DESIGNING A SAFE AND COMFORTABLE SUPER-PEDELEC FOR SPAAC MOTORIZED BICYCLES

Bridging the gap between speed-pedelec and motorcycles

MASTER THESIS | Integrated product design

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Master thesis
Integrated Product Design
at Industrial Design Engineering,
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PREFACE

This thesis report is the result of a half year graduation trajectory for the master study Integrated Product Design at the faculty of Industrial Design Engineering at the Delft University of Technology. Finalizing this project means completing my studies and achieving the academic title ‘Master of Science’.

This project was done for and in collaboration with Spaac, a company specialized in motorized bicycles. The bicycles they produce and sell are speed-pedelecs: electric bicycles where the rider’s pedalling is assisted by a small electric motor. Depending on the specifications, pedelecs can reach speeds exceeding 45km/h, resembling capabilities of mopeds or even motorcycles. Spaac wants to produce such a super-pedelec (an even faster type of pedelec than the speed-pedelec). These trends in the electric bicycle industry not only demand a thorough revision of the legal status, but also a reconsideration of the design of super-pedelecs.

Besides the electric bicycle industry being a trending and rapidly developing business, this topic also lies close to my personal interest. As an enthusiastic motorcyclist and experienced cyclist, I have the ability to see the super- pedelec and its issues from several perspectives.

I would like to thank my team of supervisors for their efforts and support during the course of this project. The supervisory chair, Sacha Silvester, guided me through the progress and kept me on track. His prior experience in the bicycle industry has given direction and value to the project. The supervisory mentor, Sebastiaan van den Elshout, always had an open door through which I could ask for a critical opinion and help at decisive moments. His sharp practical point of view kept the project tangible for me. Jurrit Hollands and Jos Ramselaar from Spaac granted me the opportunity to work on this project. They both assisted me not only in the design process but, also taught me a lot about the design in practice and what it takes to run a company.

I would especially like to thank my father and mother for their support during the process. Although they were abroad during the completion of my master, they were to me closer than ever, sacrificing their own time to help me when needed.

Last but not least, thanks to all of my friends and girlfriend who used their skills and experience to help me.

EXECUTIVE SUMMARY

The Dutch market has been seeing an growing interest in electric bicycles in recent years. While the trend was propelled by elderly wishing to use a bicycle longer, the e-bike market has shown the potential to loose its stigma and expand to people of other age-groups. The urban commuter as a target group demands for a faster and more attractive type of electric bicycle: from Pedelec (<25 km/h) to Speed-Pedelec (<45 km/h) to a bicycle that can keep up with other motorized vehicles: the Super-Pedelec (over 45km/h). Spaac, a young Dutch company that designs, produces and sells motorized bicycles with a unique timeless appearance based on early 1900s motorcycles, wants to explore the possibilities to add a Super-Pedelec to their product line. The Spaac S7 is able to reach speeds up to 70 km/h which requires a re-evaluation of comfort and safety measures. While Super-Pedelecs are not allowed on Dutch roads yet, this thesis dives into the possible future of Super-Pedelecs and how their comfort and safety are assured and increased compared to the current pedelecs. The final design for the Spaac S7 achieved this by revising the frame (stiffness, seating position), suspension, road holding, ergonomics, visibility and power. The potential of Super-pedelcs is clear but some important factors have to change:

The law and regulation in the Netherlands is not likely to allow Super-pedelecs on the roads in the Netherlands on a short term. But the Super-pedelec can be restricted to Speed-pedelec until then. The structural stiffness is optimised to ensure the bike remains stable while heavy breaking, steering and accelerating. To ensure riders fit comfortably on the bike is modelled to fit, the smallest, average and tallest rider. Smart brakes are available but not yet developed far enough to be implemented on the bike. The comfort of the rider is improved with a suspension system that absorbs bumps without converting energy of the rider into a bouncing motion. The rider's posture is changed to a more upright position this results to increased seating comfort, en more oversight on the road.

Image left page:
Workshop of Spaac Motorized Bicycles in The Hague (Spaac, 2016)

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* to be found in a separate document: appendices report

Used terms

The following text explains important used terms in this report. The image on the right page (Fig. 0.1) illustrates the key elements that are part of a bicycle frame.

- The word bicycle is sometimes simplified to bike, both terms are used interchangeably in this report.
- If not addressed differently all explanations refer to situations in the Netherlands.
- The user of the bicycle can be referred to as user, cyclist, rider and driver.

Electric bicycle	A type of enhanced bicycle, also known as an e-bike, powerbike or booster bike, with an integrated electric motor which can be used for propulsion.
Pedelec	**Ped**al **Ele**ctric **C**ycle, a bicycle where the rider's pedalling is assisted by small electric motor; a type of low-powered electric bicycle. It is capable (and thus allowed) to reach a maximum speed of 25km/h, wearing a helmet is not mandatory.
Speed-Pedelec	A Pedelec that is capable (and thus allowed) to reach 45km/h, this type of bicycle needs a licence plate and the driver is obliged to wear a (pedelec-)helmet (conform to the NTA-8776-norm).
Super-Pedelec	A Pedelec that is capable of traveling faster then 45km/h, these bikes are currently not allowed on public roads in the Netherlands. Since this type of vehicle is not allowed on the road yet, there are no regulations operative (yet).

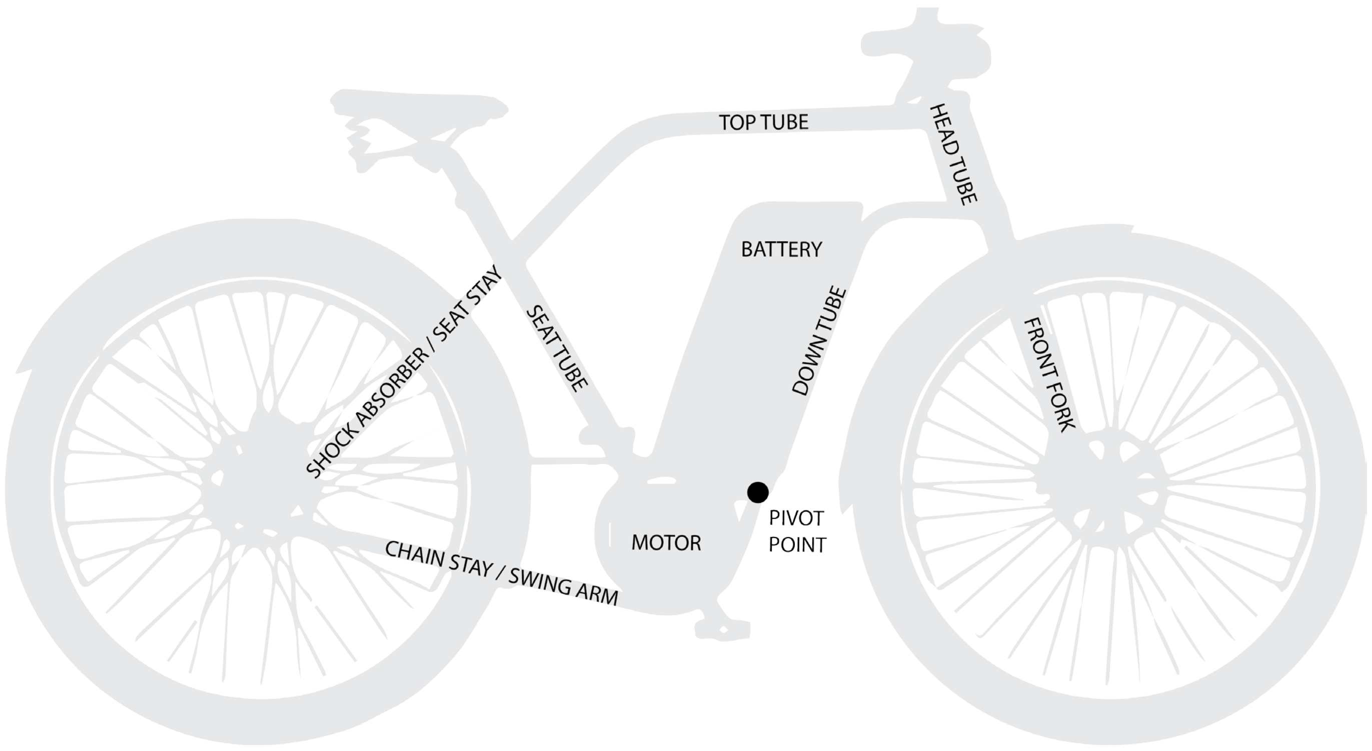
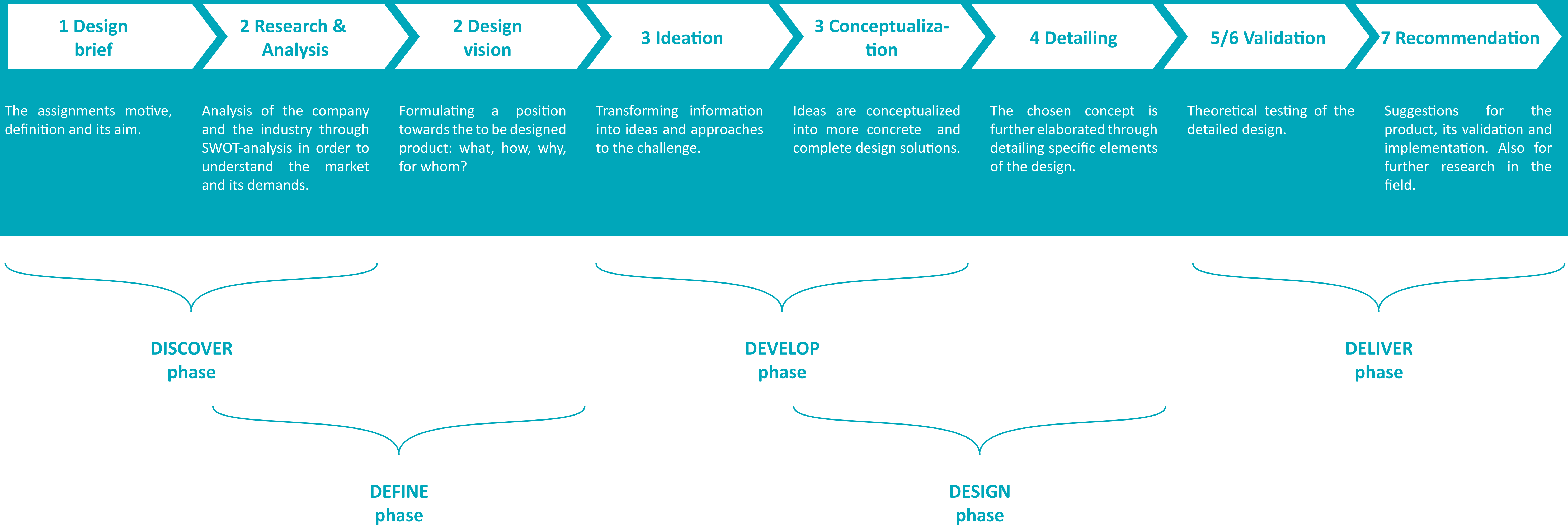


Fig. 0.1 *Key elements of a electric bicycle frame (Author, 2018)*

FRAMEWORK OF PROJECT AND REPORT

Report structure



1 Design brief

The assignments motive, definition and its aim.

