

Downtube
Initially the arms for the connection of the wheels consisted of two tubes that would be welded to both sides of the downtube. The manufacturing of these tubes turned out to be complicated, because of the position of the kingpin as a result of the steering axis inclination and caster angle. The other side of the tube needed to be prepared for connection to the downtube. To maintan the angles of the kingpin, the positioning of the tube in the milling machine was crucial. Precise positioning of the tube turned out to be difficult. Additionally, it would be complicated to position both arms in the right position to create a completely symmetrical product. Not achieving this symmetry would result in imperfect steering and unbalance of the bike. For these reasons the arms were made of one piece. As a result, a hole needed to be cut through the downtube (figure 213). Cutting this hole required improvisation, because a milling head of the required diameter was not available.

figure 214: To correct the position of the steering arms they had to be cut off

Steering arms
The steering arms were welded under an incorrect angle. This caused the kingpins to point outwards, instead of inwards, which is required for center-point-steering. To correct this the arms were sawn off (figure 214) and attached under the correct angle by inserting a tube and welding.

Shaft drive
It was assumed that the shaft drive is symmetrical and thus the chainstay was designed to mirror the shaft drive. This assumption was wrong, the centreline of the bike runs through the centre of the bottombracket (figure 217). This error could be partly corrected by placing the downtube, seattube, headtube and steering arms in the right position, but led to an incorrect position of the chainstay and seatstay. Due to, this the positioning of the rear wheel was critical and a thinner tyre had to be used to avoid collision with the chainstay.

Motor
The E-shaft motor of Bafang is designed for a 28 inch shaft drive, which has a larger diameter. For this reason the shaft drive did not connect well with the motor. Because of the smaller diameter of the shaft, there was slack between the shaft and the sprocket of the motor. Because of this the shaft drive would slip when force was applied to the pedals. The slack was removed by inserting metal strips (figure 215) to fill up each side of the hexagon shaped end of the shaft (figure 216).

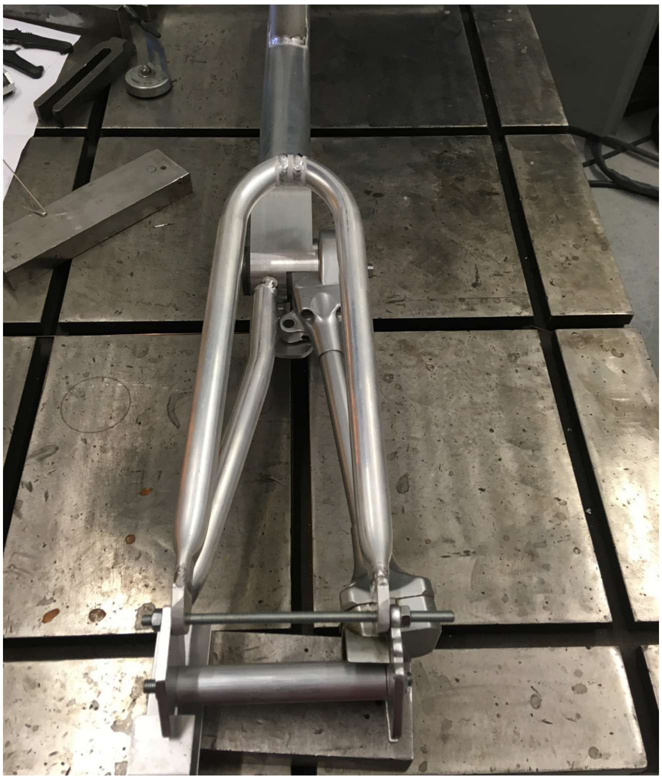


figure 217: The shaft drive and chainstay are assymetric

figure 215: Metal strips to fill up the gaps between the shaft and the sprocket

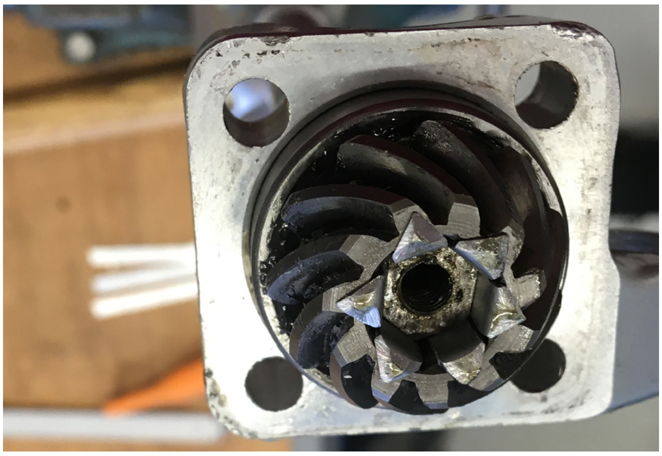


figure 216: The slack between the shaft drive and motor was removed by adding metal strips that fill up the gaps

9

Dutch Design Week 2018

The project was presented in the Embassy of Health during the Dutch Design Week 2018. The topic of the Embassy of Health was 'Chronic Health: if not us then who?' with the focus on empathetic solutions for healthcare in the future. The text about the Embassy of Health in the DDW brochure can be found on page 121.

The exposition is realised by the partners Waag, VanBerlo, Philips, Maxima Medical Centre, the Dutch Design Foundation and U CREATE and hosted in the Innovation Powerhouse, where the headquarter of VanBerlo is located. VanBerlo proposed that this project is showcased at the exposition, because of its fit with the topic.

9.1 Exposition topic

This project fits the topic of the Embassy of Health exposition, because it improves the quality of life of people with a chronic condition. By using an empathetic approach, the needs and emotions of the users are well understood and translated into a practical solution that enables the targetgroup to cycle with confidence, thus stay mobile, active and independent for longer.

Unlike other projects presented at the exposition, this project does not require future technology. Instead, it builds on contemporary and future trends. In the future cycling will become increasingly relevant as an alternative ways of transportation to motorised vehicles. Cargo bikes and electric bicycles have grown in popularity and are expected to extend to other markets and wider target groups (Reid, 2018).

Whether it concerns serious games for patients and healthcare providers or hacks of healthcare applications, designers are in many ways active in the healthcare system. With both existing and more speculative projects the Embassy of Health shows how designers are involved in modelling our health.

Designing for Chronic Health

An artificial womb, a bicycle suitable for elderly, insecure cyclists and a game that helps teenage girls cope with the death of a father or a brother – three examples of design interventions that visitors will encounter at the Embassy of Health. At the exhibition entitled 'Chronic Health: If not us then who?' at Innovation Powerhouse on the Strijp-T terrain, you will see how designers participate in designing (the future of) healthcare. The accompanying enrichment programme featuring international speakers, meetings, workshops, creative sessions and expert gatherings will further expand on the role of designers in healthcare.

It all starts with empathy

'Designing for the world of healthcare starts with empathy, the ability to see and to experience through someone else's eyes,' says Sabine Wildevuur, programme manager at Waag's Care and curator of the Embassy of health. Together with VanBerlo design agency, Philips, Maxima Medical Centre, the Dutch Design Foundation and U CREATE, Waag is part of the partnership behind the embassy. These six organisations combine a variety of perspectives in terms of crossovers between healthcare, design, science, technology and art. Last year the collaboration resulted in an exhibition entitled 'Chronic Health: Designing a Healthy Future' which was held during the 2017 Dutch Design Week, with support from WDE and DDF.