2 Research & Analysis

Analysis of the company and the industry through SWOT-analysis in order to understand the market and its demands.

2 Design vision

Formulating a position towards the to be designed product: what, how, why, for whom?

3 Ideation

Transforming information into ideas and approaches to the challenge.

3 Conceptualization

Ideas are conceptualized into more concrete and complete design solutions.

4 Detailing

The chosen concept is further elaborated through detailing specific elements of the design.

5/6 Validation

Theoretical testing of the detailed design.

7 Recommendation

Suggestions for the product, its validation and implementation. Also for further research in the field.

DISCOVER phase

DEFINE phase

DEVELOP phase

DESIGN phase

DELIVER phase

1. DESIGN BRIEF

1 DESIGN BRIEF

In this Chapter the problem is first defined, then a description is given of the client (Spaac) and the assignment as defined by the TU Delft. The Chapter ends with a description of the design process.

Fig. 1.1: *Example of what the bike lay out will look like*

The goal of this thesis is to design a two-wheeled electric bicycle that has, when compared to current high-speed Pedelecs, a higher maximum speed, more comfort and a higher level of safety. The target customers are Dutch bicycle riders in the age between 25 and 65. In a windy country like the Netherlands where people love cycling, there is a big market for electric bicycles (SWOV, 2017). The evolution of the electric car is also causing a revolution in lightweight high powered affordable batteries. This creates big opportunities to those who produce electric bicycles. One such producer is Spaac, the key partner in this master thesis. The design must fit in the Spaac bicycle family and its production must be compatible with the production facilities of Spaac and their partners. The to be designed bicycle is a super-pedelec, the name of this model will be Spaac S7. The design of this super-pedelec should bridge the gap between Speed-pedelecs and motorcycles.

1.1 Problem definition

Imagine a Speed-pedelec that was designed for speeds higher speeds than 45 km/h, while adding to comfort and safety of the use of the bicycle as well. In this Graduation project the possibilities of such a “Super-Pedelec” will be investigated.

Electric bicycles are getting more accepted in the society, speed-pedelecs (capable of travelling at 45 km/h) are getting more common, technically they reach 45 km/h but often they are not safe nor comfortable at these speeds. Speed-pedelecs are by law restricted to drive on the normal road and are prohibited from the bicycle lanes. This leads to dangerous situations since cars often drive 60 km/h on these roads (Stelling, 2017) and push the Speed-pedelecs of the road.

Adaptation of the pedelec market towards more high speed pedelecs might lead to more dangerous situations on the road (see Fig. 3). An important safety element is the perception by other road users.

There is a noticable gap in the market between Speed-Pedelecs and motorcycles (going faster than 45km/h). Spaac wants to explore the possibilities to bridge the gap and create a Super-Pedelec model that expands their current product line. However, higher speeds demand a different approach to the conventional consideration of comfort and safety of pedelecs. The main challenge is **to assure and increase comfort and safety in the design of a faster pedelec: a Super-Pedelec.**

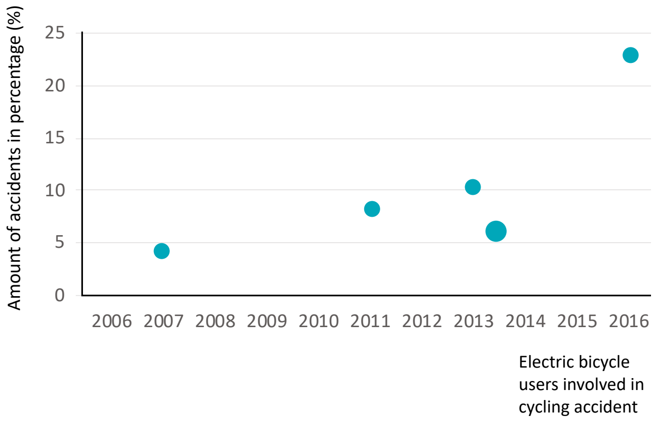


Fig. 1.2 *The percentage of electric bicycle related accidents that were reported in the emergency aid clinics in the Netherlands (SWOV, 2017)*

1.2 Client description

Spaac is a The Hague based company that developes, creates, and sells motorized bicycles. Founders Jurrit Hollands and Jos Ramselaar started their company in 2015 with the aim to create attractive motorized bicycles to be used by people in between the age of 25 and 65 who commute to work in urban environments.

Spaac is proud of the technical content of their bikes, and therefore the design of their models differs from most electric bikes, e.g., the Spaac S5 is a stylish bike that is not hiding the motor and battery pack but enhancing those elements in the appearance. This model is capable of travelling at 25 km/h. The market of faster electric bicycles is yet to be explored by Spaac. Spaac is currently working on two newer versions of the S5, this thesis will focus on the Spaac S7, a Super-Pedelec (with speeds of over 45km/h).

The company fits perfect in the start-up definition by Steve Blanks “*a start-up is an organization formed to search for a profitable and up-scalable business model*” (Blanks, 2012). Spaac is in the middle of their search for a profitable and scalable business model. The previous series of bikes had a batch of 30. The initial batch of the new generation is estimated to be 200. Spaac sells the bicycles online an trough a user network, the service on the bikes is done by Spaac personally and selected dealers.

The previously mentioned characteristics makes Spaac an interesting company for the IPD thesis. Spaac has a lot of in-house knowledge about design, R&D and numerous connections and facilities, therefore Spaac is a brand that creates products that are unique but at the same time cater to the dynamic market. On the other hand the company is small enough to keep a horizontal organisation and close collaboration in the complete design, production, sales and service processes. The company was also selected because it offers the opportunity to gain insights in entrepreneurship and to learn more about the start-up business.

Figure 1.3 shows the part of the design cycle (Rozenburg and Eekels, 2017) that is applicable to Spaac. This report is focusing on the formulation of goals and strategies, to validate the new business idea of creating a Super-Pedelec.

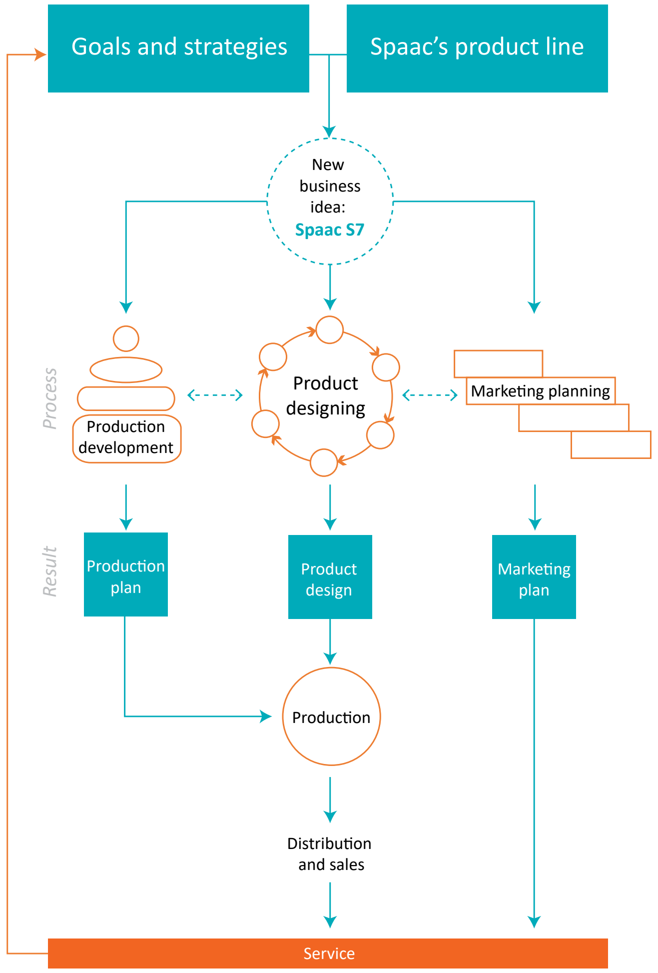


Fig. 1.3 *The design cycle (based on Rozenburg & Eekels, 2017) that is applicable to Spaac's S7. (author, 2018)*

1.3 Assignment

The assignment can be summarised as “*To design a 2 wheeled electic bicycle with increased speed, comfort and, safety compared to current high-speed bikes. The price range is 5000 - 10.000 euro. The design must fit in the Spaac bicycle family as well in the production facilities and its partners. Also the design must have a scientific value that meets the requirements of the TU Delft. Throughout the project the user is the central key in design decisions. This project should bridge the gap between speed-pedelecs and motorcycles.*” The final deliverables also contain a 3D Solidworks model.

A special focus will be given to design a system where the motor and wheel pack might be replaced in the future to increase the lifespan of the design.

Fig. 1.4 *Jurrit(left) and Jos (right) of Spaac - motorized bicycles (Spaac, 2016)*

1.4 Design process

To solve the problem as defined in 1.1 the following process phases will be applied.

The Research and Analysis phase is described in Chapter 2. This is the first phase in the design process and starts with an internal and external analyses. The Spaac S7 user was defined and the needs in safety and comfort were investigated. The current Speed and Super pedelec market was investigated to determine what the drivetrain would look like. The law and regulation around these bikes was analysed to examine the feasibility of the project. This phase ends with a design vision and list of requirements.

The Product Design phase is described in Chapter 3. Different concept directions are explored. Starting with an ideation phase where different design directions are examined. The Spaac form language and user expectations are taken into account in every step. Finally working towards a definitive design. Simultaneously the production and marketing are taken into account. An example of a marketing approach that Spaac could use is full funnel marketing.

Detailing is one of the most important topics of this thesis, about 15 important topics of detailing were designed and described in Chapter 4. The most important ones are geometry, suspension, swingarm, motor and mounting, belt and gears, swingarm pivot point and brakes.

Testing and validating is described in Chapter 5. Models in SolidWorks simulations and Linkage (a bike geometry analysis program) were used to determine if the model meets the strength requirements and to optimise the geometry and suspension.

How to implement all the above is described in Chapter 6. The design is now completed, what does it look like, what are the assembly steps, and what will be the total costs.

The last step in any design process is an evaluation of the final design, this makes the iteration complete. Also the recommendations for future development of the Spaac S7 are discussed in Chapter 7.

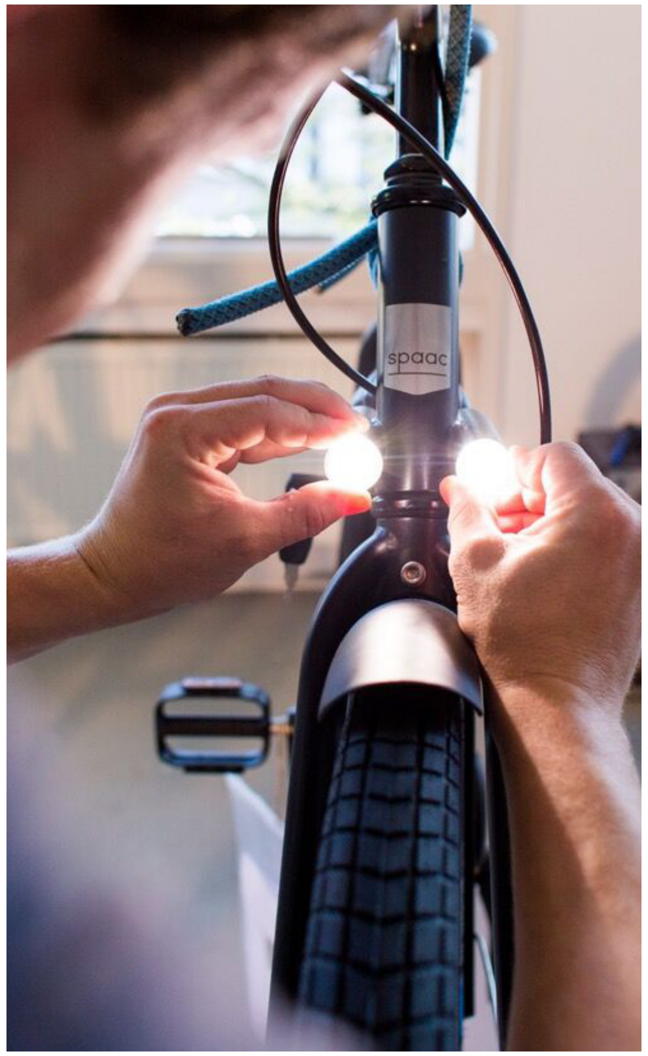


Fig. xx: *Detail of a current Spaac model (Spaac, 2016)*

2. RESEARCH

2 RESEARCH

The first phase in the design process starts with an internal and external analyses. The Spaac S7 user will be defined and the needs in safety and comfort of this user were investigated. The current Speed and Super pedelec market will be investigated to determine what the drivetrain should look like. The law and regulation around these bikes was analysed to examine the feasibility of the project. This phase ends with a vision and list of requirements.

2.1 Internal analysis through the business model canvas

Company analysis
To better understand Spaac, their partners, facilities and possibilities, semi structured interviews were conducted with the owners, also the website (www.spaac.nl) was examined to gain knowledge about the company and the business plan of Spaac. The findings are discussed following the business model canvas from Alexander Osterwalder and the book Business Model Generation (Osterwalder, 2015). Spaac has three main pillars on which they base the design, Ease of use, Robustness and the Iconic shape. These pillars will be kept in mind and finally used in the evaluation of the design.

Founders > key resources
Jurrit Hollands and Jos Ramselaar, the owners of Spaac are both alumni of the TU Delft, faculty Industrial Design Engineering. Their professional network involves other alumni, entrepreneurs, and investors. They are well established in the pedelec sector. In the past few years Jos and Jurrit have set up the company that is located in the Binckhorst area in Den Haag.

Facilities > key resources
Their facilities consist out of a main location where the bikes are designed and tested. The various parts of the bikes are ordered overseas, the frames are currently made in Czech republic, the frames arrive in the Netherlands with a base coating, they are finished with a professional powder coat in the Netherlands. The bikes of Spaac are showcased in all the 6 Juizz E-bike stores.

Funding > key resources
For the previous series the Spaac S5 Classic, a pre order crowd funding campaign was started to fund 30 bikes.

Products > Value Proposition
The new series consisting out of the Spaac S5 Sport and the Spaac S5 comfort, the bikes will be launched with an equity crowdfunding. Bothe the new bikes will be available as pedelec and speed-pedelec. The series might not directly go through type approval process so it is possible that the speed pedelec will be available later. The bkes The initial production batch for the new Spaac will be around 200 pieces.

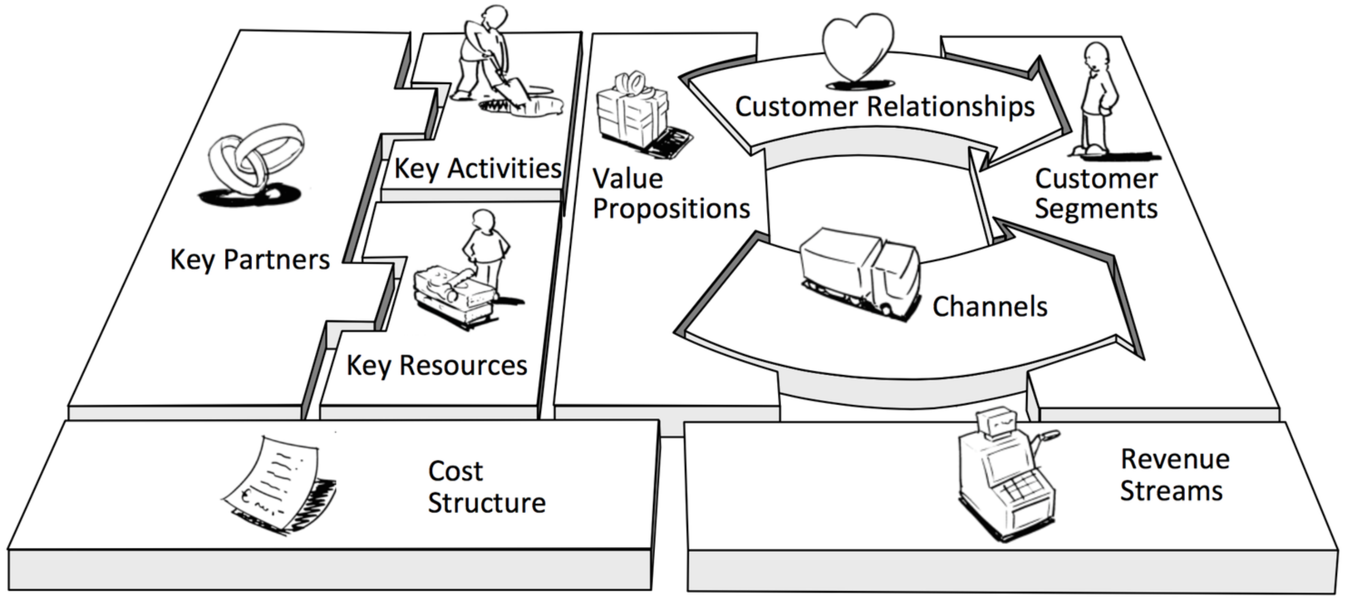


Fig. 2.1 *The business model canvas that was used for the internal analyses (Osterwalder, 2008)*

Target group/Use > Customer segments
The goal of Spaac is to create E-bikes to be used by people between the age of 25 and 65 who commute to work. The design of their bikes differs from most electric bikes, Spaac is proud of the technical content of their bike, the Spaac S5, is a stylish bike that is not hiding the motor and battery pack. Spaac currently offers high-end / premium products ranging from 3000-5000 euro.

The mission of Spaac is to:

> *“Increase the use of electric bicycles among commuters in urban areas by offering them an accessible and reliable electric bicycle and complementary service system.”*
>
> Spaac, 2018

Spaac focusses on e-bikes for functional movement instead of e-bikes for recreational purposes. Recreational purposes like bicycle tours, cycling races or mountain biking are left out of consideration. Their coorporate objective is to achieve a profitable and scalable business within three years, by selling high quality e-bikes together with a complementary service.

> *“The electric bicycle will lose its stigma and high acquisition threshold and will become a most obvious transport solution for young adults in the city.”*
>
> Blank & Dorf, 2012

The above statement confirms Spaac’s view on the future and can relate to their vision to make pedelecs widely acceptable and available.

The box to the right concludes how the Business Model Canvas (Fig. 2.1) of Spaac is filled in.

Key partners: Spaac has the contacts to easily combine forces and focus on their own strongest points.
- Production partners for specifically designed parts: frames, center stands, bicycle carriers and assembly
- Component suppliers of general parts
- Sales and service: Juizz
- R&D: TU Delft prototype assembly

Key activities: Spaac’s activities to add value.
- Designing pedelecs, setting up the production process and the promotion
- Marketing and image-branding

Key resources: Resources that are necessary to create value for the customer and sustain and support the business.
- No large investment rounds
- Founders invested lots of engineering and marketing hours add value
- Network

Value propositions:
- Positive brand image
- Unique design, dedicated/visible electric
- Suits a high end niche market
- Spaac products are customisable to needs of customer
- Spaac creates products that last

Customer relationships:
- Short lines; Spaac offers good personal customer support, pre-sale, during sale and after-sale (during the lifetime of the bicycle)

Customer segments: Spaac’s customer description.
- The owners of spaac are part of the user group that they show in their marketing. The real speed-pedelec target group is quite a niche market, they are somewhat older and have more money to spend.

Channels:
- Spaac sells their own bikes online and at their partner: 6 Juizz stores which grants spaac access in a premium dealer network

Cost structure:
- High cost price, low volume
- Low costs for resources

Revenue streams:
- Bicycle sales and related products/services
- Revenue is created by selling design, sales, Research and Development services.

2.2 External analysis

2.2.1 Law and regulation

The Netherlands

Speed-pedelecs are electric bicycles that offer pedal-support up to a speed of 45 km/h. Until 1 January 2017 the law defined Speed-Pedelecs as a “slow” moped. When there was a bicycle path these “slow” moped had to use it. The speed limit was 25 km/h en it was not necessary to wear a helmet. Due to new European regulations per 1 January 2017 a Speed-Pedelec is defined as a “fast” moped. This meant that inside the cities it was mandatory to use the roads and not the special bicycle lanes (paths). On these roads the maximum allowable speed is 45 km/h. On combined bicycle and “fast” moped lanes the maximum allowable speed is 30 km/h inside the cities and 45 km/h outside the cities. Since 1 January 2017 it is also mandatory for Speed-Pedelecs riders to wear a helmet that meets the NTS-8776 norm. For Speed-Pedelecs enthusiasts a special helmet was developed that allowed for more cooling of the head.