Creative and disruptive thinking

Through the Embassy of Health, the six partners encourage creative and disruptive thinking about the future of healthcare. The programme aims to raise awareness among citizens, patients, healthcare professionals, policy-makers and others about the role and significance of design in the development of innovative healthcare interventions.

'The Embassy is an open platform that encourages crossover partnerships in healthcare,' says Wildevuur. 'The starting point in this context is empathy, which is a quality particularly well-developed among designers. This enables us to design meaningful and personalised products, services, experiences and systems. In addition, the Embassy focuses on the ethics of designing for healthcare.'

"Designing for the world of healthcare starts with empathy, the ability to see and to experience through someone else's eyes" - Sabine Wildevuur, Curator of the Embassy of health

Concrete and speculative design

The primary objective of the Embassy of Health is to inform people about the potential of design thinking and design research in healthcare. And to inspire those directly involved in terms of how to actually implement these things. One way the Embassy will achieve this is through the exhibition entitled 'Chronic Health: If not us then who?' in which the Embassy of Health with both concrete and more speculative design projects indicates what directions healthcare is (potentially) going in now as well as in the near and distant future.

One of the things the exhibition highlights is the possibility of hacking healthcare applications in order to take control yourself. It's also about designers, creators, care and tech professionals who are clubbing together to produce care applications in MakeHealth Live! In addition, the exhibition will display examples of personal digital manufacturing (such as 3D printing), applied gaming, activating programmes and other innovative services and products that can help improve quality of life. The projects on display will provoke discussions about existing and futuristic developments in healthcare.

Enrichment Programme

A logical second objective of the Embassy is to facilitate co-creation in healthcare and to bring together relevant partners in order to stimulate surprising innovations. The Embassy hopes that in the long-run this will lead to design thinking and design research becoming an integral part of innovation in healthcare and in policy-making surrounding healthcare. This way we hope to properly equip future generations of healthcare providers and users to cope with future healthcare challenges.

The Embassy of Health's enrichment programme offers the deeper understanding essential for preparing people's minds to accomplish this objective. The Embassy partners will organise ten enrichment sessions, some of which will be open to the public and some of which will be gatherings of experts. These activities will range from workshops, creative sessions and expert gatherings to seminars featuring international speakers.

figure 218: Text about the Embassy of Health as presented on the website of DDW: https://www.ddw.nl/en/updates/magazine-archive/181/embassy-of-health

figure 219: Photographs at stand showing product in use

9.2 Stand design

The design of the exposition was done by a hired design agency. They provided each participant with a stand consisting of a platform and walls. Together with the participants a hired editor composed a short information text about each project. The text composed for this project is the following:

"Cycling is healthy, and often faster than traveling by car. But if you've difficulty keeping your balance and are afraid of falling, you have to rely on other modes of transport. 'Cycle through life' offers a practical solution that does not stigmatize. This trendy transport three-wheeler looks nothing like an adapted bike, but is instead very practical and safe to use for everybody. Falling over is impossible, and the extra low step and compact basket are designed for those who are shaky on their feet. Cargo bikes are not just for young parents. From now on, they're perfect for people of all ages!"

The participants were free to design the content of their stand. The stand for this project presented the prototype and photographs of the product in use (figure 219, figure 221). Cards with information about the project and contact details were designed to distribute to interested visitors (figure 220).

Cycle through life

With this bicycle designed for Beixo by Isabelle Lugert even people with reduced balance can cycle with confidence. The focus of this graduation project is to design a non-stigmatising stabilised bicycle. By using an intergenerational design approach and design strategies for avoiding stigma, the tricycle has been transformed into a convenient and stylish means of transportation for everyone.

This graduation project was commissioned by Beixo and supervised by vanBerlo.

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figure 220: Cards with information about the project for visitors to take

figure 221: Stand design

9.3 Reactions of visitors

There were a lot of positive reactions from curious visitors during the Dutch Design Week. Many people recognize the problem, because they have a family member, friend or neighbour who has difficulties accepting a mobility aid. Some visitors had problems cycling with a normal bicycle themselves.

female, 20 years:
"Mijn oma vindt het verschrikkelijk om op een driewieler gezet te worden, maar ze kan anders niet meer fietsen."
translation: My grandmother hates it to be put on a tricycle, but it's the only way for her to keep cycling.

female, 50-60 years:
"Mijn vader heeft afgelopen zomer een herseninfarct gehad en hij gaat voor geen goud op een scootmobiel. Maar deze fiets is gewoon mooi, hij ziet er gewoon uit."
translation: Last summer my father had a stroke. He would never use a mobility scooter, but this bike is nice, it looks normal.

female, 50-60 years:
"Mijn moeder is bang om te vallen. Nu loopt ze met een boodschappentrolley. Maar ze vindt het geweldig om door de natuur te fietsen."
translation: My mother is scared to fall. She now walks with a shopping cart, but she loves to cycle through nature.

female, 50-60 years:
"Ik ken een ouder iemand die kan niet meer auto rijden en is aangewezen op de fiets. Dat is soms ook spannend, want je kunt vallen. Hij gaat graag naar de bibliotheek, maar dan moet hij zo veel zware boeken meenemen op de fiets. Dan zou dit ideaal zijn!"
translation: I know an older person who cannot drive anymore and is dependent on the bike. That's scary sometimes, because with a bike you can fall. He loves going to the library, but then he needs to transport heavy books on the bike. This would be ideal for him!

male, 60-70 years:
"Mijn vrouw heeft rugklachten en evenwichtsproblemen. Wij zijn op zoek naar een driewieler. Deze is veel mooier en ziet er inderdaad niet gehandicapt uit. Het zou fijn zijn als je hem zou kunnen inklappen voor transport op de camper of auto. We fietsten altijd veel op vakantie."
translation: My wife has back and balance problems. We are looking for a tricycle. This one is much nicer and does not look like it is for a disabled person. It would be great if it was possible to fold it up so it is easier to transport it with the car or camper van.

female, 60-70 years:
"Ik heb zelf evenwichtsproblemen gehad en door jarenlang naar de sportschool te gaan is dat verholpen. Maar met deze fiets hoef je niet naar de sportschool, dan kun je gewoon fietsen."
translation: I used to have balance problems myself. I got rid of it by going to the gym for years. With this bike you do not need to go to the gym, you can just keep cycling.

female, 60-70:
"Je wil niet meteen op zo een invalide karretje rijden. Ik woon in hartje Eindhoven en ik ben zelf niet zo een held op de weg. In 10 jaar zullen we meer op dit soort dingen, autonome auto's of OV aangewezen zijn. Maar zelf fietsen is natuurlijk wel fijn en dan is het heel fijn als ik me veilig voel en mijn boodschappen kan meenemen."
translation: I wouldn't want to immediately use a disabled cart. I live in the centre of Eindhoven and I am not so good at cycling. In 10 years from now we will dependent on these kinds of transportation, autonomous cars and public transport. But being able to cycle yourself is great and it is also great if I feel safe and can take my groceries.

female, 80 years:
"Ik fiets al jaren niet meer. Ik heb een gewone fiets. Ik ben bang om te vallen door verminderd evenwicht. Soms denk ik: zal ik het weer eens proberen? Maar nee."
translation: I quit cycling years ago. I have a normal bike. I am scared of falling because of lack of balance. Sometimes I think: shall I just try again? But no.

Also, many visitors said that this bike does not look like it is a bike for users with disabilities.

male, 50-60 years:
"Hij hoeft niet alleen voor gehandicapten te zijn!"
translation: It does not have to be just for disabled people!

female, 60-70 years:
"Ja ik zou ook niet zo snel op een driewieler fietsen, maar dit is gewoon een leuke fiets."
translation: I would not easily accept to use a tricycle, but this is just a nice bike.

male, 60-70 years:
"Dat is wel goed gelukt. Ik zou ook niet met een rollator willen lopen, maar hier zou ik wel mee fietsen."
translation: You succeeded with that. I also would want to use a rollator, but I would cycle on this.

Many visitors associated the bike with a cargobike.

male, 20-30 years:
"Hij ziet er heel hip uit! Het is dus eigenlijk een hippe bakfiets voor ouderen."
translation: It looks very trendy! So it is a trendy cargobike for elderly.

male, 20-30 years:
"En natuurlijk niet alleen voor mensen met moeite met fietsen. Bakfietsen zijn überhaupt populair."
translation: And of course it is not just for people who have

difficulties to cycle. Cargobikes are very popular among all kinds of targetgroups.

Some of the visitors would use the bike themselves, even though they do not experience balance problems. They think that the bike looks good and is convenient.

male, 30—40 years:
"Ja hier zou ik ook mee fietsen. Super handig!"
translation: Yes, I would also cycle with this. Very convenient!

female, 60-70 years:
"Ik zou er wel mee naar de volkstuin willen fietsen, daar moeten we vaak veel dingen mee naartoe nemen. Ik zou hem nu nog niet elektrisch willen."
translation: I would like to use this to cycle to my garden, because there we often need to take a lot of things. For now I would not want it to be electric.

Visitors were also positive about the design. The low entry and electric motor were seen as an advantage, because it would make cycling easier. There were also positive reactions about the material and colour combination. The combination of aluminum and bamboo was perceived as trendy.

female, 50-60:
"Handig. Modern zo met het hout en de kleuren."
translation: Convenient. And modern with the wood and the colours.

female, 60-70 years:
"Als ik straks niet meer op een gewone fiets kan, dan wil ik op zo een hippe."
translation: If in the future I cannot cycle on a normal bike, I want a trendy one like this.

Not everyone noticed at first sight that the bike is electric. This can be seen as positive, because it could mean that the motor and battery are well integrated.

Some points for improvement were mentioned by the visitors. The first point for improvement is adding holes in the container through which rain water can run out. Another point is choosing a material for the container that is durable and requires no maintenance. One visitor had experience cycling with a tricycle and suggested to provide driving instructions, because cycling on a tricycle is different than cycling on a tricycle.

female, 60-70 years:
"Ik denk wel dat je instructies moet toevoegen over hoe je moet sturen met twee wielen voor. Ik heb geprobeerd op met een bakfiets met twee wielen voor te fietsen, maar ik vond het lastig, want normaal stuur ik met mijn lichaam. Dat was een fiets waar je de bak meestuurt."
translation: I think that you should provide instructions on how to steer with two front wheels. I have tried cycling with a cargobike with two front wheels, but it was difficult for me, because usually I steer with my body. It was a bike where the container was attached to the wheelbase.

Another visitor proposed to look into a future model which can be folded to be easily transported with a car or camper van.

There were a lot of people who asked if the bike was already in production, what the price would be and where they can by it. This indicates that there are people who may have real interest of buying this bike.

The personal stories about a friend or family member not being able to cycle anymore or refusing a mobility aid, indicates that there is indeed a market for this product.

In general, the reactions were very positive. People stated that they like the design, that it looks like a cargo bike, or that it looks much better than the tricycles they have seen. This indicates that the design is less stigmatising than other tricycles and that people might accept it.

However, it can be assumed that people who did not like the design did not stop to tell their opinion. Further research is required to form a final conclusion about the stigma of the bike, but so far the impression is that many people do not find the bike stigmatising.

9.4 Reflection

The DDW was a great experience for me as a young designer and a good way to get feedback on the design. 11000 people visited the Embassy of Health. The many positive reactions of the visitors and personal stories indicate that the project addresses a relevant topic and that it may even have been succeeded to create a non-stigmatising mobility aid. The DDW helped to get in touch with potential users and participants for the user validation.

Additionally, it was a learning experience to design a stand and other materials for an exposition. Because the project is quite practical and the product is clear and recognizable for people, very little additional information was needed to explain the project.

Even though the text on the walls of the stand explain the project well and the prototype stands for itself, the experience of the visitors was probably better when the stand was manned. By starting a conversation with the visitors they were more engaged and could ask their questions.

10

Evaluation

figure 222: The frame is not completely stiff

figure 223: In turns the rider hangs to one side

figure 224: The rider can stay seated after stopping

figure 225: Parking in a regular parking spot takes some more effort

The aim of the project was to design a non-stigmatising stabilised bicycle. This means that the bike should provide stability during use and that the bike should not be associated with a handicap. Next to the objective stability, it is also important that users feel confident on the bike, so the subjective stability is also relevant. Two tests were done to validate the design proposal.

A stability test with several test rides was executed to evaluate the stability of the bike in different cycling situations. This test was done prior to an evaluation with users to ensure the participants' safety. From the stability test dangerous situations could be identified and avoided in the user evaluation.

In the user evaluation the subjective stability and stigma of the bike was tested with potential users. This was done by allowing the participants to try out the bike on a safe parcour and interviewing them about their experiences.

10.1 Stability test

The stability of the bike was tested by doing a few test rides in cycling infrastructure. The first two rides were made around the block near the Beixo shop. This parcour consisted of four turns, a stop and straight parts and takes about 3 minutes to complete. Test ride 1 was done without load and test ride 2 was done with a load of 36 kg, because without the load the bike felt unstable in turns. The bike was also used for a longer testride (test ride 3) with the goal to do groceries. In this round different situations were covered, including roundabouts, bicycle paths, being over taken, parking the bike, loading and unloading cargo. Afterwards, the stability of the bike was tested while taking the smallest possible turn. This is a turn with a radius of 3 m. Loads were added to see how it increases the stability.

Results

Test ride 1

In the first turn during test ride 1 the outer wheel came off the ground. After a few seconds the wheel was back on the ground and nothing happened to the rider. In the other turns the bike stayed stable. These turns were taken at a speed of approximately 12 km/h. Straight paths were cycled at 25 km/h without any effort and while feeling stable.

During cycling it feels like the frame is not completely stiff. At zero speed it was tested what causes this. It was noticed that the seattube moves sidewards and that the wheels move inwards (figure 222).

Test ride 2

During test ride 2 the bike ended up on the other side of the street after taking the second turn. The width of the street was 3 to 4 metres. All other turns were made without any problems. It was noticed that during the turns there is a force pushing the rider to the outside. The rider compensates by hanging to one side (figure 223).