Other countries

In all European countries the rules for Speed-Pedelecs seem to be quite coherent. The bikes are limited to a maximum speed of 45 km/h. The place on the road is more flexible, as bike-lanes are rather often non-existent. A significant difference with the Netherlands is the amount of off-road tracks. The rules that normally apply to roads do not apply to large off-road areas in for example Germany and France.

2.2.2 Current market and facts

E-bikes and Speed-pedelecs are booming. The graph on the top right (Fig. 2.2) shows the market share of all electric bicycles in the bicycle market in the Netherlands (CBS, 2018). It is clearly visible that every year a bigger percentage of the bicycle market is represented by electric bicycles. The graph on the bottom right (Fig. 2.3) shows the sales of new bicycles in the Netherlands in numbers (RAI Vereniging & Bovag, 2017 & GfK & RAI Vereniging, 2018). After years of growth, since 2007 (direct effect of the economic crisis) the sales of bicycles has been going down until it stabilized in recent years. However, the amount of sold electric bicycles has grown, hence the remarkable growth in market share of electric bicycles visible in figure 2.2, up to almost 1 in every 3 sold bicycles being a electric bicycle in 2017. Additionally, since the introduction of Speed-Pedelecs on the Dutch market in 2013, this category has grown rapidly as well (from 171 in 2013 to 4507 in 2017), even if in relatively small numbers compared to all electric bicycles (from 0.1 % in 2013 to 1.5% in 2017).

Furthermore, from average sale prices of bicycles in the Netherlands (as shown in Fig. 2.4. on the next page), we see another trend: people are spending more on their bicycle. This is most probably related to the increasing sales of electric models, which are more expensive, but the following graph (Fig. 2.5) illustrates a decrease in the sales of the cheaper category bicycles (under 300). This shows that there has been a shift from cheaper, regular bicycles towards more luxurious and advanced bicycles. A big share of these high category bicycles are the electric bicycles and the even pricier Speed-Pedelecs. Together with the increasing numbers of sales, the willingness to spend more on their (electric bicycle) reveals a growing trust in electric bicycles.

- In 2016, **16% of Dutch people** owned an electric bicycle.
- Of all cycling kilometres made in the Netherlands, **over 12%** are made with electric bicycles. The average distance made is **6,3 kilometres**, close to twice the average distance made on a regular bicyle.

Univé Consumenten Monitor: Elektrische fietsen, 2016

On 20 March 2018, Dutch Ministry of Finance announced measures to increase the appeal of lease (electric) bicycles. From 1 January 2020 all bicycles and electric bikes will benefit from the so called “*bijtelling*” rule that will be simplified to mimic the 4% “*bijtelling*” that electric cars have (a financial benefit for the use of the vehicle). Through this new rule, the government wants to stimulate commuters to take the bicycle or electric bicycle, thereby reducing traffic jams and keeping the population healthy (Rijksoverheid, 2018). This financial advantage is a positive factor for the Speed-Pedelec sector since the high purchase cost are one of the biggest reasons restricting people to buy one (De Vries, 2018 & Bovag Rai Vereniging, 2018).

CBS and SVOW(2018) have gathered data on the age of the Speed-Pedelec owners per 100 000 inhabitants in the Netherlands in 2017. From the graph on the next page (Fig. 2.6) is readable what age group is the main target group for this type of bicycle: 35-65 years old, with the peek around 54 years old. The questionnaire done for this thesis (De Vries, 2018) roughly confirms this age group among Pedelec-enthusiasts, as can be seen in figure 2.7. With the increasing acceptance of Pedelecs by young adults, this target group could be expanded to 25-65 years old.

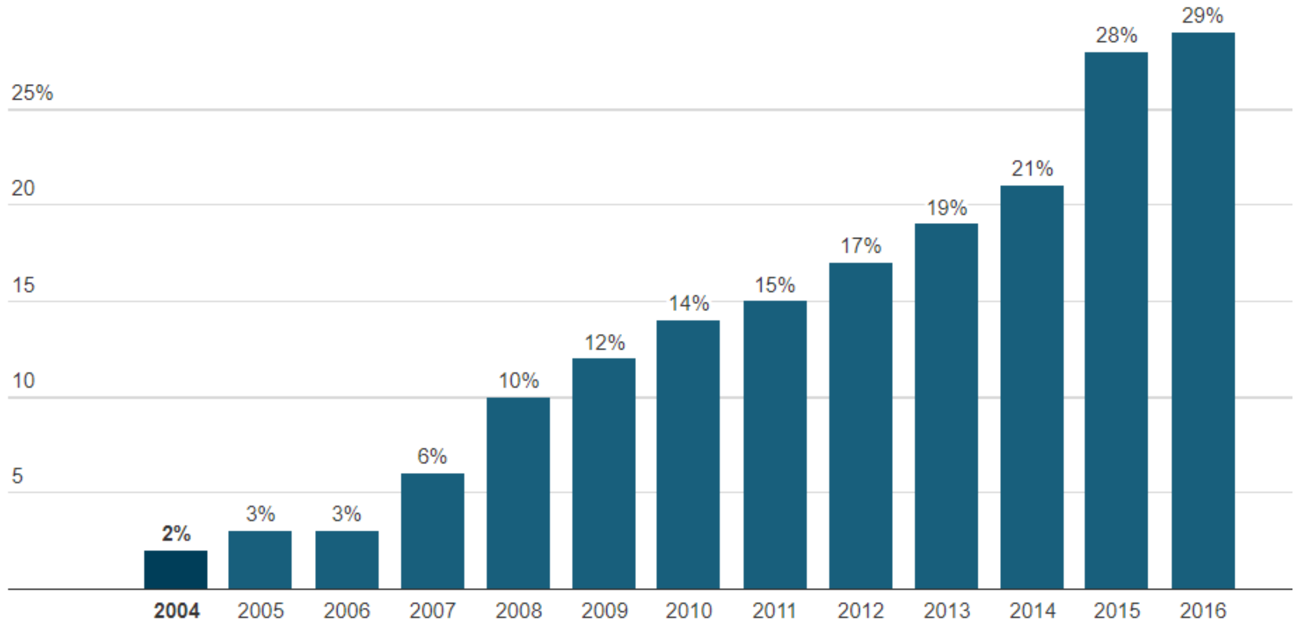
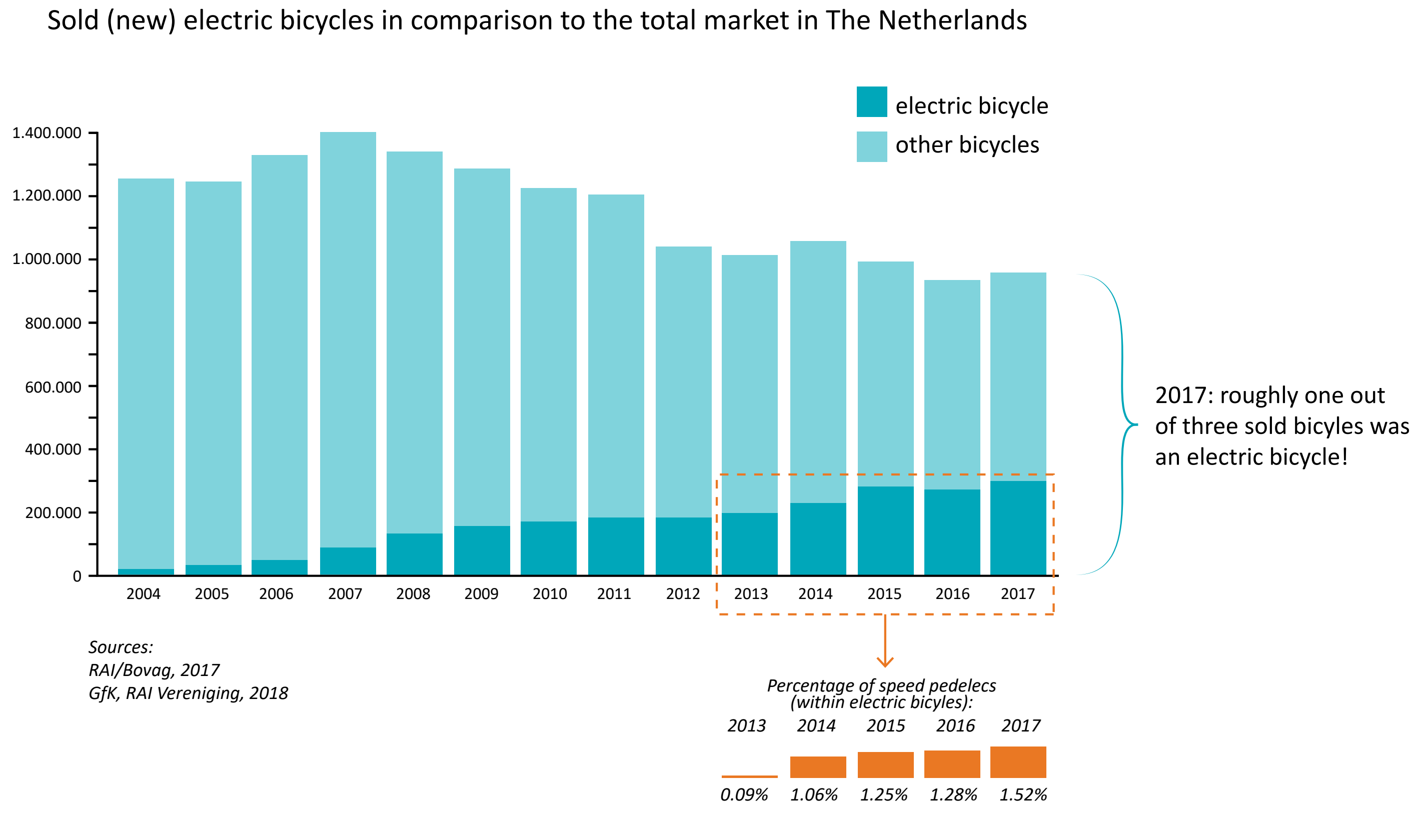


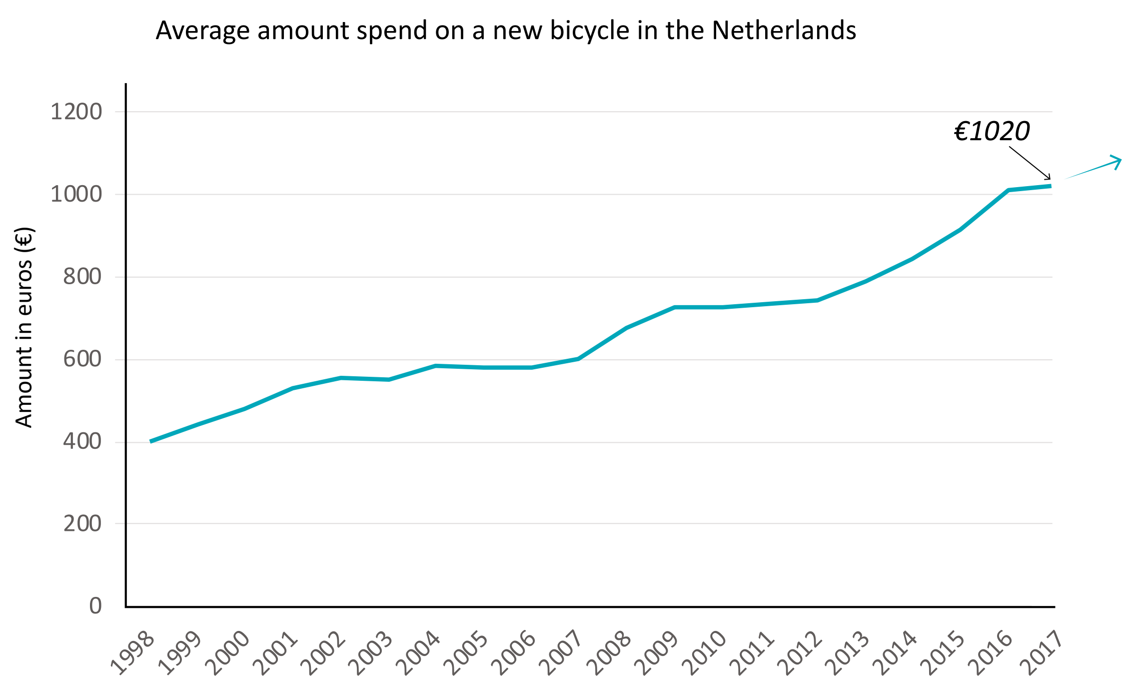
Fig. 2.2 *The percentage of the Dutch bicycle market that is represented by electric bicycles, 2004-2016 (CBS, 2018)*



2017: roughly one out of three sold bicyles was an electric bicycle!

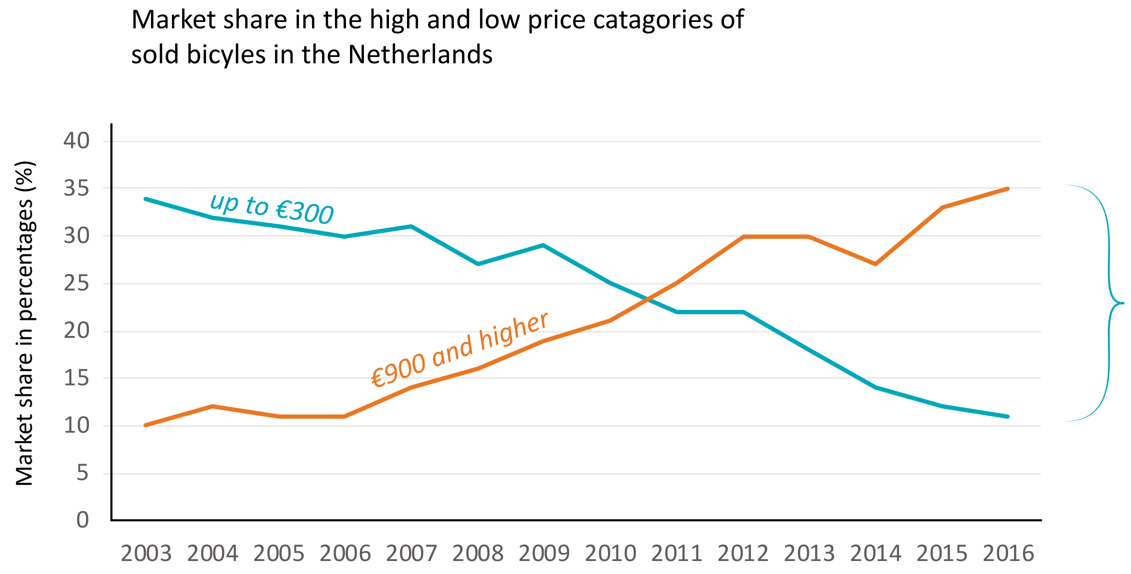
Sources:
RAI/Bovag, 2017
GfK, RAI Vereniging, 2018

Fig. 2.3 *Bicycle sales in the Netherlands 2004-2017 (RAI Vereniging & Bovag, 2017, GfK & RAI Vereniging, 2018)*


Average amount spend on a new bicycle in the Netherlands

This amount has risen partially due to the higher sales rates of electronic bicycles, but nonetheless reveals that people are willing to spend more.

Fig. 2.4 *The average value of sold new bicycles in the Netherlands, 1998-2017 (RAI Vereniging & Bovag, 2017, GfK & RAI Vereniging, 2018)*


Market share in the high and low price catagories of sold bicyles in the Netherlands

While the middle segment remains more or less constant, the higher segment bicycles are rising in sales whereas the lower segment bicycles are falling.

Fig. 2.5 *The shift in the market share of high end and low end bicycle sales (RAI Vereniging & Bovag, 2017)*

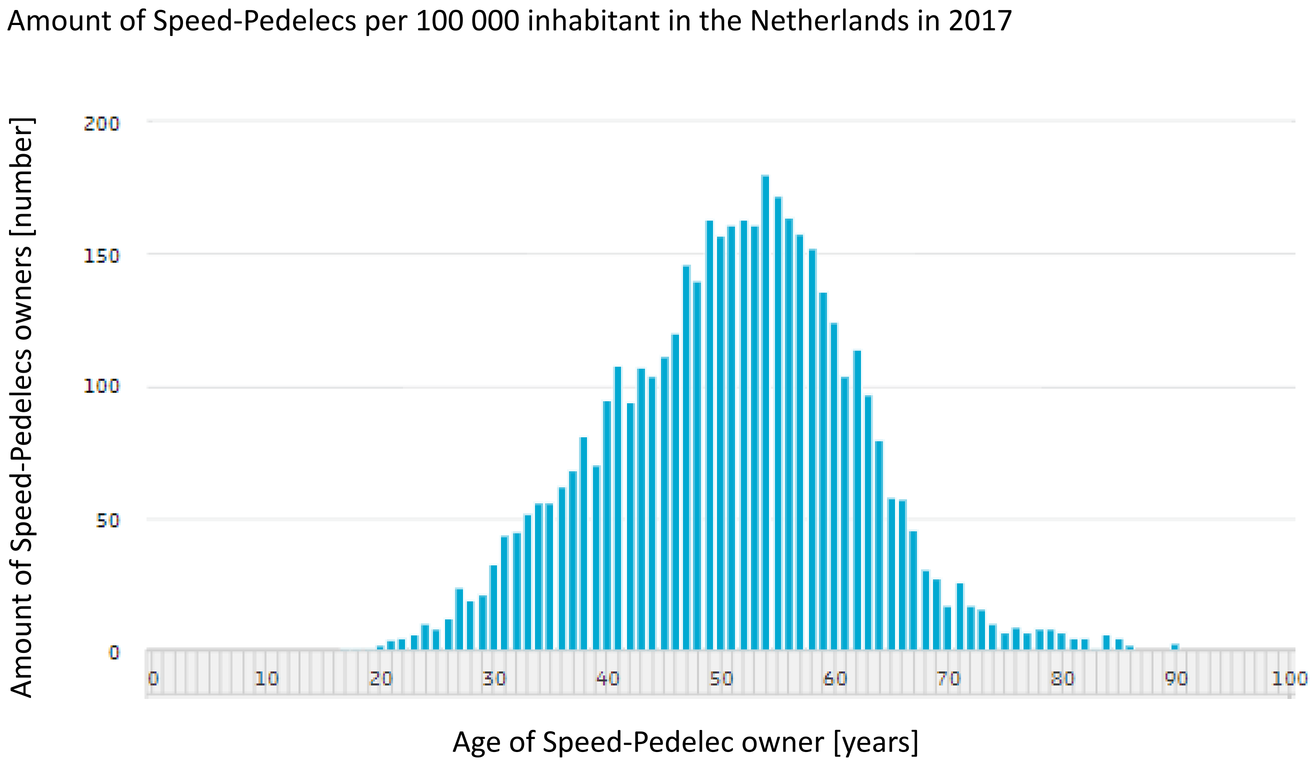

Amount of Speed-Pedelecs per 100 000 inhabitant in the Netherlands in 2017

Fig. 2.6 *Amount of Speed-Pedelecs per 100 000 inhabitant in the Netherlands in 2017 (CBS & SVOW, 2018)*

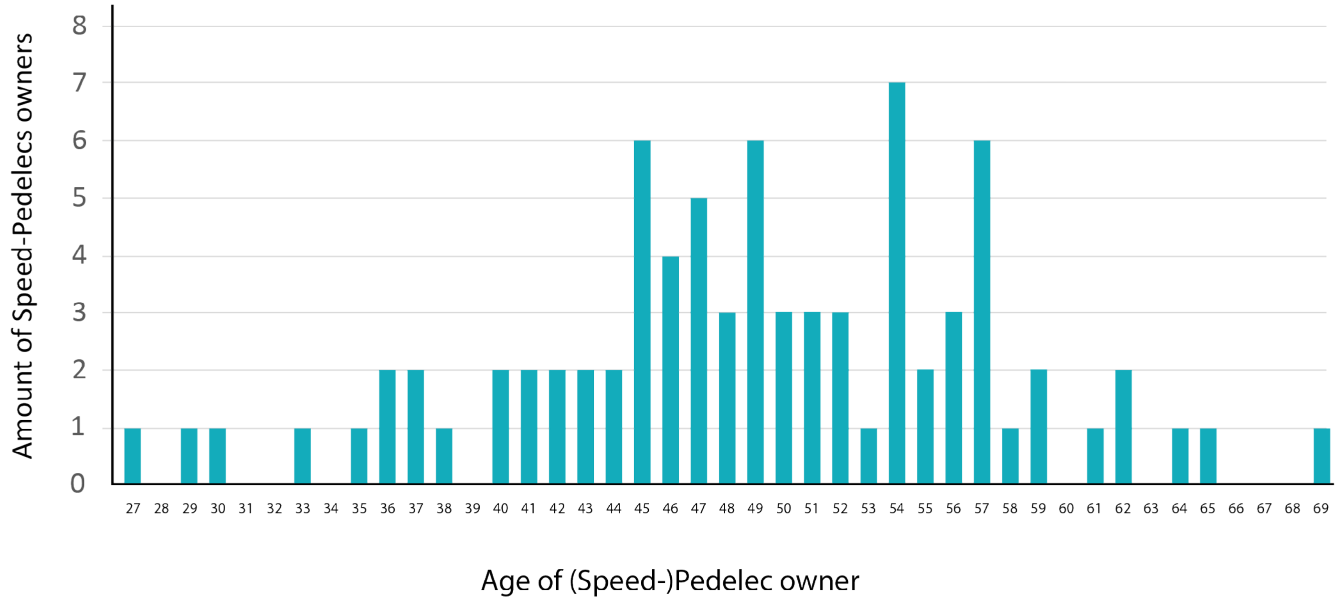


Fig. 2.7 *Ages of (Speed-)Pedelec riders participating in questionnaire (Author, 2018), more details of the questionnaire in Appendix C.*

2.2.3 Analysis of other models and companies

To better analyse the Spaac, the S5 and other companies and bikes were investigated. 7 E-bikes were selected that be grouped in 3 categories: Normal pedelec, Speed pedelec and Super pedelec. Each bike has unique features that were analysed to create a better product. The same goes for the pedelec companies, they all have key characteristics that differ from Spaac. The most interesting models and their characteristics are listed below.