Test ride 3

In general the third test ride, which was a route to the shops and supermarket and back, went well. There was no situation in which the wheels came off the ground, even when the container was not loaded. Cycling without hands was possible, because the wheels

figure 226: Taking bike through door

figure 227: Cycling through garden door

figure 228: Getting on - step 1

figure 229: Getting on - step 2

figure 230: Getting on - step 3

figure 231: Getting off - step 1

figure 232: Getting off - step 2

figure 233: Getting off - step 3

figure 234: The bike tilts in a turn without enough load

stay straight, but it was not possible to steer the bike without touching the handlebars. Staying seated after a stop was not a problem and felt stable (figure x). Finding a parking spot at the supermarket was a challenge, because there were many bicycles and no parking spot for cargobikes. By lifting the back of the bike it could be placed in between other bikes (figure x). The groceries stayed in the container and did not move a lot.

Through a door

Taking the bike through a door or garden door is not a problem, because the total width is less than the with of a regular door (figure 226 and figure 227).

Getting on and off

The stability of the bike when getting on and off the bike was also tested. Different manners of getting on the bike were tested. When getting on by first stepping over the downtube with one foot, the bike stays stable (figure 228 to figure 230). Getting on by first placing one foot on the pedal can cause the bike to tilt. During getting off the bike is stable (figure 231 to figure 233).

Braking

Braking was also tested. Even when braking from the highest speed the bike is stable. The braking was tested while steering straight.

Minimum turning radius

The stability in turns was tested by cycling turns of a radius of 3 m, which is the smallest possible turning radius with this bike. Without any load the bike tilted (figure 234). It continued to do this with one and two stone tiles of each 9 kg. With three tiles the bike stayed stable while making a turn with a turning radius of 3 m.

Conclusion

The results of the test rides show that the bike is not stable in small turns when there is no load in the container. With a load of 27 kg in the container the bike does not tilt when taking a turn with a radius of 3 m. These sharp turns seem not to be very common in daily cycling situations, because during test ride 3 there were no situations in which one of the wheels came off the ground. On straight paths the bike is stable, even when releasing the handlebars. Also staying seated after a stop is no problem. The bike is also stable while getting on the bike as long as one foot is placed over the downtube first. During getting off the bike is stable. The frame is not completely stiff and this can be felt during cycling and gives a slight feeling of instability.

The stability of the bike could be improved by increasing the mass of the front of the bike. It is assumed that lowering the centre of mass and moving it more to the front of the bike also increases the stability. Furthermore, increasing the stiffness of the frame would also increase the feeling of stability.

10.2 User evaluation

The user evaluation is a qualitative method for validating the design proposal.This validation method focuses on subjective stability and stigma. In the user evaluation potential users are asked to try out the bike on a parcour and give feedback on their experience. Before and after the test ride interview questions are asked to evaluate the user's experience. These questions focus on the user's expectations of the bike, the perception of it and the perceived stability.

Research questions
The user evaluation focuses on subjective stability and stigma, the research questions are:

1. How do users experience the stability of the bike?
2. Do users consider this bike stigmatising?

Participants
For the user evaluation a 'test day' was organised at the shop of Beixo to which eight participants were invited. The participants could sign up via an online contact form. The link to this form was distributed on the DDW, via e-mail to people who signed up on the mailing list and to people who receive the newsletter of Beixo. In the form the participants were asked why they are interested in participating. Based on these answers the participants have been selected.

Eventually twelve participants participated in the user evaluation. One participant came without receiving a confirmation and some of the participants brought along a partner or friend, thus there were more participants than expected. Six of the participants are considered to be part of the target group, the other participants are experts, people who are interested in the project and potential future users.

Not all participants belong to the target group. Participants that belong in the target group are:

Participant 4: Due to his hearing impairment and lack of balance he cannot cycle independently.

Participant 5: Due to her hearing impairment and lack of balance she cannot cycle independently. She does not cycle on her tricycle anymore, because she has fallen over with it.

Participant 6: He has fallen many times with his e-bike.

Participant 8: She has reduced strength in the right side of her body and due to this she has difficulties to balance a bicycle. She owns a Gazelle Balance, which she uses to cycle, but she does not like it very much. It is heavy, which makes it difficult for her to handle it and she feels handicapped using it.

Participant 9: In the contact form she gave as a reason for wanting to test the bike that she does not cycle anymore.

Participant 12: Cycles a lot, but since she had a stroke she feels dizzy at times.
The other participants are not the target group, because:

Participant 1: He still cycles, but realizes that he and his friends have difficulties to walk over the golf course. He wants to use the bike as an alternative to a golf cart and walking, so he can easily move to another place, while still exercising. The container would give him the possibility to transport his golf bag.

Participant 2: Does not have any disabilities and cycles a lot with different types of bicycles.

Participant 3: Does not have any disabilities and sometimes cycles with his racing bike.

Participant 7: She has reduced strength, but no balance problems. A motor with rotational sensor is more beneficial fo her because then she can go fast without applying force to the pedals.

Participant 10: As a lifestyle and health coach he is an expert who could advise the bike to patients.

Participant 11: Does not have disabilities and still cycles on a bicycle.

Procedure
The user evaluation consists of three parts. Prior to the test ride the participant is asked to answer a few questions about his/her current bike use and expectations of the bike. During the test ride the participant uses the bike on a parcour. This parcour includes turns, stops, and a parking spot. The test ride is filmed and a facilitator accompanies the participant to provide help in case it is needed. After the test ride the participants are interviewed about their experience. The interviews are filmed to record the reactions of the participants, for further analysis and to be used in the presentation of the product. The interview questions can be found in appendix K.

The interviewing, observation and analysis was done by two researchers. Two assistants helped with welcoming the participants and providing help where needed.

Based on the findings from the stability test, three stone tiles of in total 27 kg were added as load in the container of the bike to provide additional stability for the safety of the participants.

Analysis
The analysis of the data from the user evaluation was done in several steps. First, a 'data download' of each participant was done. 'Data download' is a method VanBerlo sometimes uses for user research and consists of collecting all the data from interviews and observation on post-its. This is done right after

figure 235: Clusters of data from all participants

figure 236: Clusters of data from the participants from the target group

figure 237: Participant 9 had difficulties to get on the bike

the user evaluation, because then the memories and impressions are still fresh and present in the minds of the researchers. Notes, video and memory was used to do the data download for each participant. On the post-its the number of the participant was indicated, so later it could still be identified to which participant it belongs.

Subsequently these post-its were clustered in topics that could be identified. Then the insights that could be gained from each cluster or a combination of clusters were written down and added to the overview.

Not all the participants are part of the target group. To gain insights from the target group, their post-its were clustered again. The insights from these clusters were also collected.

Lastly, conclusions from the insights gained from both clusters were formed. The conclusions are based on the interviews and observations during the test.

Results

The first part of the results is a data download per participants, which provides an overview of facts about the participants, quotes of the participants and observations. The data download of each participant can be found in appendix L.

The data downloads of all participants have been used to create clusters that are presented in figure 235. The topics that have been identified are stability, steering, cycling behaviour, stigma, add-ons, electric motor, getting used to it, fear, specifications bike, future use, disabilities, interest and getting on/off the bike.

Similar topics have been found when clustering only the data downloads of the participants that are considered to belong to the target group (figure 236).

From the clustering of the data of all participants and the clustering of the data of only the participants that belong to the target group, insights per different topics have been gathered. The insights are presented below.

Steering

For people with reduced strength the steering can be heavy. One of the participants had reduced strength in the right side of her body and for her it was difficult to steer.
Some participants mentioned that they find it difficult to steer, because the wheels have a tendency to return to a straigh position. "The bike has its own will and not everyone will like this." - participant 10. But it was also mentioned that the bike is agile and that small turns can be made. "Next to that it reacts fast and you can make small turns." - participant 10.

Getting on/off the bike

When the saddle is too high it is not easy to get on the bike. Participant 9 had difficulties getting on the bike (figure 237). She is quite short and the saddle was a bit high for her. She tried to get on the bike by first putting her left foot on the left pedal.
The low entry is a benefit for people with reduced strength or reduced balance. Participant 8, who does not have a lot of strength in her right leg was fond of the low entry, because it made it easy for her to move her right foot over it.

Electric motor

For some people the pedaling support causes more insecurity, because they feel out of control. After turning the motor off, participant 6 felt more in control. Participant 5 indicated that she felt insecure because "the bike goes so fast so quickly!". And participant 9 was scared, because she felt out of control. "It rides away with me!" - participant 9.
Participant 7 prefers a front wheel motor with a rotation sensor, because then she can reach a high speed without putting any force on the pedals. She does not have a lot of strength in her right leg, but likes to cycle fast.

Current cycling habits
Some people, like participant 11 and 12, already use a bicycle with a low entry. Participant 11, 12, 7 and 6 are used an e-bike and participant 5 has experience with a tricycle.
When participant 7 does groceries with her electric folding bike of Beixo she hangs the bag with groceries on the handlebars.
For safety participant 11 and 12 always use a helmet when cycling.

Size
The size of the frame is not suitable for everyone. Participant 8 is quite short, about 1.5m, and she had difficulties to get on the saddle. When sitting on the saddle she could not reach the pedals.

Reasons for interest
Some participants hope to feel more stable with this bike. Participant 5 used to ride a tricycle with two rear wheels. When taking a turn on a downwards slope she fell. She expects that a tricycle with two front wheel is more stable than the tricycle she used. Also participant 4, who lacks balance, hopes he can cycle independently again with this bike. Participant 8 is interested in the bike, because she is looking for more stability, but also for a bike that does not make her look handicapped. "My young kids would not accept if I ride a tricycle for disabled." - participant 8.
One participant sees another application for the bike. He would like to use it on the golf court to get from one place to another. He and his friends do not walk easily anymore. This bike could be an alternative for a golf cart. Then they do not have to walk, but still exercise.

Stability
None of the participants fell or made the bike tilt while cycling the parcour. Participant 10 wanted to see when the bike would fall over and tried his best to make the bike tilt. He managed to make it tilt by hanging on the handlebars and saddle while trying to get on.

Most of the participants felt stable while cycling straight, but felt unstable in turns. Participant 6 was sitting very tense on the bike and tried to hang in to compensate in the turns. Participant 5, who has no sense of balance, was the only participant who said that she felt stable while cycling on the bike.

Getting used to it
This bike is quite different than a normal bicycle. Its motor, steering and the three wheels are all things that make cycling on it feel different than on a bicycle. Many of the participants mentioned that they would have to get used to cycling on this bike. Some participants learned quickly, like participant 5, who had less difficulties with each more round she made. Participants 6 and 7 had more difficulties to steer with the bike, but both said they would like to learn it.
The participants who had no alternative had a bigger drive to learn how to cycle with this bike. "Dit moeten we leren. Nu voelen we ons onzeker, maar we kunnen dit leren." - participant 5.

Insecurity
Having difficulties to steer and feeling unstable in turns made many of the participants feel insecure. Participant 9 was so scared that she stepped off the bike after a small round. "This is nothing for me!" - participant 9.
Participant 6 felt more insecure on this bike than on his own e-bike, even though he has fallen several times with it already.

Stigma
The opinions about the stigma of the bike were divided. Participant 3 considered a cargo bike to be stigmatising too. He thinks cargo bikes are "clumsy and pathetic." His opinion is that it would look less stigmatising if the container is more open, for example by using wire around a frame. Participant 7 thinks that the bike still looks like a disabled bike. As reasons she mentions the three wheels and the width and also the low entry.
Participant 4, 5 and 8 were positive about the appearance of the bike. Especially participant 8 would like to have the bike, because she thinks it looks like a cargo bike and not like a disabled bike. Participant 11 said he would feel "stubborn" when using this bike. He compared it with using a Beixo folding bike. Because of the shaft drive and the electric motor he often gets attention of bystanders. He likes this attention and thinks he would receive the same kind of attention with this bike.

Discussion
First of all it must be mentioned that this is not a normal bicycle and that cycling on a tricycle will always feel different than cycling on a bicycle. It is a trade-off between stability and a bicycle-like feeling. A solution that combines both has not been found within this project, but would be interesting to look into for future work. Because of the three wheels a tricycle is stable when riding straight, but not stable in turns, especially at high speed. This explains why participants felt insecure in turns and needed to get used to the bike feeling.

Not all of the 12 participant belong to the target group. For this reason the analysis was done in two parts. This way the insights from the target group were collected, but without neglecting insights from the other participants. The insights from the other participants are considered relevant, because they are experts with experience with patients or can be seen as bystanders or potential future users. They will likely not use the bike themselves (now), but have an opinion about the bike and its users.

Additionally, it was interesting to see the difference in the sense of stability between people with balance problems and people without balance problems. It seems that the amount of balance a person has and whether they still use a bicycle influences how stable people feel on the bike. The participants that had no sense of balance felt more stable on the bike than those who had no or slight balance problems. The people without balance problems had to get used to the feeling, but did not feel insecure. The people that have balance problems, but do still use a bicycle, had the biggest problems with feeling secure on this bike. They probably already feel insecure on a bike, because they are scared of falling, and are used to try harder to keep their balance. This makes cycling on the stabilised bike difficult, because it is counter-intuitive. This suggests that people who are looking for more stability need to take some time to get used to this bike. Maybe a set of lessons on how to use the bike prior to buying the bike can help to convince these people and make them feel confident.

The bike was tested with an additional load to provide safety for the participants. This means that the bike was not tested by the participants with its original stability. Without the load the reactions of the participants may have been different, but safety was the highest priority. In any case, the stability of the bike will need to be improved to create a bike that does not tilt when taking turns. Thus, the test gives a good indication of how users will feel on a stabilised bike.

During the testing a part in the steering mechanism bent, affecting the steering. When this happened, also the handlebars moved out of position, which made steering not possible. Participant 4 could only cycle a small round due to this. This flaw in the steering mechanism is likely to have also influenced the experience of the participants who were cycling while the steering mechanism was breaking.

There was no universal opinion about the stigma of the bike. Two participants indicated that they consider the bike stigmatising. Both do not belong to the target group. One participant, who belongs to the target group is specifically interested in the bike because of its appearance. And also the two participants who lack the sense of balance and cannot cycle on a bicycle did not consider the bike stigmatising. There is a tendency that the people who can benefit from this bike, because they have balance problems, consider the bike less stigmatising than the people who still use a bicycle.

Not everyone's opinion about stigma of the bike could be collected, but the fact that there were so many people interested in taking part in the test day and even more people signed up to stay up to date about the project, indicates that many people like the project or product. Whether the non-existence of stigma is the reason for this needs to be checked. Of he 46 people who filled in the contact form to participate in the test, one fifth said they want to participate in the test because they are looking for a stabilised bicycle. Not all of these people were present during the test day, so it would be interesting to talk to or test with the remaining people who are interested in a stabilised bicycle to find out what they think about the stigma of this bike.