Regular Pedelec

VanMoof Electrictrified-S is a bike that mainly evolved around the shape of the frame. Van Moof clearly aims at younger users and sets an image that these users can relate to (Figs. 2.8 - 2.10). The specifications of the bike are not astonishing. The front wheel motor delivers enough power to speed the bike up to 30 km/h but, since it has no licence plate the bike is restricted to 25 km/h. The marketing and iconic shape of the bike add value to the Van Moof brand. Since the price of these E-bikes start around €3000 it is hard to imagine that the target group can afford these E-bikes.

In 2017 Van Moof launched a crowdfunding campaign, their business plan mainly aims at a more scalable business and to promote their sales at international levels. (VanMoof Crowdfund plan,2017).

The *Coboc ONE* pedelec (Fig. 2.11) can be described as a minimalistic slick and lightweight electric fixie. Their website shows bearded man around the age of 30 cruising through town. The bike has a small rear wheel engine and no gears. It is clearly designed after a “fixie bike” that is popular among a younger lifestyle group. Users have to pedal a high RPM to reach top speeds.

Speed pedelec

The *Stromer ST2* (Fig. 2.12) is one of the best selling Speed Pedelecs. The bike is designed to be used on the road and does not have shock absorbers or other gadgets. The form language of the Stromer is timeless. The 500 W engine has enough power to cruise at 45 km/h. The Stromer has an integrated screen on the front upper tube that can connect to the users smartphone and the Stromer portal. Stromer always uses a rear wheel engine and a derailleur gear system, The derailleur tends to damage in urban usage and storage.

Fig. 2.8 - 2.11
Top three: Lifestyle, target group and design of VanMoof bicycles (VanMoof, 2018)
Bottom: the Coboc one (Coboc, 2018)

The *Rieser Muller Supercharger GT* (Fig. 2.13) is an interesting reference because of the powerful Bosch performance speed mid engine and because of the Nuvinchi N380 SE stepless gear system. This drive system appeals to Spaac because of the clean look and minimal maintenance required in this system. The bike also has MT4 hydraulic disc brakes.

The next page (Fig 2.17 and joining texts) shows an overview of the most popular Speed-Pedelecs in The Netherlands.

Super pedelec

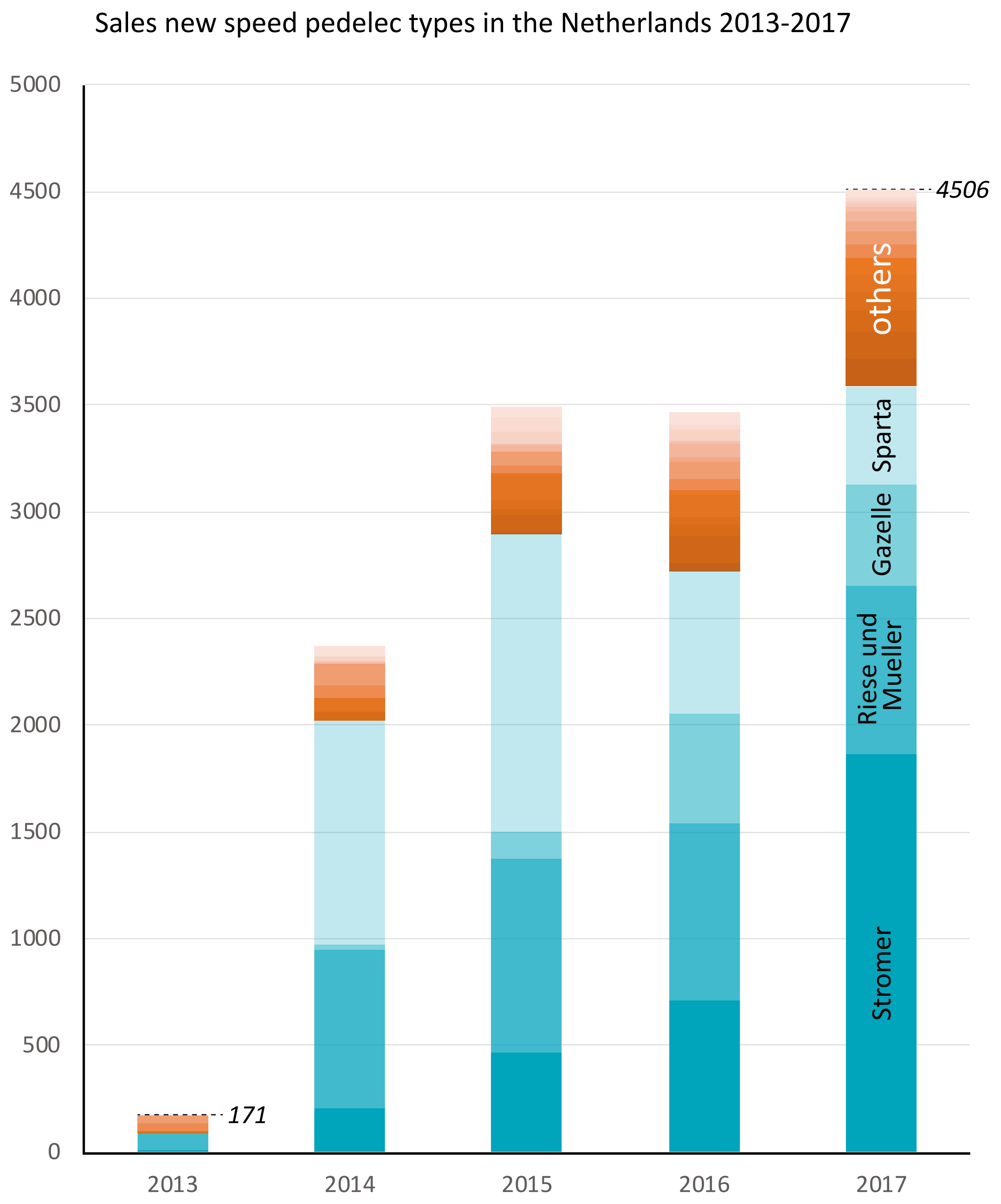
The *Stromer ST5* (Fig. 2.14) is the latest of the Stromer family. The ST5 has an 850 W Syno sport engine and a 1000 Wh battery. The bike is clearly designed for road use, their yellow licence plate allows to travel 45 km/h and it became available in June 2018. The main question is: how fast does is go without restriction and how do people remove the restriction. This is one of the first mass produced bikes with an engine over 750 Watt. It will be in stores fall 2018.

Das Spitzing R pedelec (Fig. 2.15) by the German brand Spitzing , which is already in the MTB market for a few years. Their R pedelec can reach speeds up to 75 km/h with a 750 W engine. The bike does not have a licence plate, probably because it is an MTB and they don’t want to go through the type approval process. The form of the Spitzing does not appeal to Spaac but, the specifications are attractive.

Trefecta (Fig. 2.16) is clearly the most expensive bike in this list. Roughly it costs around 25.000 euro. The bike has generative braking It has the most powerful engine (4000W peak as thay state) in the market. Trefecta created their own gear system where rear hub gears are combined with a front gear system.The gears make a lot of noise and do not always shift at the right moment. The bike is also foldable for easier transportation and is limited to speeds of 70km/h.

The diagram on the next page (Fig. 2.18, author, 2018) illustrates that price and power of the previously discussed models. It also is visible that price and power are directly related: the more power, the higher the price.

Fig. 2.12 - 2.16
From top to bottom: Stromer ST2, Rieser Muller Supercharger GT, Stromer ST5, Das Spitzing R pedelec, Trefecta (Stromer, Rieser Muller, Spitzing, Trefecta, 2018)



Other brands:

Dutch ID
Accel Nederland
Winora-Steiger GMBH
DIAMANT
Kalkhoff
Klever
ZEG
Specialized
Flyer
Cannondate
Grace
Cube Bikes
Stevens
Trek
Unknown/specific

Fig. 2.17
Types of speed-pedelecs sold in the Netherlands, 2012-2017
the most popular ones in hues of green (examples shown in right column),
the other ones in hues of orange (listed to the right)

(Data: RAI Vereniging & Bovag, 2017)
(Images right column: Stromer, Riesen Muller, Gazelle, Sparta, 2018)

** The table in Appendix C provides an overview of typical high-Speed-Pedelecs that are limited to 45 km/h. 90% of these are Speed-pedelecs*

Stromer ST2
From € 6490,-
- popular but pricey
- assemble according sizes and preferences
- Schwalbe BigBen-tyres
- several motor types

Riese & Muller
BlueLABEL Charger HS
From € 3369,-
- elevated chainstays
- optional Gates Carbon Drive (carbon belt drive)
- also as E-MTB

Gazelle CityZen Speed
From € 4199,-
- target is urban commuter
- battery in frame
- Magura hydraulic disk breaks
- Bosch mid motor

Sparta E-speed
From € 2599,-
- bestseller in NL
- 9 gears, battery in frame
- top speed of about 40 km/h
- rear wheel drive motor