Although the test day was well prepared it went different than planned. The interview prior to the testing and also the testing itself took longer than expected, because the participants had a lot to tell. Due to this it got crowded at some point. To avoid that participants had to wait too long, some of the questions were covered together in one question or asked during the testing.

To reduce waiting time some participants were interviewed simultaneously in a group. One time the researchers split up to interview participants simultaneously. This made data gathering more difficult and the participants may have influenced each other. However, the advantage of having several participants at the same time is that they started talking about the bike with each other. This also created a good and relaxed atmosphere.

The user evaluation helped to get a good impression of the subjective stability and how people feel when cycling with the bike, but not such a good impression about what they think about the stigma of the bike. Not every participant told his/her opinion about the stigma of the bike. What the test day did show is that people have different opinions concerning the bike's stigma. This seems to be related to which type of bike people compare it with; a bicycle, e-bike, tricycle or cargo bike.

Conclusion

From the user evaluation it can be concluded that the feeling of stability can still be improved and that not everyone considers the bike non-stigmatising.

Cycling on this bike does not feel like cycling on a normal bicycle, because of the pedaling support, three wheels and steering mechanism. The bike does not lean in a turn, which makes the user feel a force that pulls the user to the outside of the turn. For some people this creates a feeling of instability. The pedaling support makes the user go faster with little effort. When not being used to this, one may feel out of control, because the bike goes faster than one expects. Because of the three wheel and the container the turning radius is larger than with a normal bike, which makes it more difficult to take a turn. A smaller turning radius might make it easier for people to get used to this bike, because the steering would be more like on a bicycle.

Getting on the bike is also different than getting on a bicycle. A bicycle can be tilted to more easily get on the saddle. For users of the bike it will be important that the saddle is at a correct height, so getting on is easy. It must also be considered that people are likely to step on the pedals to push themselves up on the saddle. The bike should be stable then.

People who do not have a reference to cycling on a bicycle are likely to have less difficulties to getting used to cycling with this bike. This means that for people who are switching from a bicycle to this bike, because they experience balance problems, that it probably needs time and practice before they feel confident. Beixo should consider to offer lessons for these people so they can learn to cycle on the bike. It is unlikely that people will buy the bike if the first time they tried it they feel insecure. It is therefore important to show them that they can learn it and that they do not need to be afraid to fall. Based on the insights it is expected that people who do not have an alternative to this bike are more motivated to learn how to cycle with it than people who can still use a bicycle.

Even though none of the participants fell with the bike, many of them felt unstable. This can be partly explained by the force the users feel when taking a turn due to the fact that the bike does not tilt. People are also used to using their body weight in a turn, but with this bike this does not work. The combination of the pulling forces and trying to balance are likely to be the cause of the feeling of instability. For people with no sense of balance the bike seems to feel more stable, because their body does not try to compensate in the turns.

The results also indicate that it is important to cover all frame sizes, because some people in the target group are short and others are tall. It could help to make two frames, a small one and a large one.

The choice has been made to use a middle motor with torque sensor in the design, because the pedaling support feels more intuitive. The results of the user evaluation indicate that for users with reduced strength, a motor with rotation sensor might be more beneficial, because they can reach a high speed without applying a lot of force. Further research is needed to make a decision about this, but it is an aspect that should be considered.

People with reduced strength can also benefit from a lighter steering. This could be achieved by making changes in the steering mechanism and the ratios.

The test ride also showed that some parts of the steering mechanism, especially the connection between the steering tube and the steering rod, need to be redesigned for more strength and stiffness.

Whether people experience stigma with this bike seems to depend on what they compare it with. When comparing it with a tricycle, it is easily seen as more attractive, but when comparing it with a bicycle, e-bike or cargo bike, people may find some characteristics more stigmatising. This is an important realization for the positioning of the product.

What also needs to be considered when positioning the product are potential subsidies. The expert in the field of mobility problems mentioned that he believes there are possibilities to get subsidies or reimbursement from the health insurances if the product is sold as a mobility aid.

10.3 Conclusion

The aim of this project was to design a non-stigmatising bicycle for elderly that provides stability when getting on and off the bicycle. By applying design strategies for avoiding stigma, a tricycle has been designed that provides the target group with stability without being stigmatising.

The problem
Validations with users and the DDW showed that being afraid of falling with the bicycle is indeed a problem that many people recognize and to which a solution must be found. Especially in an aging population and a society where mobility, health and sustainability play an important role, safe bicycles for elderly can be very beneficial. A safe bicycle that enables elderly to cycle with confidence, helps elderly to stay mobile, independent and active. And by stimulating more people to cycle and continue cycling, cities can be become cleaner.

The design proposal
The proposed design is a compact three wheel cargo bike that combines the functions of a tricycle and a cargo bike. The three wheels stabilize the bike and the transport function places the bike in the product category of cargo bikes, which is a widely accepted product used by different age groups. With the proposed design it has been achieved to solve both problems of stability and stigma and to fulfill the needs of the target group. Nevertheless, there are certain aspects that can be improved.

Stability
Because of the three wheels the bike is stable when getting on and off and when cycling straight. But, because of the three wheels the bike is not so stable in turns. This is because the bike does not tilt in turns, like a bicycle. The test rides show that the prototype tilts when making the smallest possible turning radius of 3m at a speed of 10km/h. The tilting was eliminated by adding a load of 27 kg in the container. This shows that by changing the centre of mass and increasing the mass of the bike, more stability in turns can be achieved. Further research is needed to optimize the bike for stability and weight.

Avoiding stigma
By applying several design strategies to avoid stigma, a tricycle that looks like a cargo bike has been developed. The reactions from visitors at the DDW and participants of the user evaluation indicate that many people do not find the bike stigmatising. However, there are still some people who think that some elements of the bike create the association with a handicap. Mentioned were the low entry, three wheels and the width of the bike. It is considered that whether or not people find the bike stigmatising, is influenced by the product category they compare it with. This can be explained by Vaes' Product Apraisal Model for Stigma (Vaes, 2014a). People who compare the bike to a bicycle have a different standard, a different expectation, than people who compare the bike with a tricycle. This may explain the differences in opinions

about stigma. The positioning of the product can help with setting these standards, by managing people's expectations of the bike, and is therefore a very important next step to take towards implementation of the product.

Next steps
With the design proposal the first step towards a safe bicycle for elderly that solves the problem of stability and stigma has been made. Before implementation, further development on mechanical level and marketing level is required. By looking into improvements of the frame and steering, stability also in turns could be improved. By looking into marketing strategies for positioning the product in a non-stigmatising way, a lot of potential customers, not only within the target group, could be reached. What to consider in the next steps is explained in the next chapter 'recommendations'.

10.4 Recommendations

Within the scope of this graduation project there is no room for further optimisation of the design. However, for a successful market implementation of the product, further development is required. In this section recommendations for optimisation and implementation of the product are provided. The recommendations are presented per aspect.