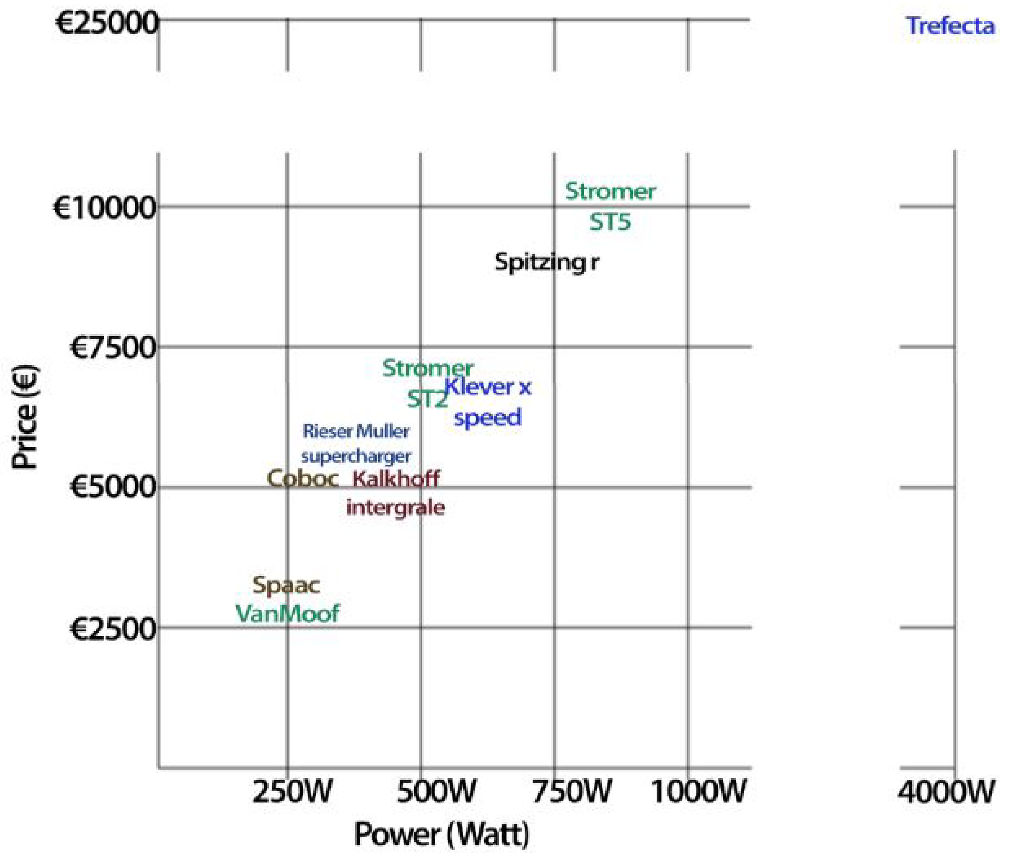


Fig. 2.18
Price and power of discussed Pedelecs.
(Author, 2018)

2.2.4 Testing of speed pedelecs

The Speed-Pedelecs that are described in Appendix B were tested under equal conditions in Zandvoort (racetrack, see Fig. 2.19) and in Rotterdam (busy urban environment). The first test at the E-bike test day in Zandvoort was to get general knowledge about the bikes In advance a list was made of the specifications of the bikes that needed testing. The bikes could be tested for feeling of comfort and to experience the drivetrain in real life. Afterwards interviews were conducted with potential buyers to learn about their needs.

From the table seen in Appendix B it can be concluded that:

- Almost all Pedelec brands have at least one Speed-Pedelec model.
- Speed-Pedelecs come in all shapes and sizes, prices vary from 3000 to 10.000 euro.
- By law all Speed-Pedelecs are restricted to 45 km/h.
- Not a single Pedelec is branded on safety or has features that specifically make the bike safer than others. Some bikes have “better brakes” than others and that is what the consumer perceives as safety.
- Bikes are really comfortable at high speed, the track at Zandvoort is so flat and wide that the speeds up to 45 km/h feel natural. This can be dangerous for new users who do not realise how fast they are going.
- Some motors make quite some noise at high speeds.
- Some full suspension bikes have trouble with pedal bob (see chapter 5.2 for further analysis).

Fig. 2.19
E-Bike Testing day at the Zandvoort Circuit. (elektrischefietsen.com, 2018)

2.2.5 Conclusions external analysis

From the previous market research several conclusions can be drawn, as listed in the text block below. These were used to create the SWOT matrix and later used for the programme of wishes and demands.

- Looking a Van Moofs crowdfunding business plan we learn to keep the product portfolio simple, multifunctional and scalable for future international sales amounts. flagship stores can be used around the globe to promote the product internationally
- There are little to none pedelec companies that focus on the safety of an E-bike. This can be a new market like we saw the car industry shifting toward safer smarter cars.
- There are some companies that focus on theft prevention, this could be an interesting niche for Spaac’s current products and also for the new Super-Pedelec.
- The new product should work intuitive and the functionality may not suffer from start-up problems. Spaacs customers expect
- a timeless design attract a larger user group and also enables Spaac to keep their products in the market as long as possible

2.2.6 Trends and developments

Market trends
Numbers of sales and overall marketing of pedelec producers shows a shift towards stronger and faster pedelecs Stromer already had the successful Stromer ST2 and just launched the Stromer ST5 (see previous chapter) This is a direct consequence of the market demanding faster bikes. The last few year the market has slowly been entered by numerous electric mountain bikes, electric cargo bikes, electric folding bikes. Anything is possible, people just want the latest thing.

Sociological trends
The fact that sports are healthy becomes more and more known around the world, the life expectancy keeps increasing due to better medical service and knowledge on a healthy lifestyle. Also the group of people that exceeds 65 is now way more sportive compared to a generation ago.

The idea for Spaac was made 7 years ago because there was a lack of pedelecs that were not hiding their electric motor and battery. Currently there are numerous brands like Klever (Fig. 2.20) that proudly show their electric power. This together with the increasing sales of all pedelecs shows that people are accepting the new vehicle.

Fig. 2.20
Klever X Speed, a model that does not hide being a electric bicycle (Klever, 2017)

Technological trends
The internet of things is a growing phenomenon, Increasing amounts of products are connected with each other through electronics, options like GPS trackers, phone bluetooth connections and feedback on the usage of the pedelec are currently becoming more common.

The growing demand for lighter batteries in the automotive industry also causes a revolution in pedelec batteries, they become lighter, stronger and charge faster. This increases the range and comfort.

Development
Currently there are at least three major manufacturers (Bosch brakes, brake force one and Blu brake) working on anti-locking bicycle brakes: the ABS. systems, The different manufacturers show positive test results and claim to have it ready for retail in Fall 2018. However, the systems are not fully integrated so the aesthetics is not optimal.
The government stimulates a sustainable ways of transporting, this also affects the pedelec market. The Dutch government has recently announced an initiative to lower the taxes paid over sustainable ways of transport, including pedelecs.

The new LED lighting systems provide brighter lights that consume less energy. This development may lead to safer electric bicycles.

For the conclusions of these trends and the developments for the design, see the SWOT in section 2.6 Conclusions of Research.

2.3 User analysis

In this chapter the user of the Spaac and the S7 are explained, different kind of user research is performed, different types of accidents are analysed.

- Visit location of Juizz, talk to the bike mechanics and testing bikes.
- During an E-bike test day interviews were conducted with riders and suppliers.
- Multiple (E)bike shops were visited and interviews were conducted with the mechanic and sales persons.
- A questionnaire was conducted amongst 83 active speed pedelec riders.
- Some semi structured depth interviews were conducted in addition to the questionnaire (see Appendix B).
- The owners of Spaac were interviewed to find out details about their customers.

2.3.1 Accidents

After investigating different speed-pedelec accidents (SWOV,2017), five types of accidents causing the most casualties were selected to give direction to the design process. These five types all happen in different situations where the design of the bike could influence the safety on the road.

Often speed-pedelec accidents happen because the driver is lacking skills in danger recognition, emergency braking and cornering techniques. Furthermore, other road users are often not used to Pedelec drivers, causing misconceptions and misjudgement.

On the right page the five types of accidents causing the most casualties are described.

1. **Panic brake, blocking the front wheel causing loss of grip or katapult over the front wheel.**
   The first solution here is to implement a smart brake system Or ABS system, anti blocking system. Brose announced to have such a system on the market next year. Also, there are small start-up companies that make this type of brake already. The ABS system can best be applied on hydraulic brakes because the pressure can then be regulated with an oil pump and a regulating valve. The downside is that such a system is often expensive and heavy.

2. **Other road user don’t realise how fast a pedelec is traveling, sometimes the path of the pedelec is blocked and accidents occur.**
   On large distances, road users categorise other users and rate them on how much of a threat they are. This happens mainly through the frontal view and appearance of the user. The identification is also sensitive to headlights and leg movement. A design solution would be to design a pedelec that looks bigger and faster than a normal bike; the headlights have to become brighter, and the frontal view of the bike has to change.

3. **Pedelec driver realises a corner is too tight, either loses control over the wheel and falls or does not make the corner and runs off the track.**
   This problem mainly involves the rider not being aware of its own speed and the dangers it brings. The bike could warn the user if a sharp corner or dangerous intesection is approached through GPS and a small speaker or warning on display.

4. **Passing another road user silently at high speed, the other road user might swindle a bit because he or she does not realise someone is approaching from behind.**
   This problem applies to all electric vehicles. They are really silent but, this implies that other road users don’t realise that an electric vehicle is approaching them. This can lead to panic reactions where the user might go into dangerous directions. An solution is to choose a motor that is not completely silent.

5. **Distraction due to a smartphone.**
   A large part of the bike (and traffic) accidents occur because road users are distracted by their smartphone. This can even be caused by simple operations as choosing a next song in the playlist or checking the navigation. The traffic minister Cora van Nieuwenhuizen recently announced that changes are on the way to fine smartphone use on any bicycle (AD,2017)

2.3.2 Target group definition

Spaacs current user definition is the commuter aging 25 to 65. Research on users of speed pedelecs in the Netherlands shows that the majority of speed pedelecs are bought by male users between the age of 45 to 65. Spaac still focuses on their regular target group but user ergonomics and comfort studies are focussed on the older target group. In the questionnaire discussed in 2.2 it is clearly noticeable that the participants that want to go even faster are the younger ones in the group.

Spaac wants to serve the biggest group of possible users, after detailed interviews with potential buyers of the product and the owners of spaac, we conclude that the spaac S7 must add comfort for the older users but must not look like a typical comfort E-bike (low step in) The posture on the bike may not be too sporty since the older users might find it uncomfortable to lean too far forward and the back and seating area start hurting. In the following chapters a posture will be found for the rider on the bike.

The bike will be designed for a broad group: commuters between the age of 30 and 65,89-85% is male(de Vries, 2018), (SWOV, 2017) The bike will be designed for an average sized Dutch male from ideally the market will be served with different sized frames but regarding the production facilities of Spaac, the initial batch will consist out of 1 model that serves the biggest market as possible.

The smaller females and larger males are checked on their sizes and weight to see how they will fit the bike. The relevant sizes of the users are: Length, Weight, Inner leg length, upper body length, upper arm length, lower arm length. Interviews with customers choosing their pedelec in showed that especially the older customers felt narrowed down by the availability of mostly sportive positioned Speed-pedelecs. They experienced a lack of comfortable Speed-pedelecs.

The bicycle is used for commuting between different cities, the average use is 30 minutes, a maximum time of 1 hour must still be comfortable for average user. In the column to the right (Fig. 2.22) a route is analysed that has a length of 19km, which is the average of the user research and SWOV research. It also contains all the typical pedelec hazard situations, these situations will be improved with the new design.