Stability
The stability test showed that the bike is not stable in the smallest turns possible with this bike. The stability could be improved by adding additional weight in the container. It was found that with an additional weight of 27 kg, the bike was stable in the turns with a turning radius of 3 m. The bike already has a mass of 32 kg. Adding an additional 27 kg, will not make the handling of the bike better. To improve the stability of the bike it should be calculated which is the best position for the centre of mass and distributing the weight of the bike such that when the user sits on the bike the centre of mass is at that position.

The subjective stability test showed that even though people know they cannot fall with the bike, they feel unstable in turns. This is due to the fact that a tricycle does not lean in a turn like a bicycle does. Thus, the rider experiences a force pulling outwards. The feeling of stability is likely to increase when the user gets used to cycling on the bike.

Stability when going straight and a bicycle-like feeling in turns is a trade-off in a tricycle. A more bicycle-like feeling could be achieved by adding wheels that tilt in the turns. To ensure stability while getting on and off the bike and when cycling straight, the tilting function must only be activated in the turns. This could be achieved with strong springs that only allow the wheels to tilt when enough force is applied, like in a turn. As an example for such a system the Babboe Carve can be used. This cargo bike has a 'carve lock' with which the tilting mechanism can be deactivated. Having to activate and deactivate the tilting mechanism oneself during riding is not comfortable, therefore the best option would be to have a system that does this automatically. Such a system is very complex and requires additional research. It would also make the bike more costly, so it must be considered well before investing in it.

Frame
Before the bike goes in production, the frame needs attention. It was not within the scope of this project to calculate or simulate the strength and stiffness of the frame under static and dynamic load. However, it is necessary to do this before production, because for safety reasons the frame must withstand all possible load situations. Next to the intended use, also the unintended use must be considered during these calculations.

Some deflection in the frame of the prototype was noticed. The head tube and seat tube move relative to another and also the deflection in the arms to which the wheels are connected must be checked for stiffness.

The frame of the prototype was not heat treated after welding. It is suggested that this is done with the real frames, because through heat treatment the material can regain part of the strength is has lost during welding.

The diameters of the frame tubes of the prototype were based on the available material. Some of the diameters can be reduced or increased to achieve a lighter and stiffer frame. It could also be considered to change some of the circular diameters to oval diameters, for example in the seatstay. This is more common among bike frames. Making the seatstay more standard will make it easier to apply existing solutions for connecting the lock and carrier.

After the complications with the prototype, because the chainstay was designed symmetric, the chainstay was redesigned. However, it must be checked if this results in the correct position of the rear wheel.
During the user evaluation it was noticed that for smaller people the frame is too big. The frame was designed to allow for adjustability from the smallest frame size to a large frame size. However, in the prototype the seattube turned out to be longer than in the drawings, resulting in a higher position of the saddle. A suggestion is to look at the geometry again and consider the production of a small and a large frame, to facilitate an ergonomic position for as well short as tall people. Especially for this target group it is crucial that they can take a comfortable position on the bike, because due to their lack of balance and strength, it already takes them more effort to get on and cycle on a bike.

The frame color of the proposed design is white. For time and cost reasons the prototype was not painted. In retroperspective the aluminum colour might suit the design better than the colour white. It gives the bike a simple, pure and unisex appearance and creates a link to the Beixo folding bikes, which are also available in pure aluminum. When applying a colour to the frame the contrast between the frame and the components should be considered and it might be wise to do a trend analysis to find a trendy colour for the frame.

Steering mechanism
With the steering mechanism the turning radius of 3 m, that was aimed for, was achieved. However, potential users sometimes had difficulties to handle the bike because its turning radius is much larger than with a bicycle. By optimising the turning radius of the steering mechanism the handling of the bike can be improved. Not only during cycling, also when parking the bike. One way to reduce the turning radius is by making the container smaller, allowing the wheels to turn further. When reducing the width of the container its functional volume for transporting cargo must be considered.

During testing one of the parts of the steering mechanism bended because it was not stiff enough and some of the screws loosened. These parts should be redesigned to ensure enough stiffness and durability.

There was slight slack in the steering mechanism. This could be eliminated by creating a permanent connection between the ball joints and the rods.

There are different types of steering mechanism that can achieve the same result. When optimising the steering mechanism, also these other types should be considered. A steering mechanism with less moving parts might be more durable or less costly.

The caster angle, camber and centre point steering were chosen based on examples. It could be that they are not yet ideal and therefore further testing with alternative angles is required to find the ideal angles for the steering of this bike. This could be done by manufacturing pivot arms that allow for easy adjustment of these angles.

With the additional load in the cargo, the pivot arms of the prototype bent slightly. This could be avoided in the final product by adding a support plate or using thicker material.

Cargo area
After many iterations choice for the cargo container sloped sides was made. This is a compromise between functional volume, aesthetics, safety and comfort. It is a universal solution that can be used for a lot of types of cargo. For more specific cargo, for example transporting a rollator or dog, the suggestion is to look into new designs. These designs could be offered as an alternative to the container. Thus, the cargo area can be seen as a modular system that offers different solutions for different transport needs.

Add-ons like a cane holder or rain cover could be something the target group might want to have. Thus, it could be a business opportunity to offer these kinds of add-ons. Before starting the development of new products, it can be beneficial to look into what is already available on the market and reselling these products as add-ons for the bike. For example, a product for connecting a buggy to a bicycle carrier could also be suitable for transporting a rollator.

A layer of bamboo was chosen for the outside of the container. To ensure the durability of the material, further research about the best protective treatment for the surface of the bamboo material must be conducted.

To allow rainwater to drain from the container, holes must be added in the base of the container. Because the container is mounted under a slight angle, the best position for the holes is in the base on the lower end.

Battery
In the prototype an existing carrier battery that is being used in the other Beixo models, is used and placed in a vertical position. This battery has not been designed for a vertical position and Beixo's engineer has mentioned to be concerned about water collecting in the connector, damaging the cables or the electronics.
The position of the battery is not yet ideal for replacing the battery or taking it out to charge. There is little room between the battery and the container and headtube, which makes it not so easy to take the battery out. Either more space needs to be left between the battery and the container, or the battery must be placed elsewhere.

For the position of the battery it must be considered that it can be easily taken out. Placing it very low can make it difficult for elderly to reach it, because it means having to bend over.

A low position of the battery is however beneficial for the position of the centre of mass of the bike and thus for its stability. During the stability test it was found that adding weight in the container increased the stability. For this reason it is assumed that for stability the centre of mass must be as low as possible and preferably in between the front wheels. Therefore, it would not be a good choice to place the battery on the carrier or behind the saddle. A possibility would be to create space for it in the container. Placing it under the container would be preferred for aesthetic reasons, but it must be tested if this position can be reached by the older users.

The range of the battery with the combination of motor and mass of the bike must be calculated or tested to provide potential users with specifications. In order to compete with competing products, the range of the battery must be at least 40 km, preferably 60 km.

Standard components
A choice for the specific standard components has not yet been made. The suggestion is to provide the engineers in Taiwan with a list with the specifications for the components and let them make a selection, because they have more experience with which

components are available and at a good price.

For the prototype front wheel fenders with one-sided suspension and the right size were not available, thus existing 20 inch fenders were adjusted. For the final product standard fenders for this application must be found, because custom making the fenders for the bike will be too costly.

Cabling
In the prototype the cables have not been integrated in the frame, but for aesthetic and safety reasons, in the final product they should be integrated into the tubes. It should be considered to add cable tubes in the tubes of the frame before welding, to protect the cables in the frame and to make it easier to place the cables. In the prototype the cables of the gears and the rear brake are too short. The longest available standard length cables was used. This means that a custom length cables for these functions is needed for the final product.

Motor
The design proposal presents an integrated middle motor suitable for shaft drive. This motor has a torque sensor and regulates its power based on the force the rider puts on the pedals. Based on the insights from the user evaluation, it torque sensor might not be the best choice for people with reduced strength, because they may not be able to apply the required force for the desired speed. It might be beneficial to look into possibilities for also offering a motor with a rotational sensor.

Some of the participants from the user evaluation felt out of control because of the speed generated by the motor. It should be considered to change the settings of the motor to reduce the speed when starting from a stop. Customers should also have the possibility to limit the motor to a lower speed than 25 km/h. Not every user might need pedaling support, therefore it should be considered offering the bike without it. Before making this choice it must be tested if the mass of the bike is suitable for cycling without the pedaling support.

Lessons
Some of the participants from the user evaluation indicated that they need to practice to get used to cycling with the bike. Especially people with reduced balance who still cycle on a bicycle felt insecure on the bike. Beixo should consider to offer lessons for these people so they can learn to cycle with the bike prior to buying one. Alternatively, Beixo could look into cooperations with physiotherapists or coaches that are willing to incorporate the bike in their training sessions. This way potential users can learn to cycle with the bike under supervision of a professional.

Positioning
For the positioning of the product it is very important to avoid stigma, but still reach the target group. This is a challenge best to be taken on by a marketing expert. However, some advice on this matter can be provided. By selling the bike via bicycle retailers and in a shop next to bicycles, e-bikes and cargo bikes, the association with a bike for disabled people can be avoided, because bicycle retailers is a channel through which 'normal' bicycles are sold to all kinds of target groups. By positioning the product as a compact cargobike, the attention lies on the transport function and its compact size, instead of the three wheels, which helps to avoid stigma and attract other users too. In order to reach the target group the benefits for them should be communicated too. Some of these specifications are the low entry, compact size, electric pedaling support and easy to load container. A marketing strategy is to empathize the versality of the product by presenting it with different types of users, including elderly.

Also the name of the product must be chosen carefully, because an association with a name is easily made. The name should not empathize that it is a bike designed for people with balance problems, thus it is best to avoid the association with three wheels and stability. An association with the transport function would have a positive aspect. Also empathizing that it can be used by anyone would be beneficial to avoid stigma. The name should be in line with the names that Beixo uses for the rest of their portfolio. Generally, these are short english words that are abstract, but create a link to the product.

The positioning of the product might also have influence on the availability of subsidies. The lifestyle and health coach who was present during the test day indicated that he expects subsidies from the government if the product is positioned as a mobility aid and that health insurances would also reimburse the bike if it can be proven to benefit the patients.

Retail price
In this master thesis an estimation of the retail price has been made. The exact retail price needs to be calculated based on the costs for production, transport and margins of the dealers and Beixo.

It might be possible to sell the bike with a lower sales tax, if it is positioned as a mobility aid. VanRaam can sell their tricycles with a VAT of 6%. This would provide the possibility to lower the retail price while keeping the same margins.

10.5 Personal reflection

This graduation project was a long journey with a lot of exciting moments, opportunities and learnings that I want to reflect on.

Double degree
With this project I complete my double degree in IPD and DfI. When I started my master IPD I did not expect that I would end up where I am now. But I do not regret any of the steps I have taken, because I have learned a lot and enjoyed my studies. I also think that this combination of skills suits my personality and interests very well. I am looking forward to applying these skills in future work and to inspire other designers with my vision on design.

Acquisition
The start of the project took some time, because I was looking for a client who sees something in my proposed assignment and was willing to take on the journey with me. During this time I had to network a lot, send application letters and meet the representatives of different companies. I did not have a lot of experience with applying at companies and so it took some courage to do so. But by doing it I learned a lot about how to present myself to a potential client. This learning experience will be very valuable for future job applications.

Project partners
During the acquisition period I was also in contact with large businesses like Segway, Gazelle and Siemens and companies abroad. I am very glad that Beixo wanted to partner up, because the small scale business and relatively close-by location of Beixo made the cooperation with them very easy. The communication was good and there was a lot of teamwork, which benefited the project. Because of the intensive interaction I always had the feeling that they believe in the project and this gave me motivation to try my best to get the best possible result.
VanBerlo was also a partner, but was not in direct contact with Beixo. Since I was responsible for the project, there was no need for colleagues from VanBerlo to cooperate with Beixo.
Still, both my mentors from Beixo and VanBerlo were present at important meetings and I am happy about this, because I could get feedback from an expert in the field of bicycles and from a design expert. I think that inviting both parties was also important for keeping both involved and interested.

Internship
When I was planning my graduation project I wanted to gain more work experience and learn from designers who work in the field. And so it came that I proposed the idea of doing my graduation project combined with an internship at VanBerlo to Martijn from VanBerlo whom I met during a hackathon event during the business fair at the faculty. It was a good decisions to participate in the event to get in contact with people from VanBerlo, because then I could speak with them personally about my idea.

I am very glad that the internship worked out, because I had a great time at VanBerlo and felt supported and motivated at all times. Next to learning new skills from colleagues, it also gave me insight in how the company works and what it is like to work there. The atmosphere at the office and the projects provide a very nice working environment where I would like to see myself some day.

Dutch Design Week
I got the opportunity to showcase my project at the DDW and that was a great experience. Because VanBerlo hosted the Embassy of Health in their office building in Eindhoven and my project fit the topic of the exposition well, I could present my project. It was my first exhibition and thus this was a good learning experience. It was also a great opportunity to get in touch with experts and potential users. More than 70 people signed in on a mailing list during the DDW and some people who saw the project at the DDW signed up as participants for the test day.

Planning
I had to plan all my activities in 30 weeks. At the start of the project there seemed to be nothing that could not make it possible to finish within these 30 weeks. But when the DDW was confirmed, there was additional work and pressure and so it seemed to be a good decision to extend the graduation date. And I am glad that this was approved, because it meant that I could focus on delivering good work.
I saw the planning as a working document, because it constantly changed and needed to be updated. This is because I find it difficult to foresee which exact activities are needed to get to the milestones and to estimate how much time it will take. It has again been confirmed that I am an optimistic planner. I always think that I can do things faster. When I realised, I tried to plan more time for activities and I think that I have already gotten better at it, but I will always stay an optimist. I think planning optimistically can also help to motivate oneself to do more, because there are deadlines that need to be worked hard for to be achieved.

Result
The hard work has led to a result that I am quite proud of. I think that I have taken many steps in this short time to get to the stage the project is in now. The project is not finished, there are plenty of steps to take and improvements to be made before the product can be launched, but I think that the result of my master thesis provides Beixo with a good starting point for a promising business opportunity.

Learnings
Next to showcasing my skills and showing the value of combining IPD and DfI, I wanted to use my graduation project to learn new things and gain experience that I can use in my future career.
In this project I gained more experience doing user research, I learned a lot about bicycles, I improved my Solidworks and computer sketching skills and I learned a lot about prototyping and working with metals. Next to that I learned what it is like to be part of a team at VanBerlo and which activities, next to designing, need to be done as an employee.

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