Left page, Fig. 2.21
Collage showing the lifestyle of the target group (author, 2018)

Right column, Fig. 2.22
A typical commute route and its encountered situations (author, 2018, includes images from Google Maps and Streetview, 2018)

Commute: Leiden - The Hague
19 km (8 km urban, 11 km rural)

Encountered situations:
1. pedestrian zone
2. speed bumps
3. unclear junction
4. 50 km/h road, many cars exceed limit
5. bumpy pavement
6. traffic lights & zebra crossings

	Situation	Demanded handling
pedestrian zone		to anticipate and manoeuvre quickly, dodging slower road users, unexpected stopping
speed bumps		to brace the impact of the bump whilst cycling at high speed
unclear junction		to have a clear and unhindered overview of the traffic situation
50 km/h road, many cars exceed limit		to cope safely with other motorized road users at higher speeds
bumpy pavement		to be stable and ride smoothly on rough or inconsistent surfaces
traffic lights & zebra crossings		to stop and go quickly and safe

2.3.3 Ergonomy

Determining factors on the ergonomics of a high speed bicycle are:

- Seat height (frame size) and standover height
- Distance to handlebars
- Back angle of the rider
- Pressure on steering wheel
- Pressure on seat
- Vibrations/ shock absorbance

To determine how the spaac S7 will be ridden, the user is analysed for the ergonomic stature preferences, Initial contact with seperate users that are interested in a Super-Pedelec showed that comfort can be improved by adjusting the industry standard seating posture.

The two most important factors for the posture are the seat tube angle and the top tube length. The average speed pedelec manufacturer focuses on the limits of the body in a forward position, companies like Klever and Stromer have their users bended forward, the upper body makes an angle of 110-130° with the horizon, steer is at the same height or even lower than the saddle, the seat tube makes an angle of 72-75° with the horizon. This is the limit of comfort for the average bicycle user but when we look at the users that actually buy the faster (and more expensive) speed pedelecs, we see the demand for an upright position, combined with a more relaxed seat tube angle (45-65°) like the immense populair urban arrow cargo bike.

- Decreasing the seat tube angle and putting the upper body more upright, rotates the pelvis backwards, this means the body weight is supported more by the seating bones (ischial tuberosity in latin) and less by the pubic bones (Pubic Ramus in Latin) for untrained bicycle riders, the pubic ramus often causes saddle pain when being pressured on bicycle rides.

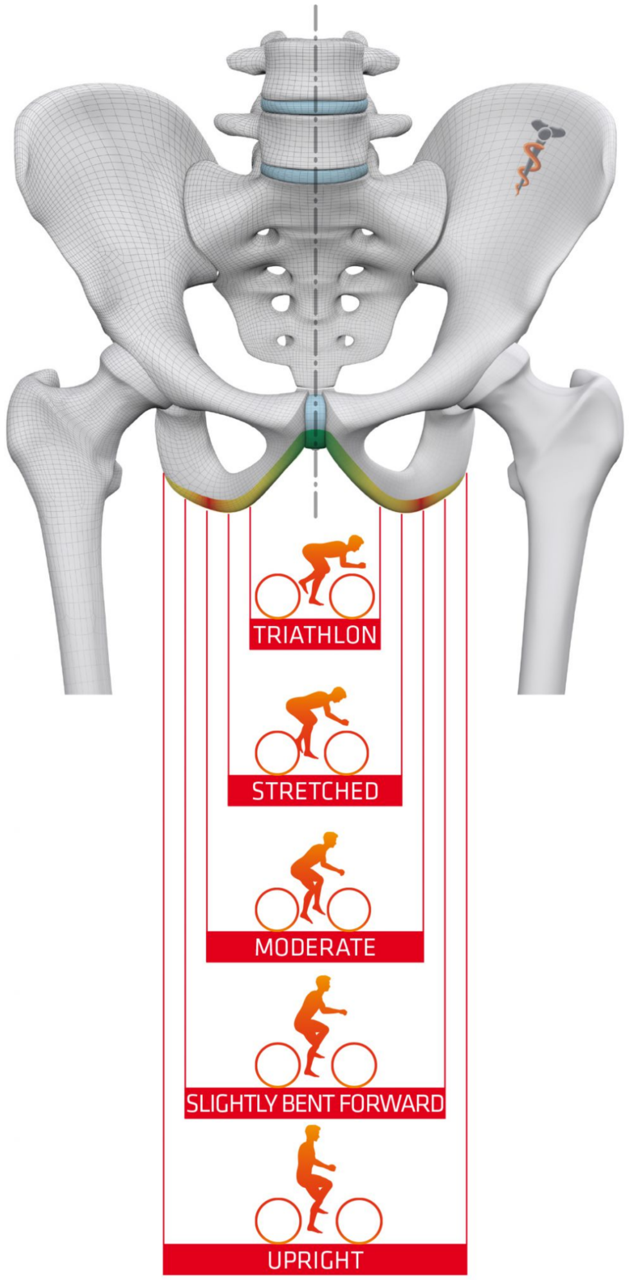


Fig. 2.23
Pressure on sit bones with different seating positions while cycling (sq-lab Sport Ergonomics, 2017)

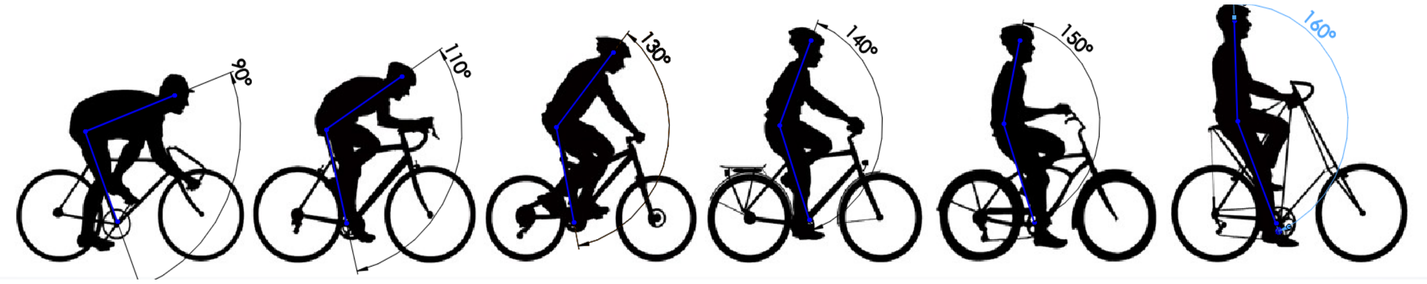
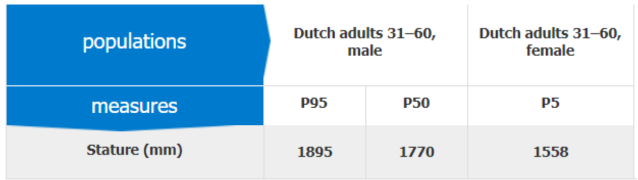


Fig. 2.23
Different riding postures for users on the bicycle or pedelec. The angle of the upper body is measured by a line from the crank upwards. (image modified by author, 2018)

- Decreasing the seat tube angle makes it easier for riders that have difficulties to touch the ground when slowing down and stepping on and off the bike.
- The upper body might catch more wind regarding the upright position, but the complete body sits lower because of the angles legs, wind resistance will increase slightly.

Positioning an average sized P50 Dutch male on the bike provides the first insights on what the lay out of the bike might look like. The next step is checking the ergonomy for smaller and bigger users (P5 female and P95 male, see Fig. 2.24), it is possible that the design of the bike only allows a minimum of P10 Dutch females, an optimum is found for these size differences.



populations	Dutch adults 31–60, male		Dutch adults 31–60, female
measures	P95	P50	P5
Stature (mm)	1895	1770	1558

Fig. 2.24 *Maximum and minimum statures: P95 of Dutch males 31-60 and P5 of Dutch females 31-60 (Dined, 2018)*

The crotch height (inseam) determines the saddle height (saddle-bottom bracket). The user needs to touch the pedal with its heel when the leg is fully stretched while the crank is in the lowest position. Taking the inner leg length and subtracting the crank length will provide us the saddle height. The inseam also shows how comfortable the standover is for different users.

A straight up position on the bike puts the pressure on the seating bones, leaning more forward rotates the pelvis forward and brings the pressure points more forward. This area is more narrow and sensitive for discomfort. The thumb rule that most bicycle shops use: Do not choose a bike with the handlebars lower than the saddle when the rider is not used to a race bike stance. In this statement it is assumed that the bike's top tube length is almost the same as the seat tube length.

v

The important factors on the ergonomics of a high speed bicycle are listed in the column to the right.

- **Seat height (frame size) and standover height**

Although the seat height can often be changed, there is a need for a minimum and maximum seat height. Looking at alternative bikes brings us to one of the most important bicycle dimensions: the frame height and standover height.

- **Distance to handlebars**

It is mainly the distance between the handlebars and the seat that determine the position of the user. Adapting the handlebars will influence the posture of the rider.

- **Back angle**

What is an ideal optimum between comfort and speed; seat height equal to steering wheel; adjustable for all people?

- **Pressure on steering wheel**

Leaning more forward will mean more pressure on the hands. Also the weight distribution will be more towards the front wheel changing the steering behaviour of the bike.

- **Pressure on seat**

The seat supports most of the weight of the user, a normal bicycle seat is relatively hard, definitely harder and smaller than a motorcycle or scooter seat. Increasing speeds will lead to more discomfort due to the seat bumping up and down. The shock absorbing will happen through the tires, wheels, frame fles, possible suspension in front and rear fork. Nowadays shock absorbing seats are gaining popularity.

- **Vibrations/ shock absorbance**

A study must be done on which and what kind of shock absorbance in the sitting area is still acceptable.

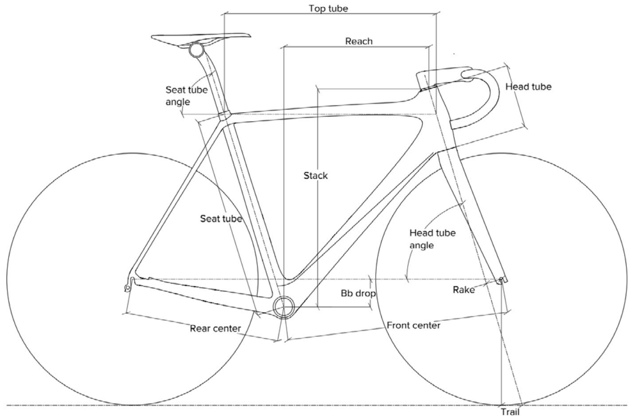
- **Road surface**

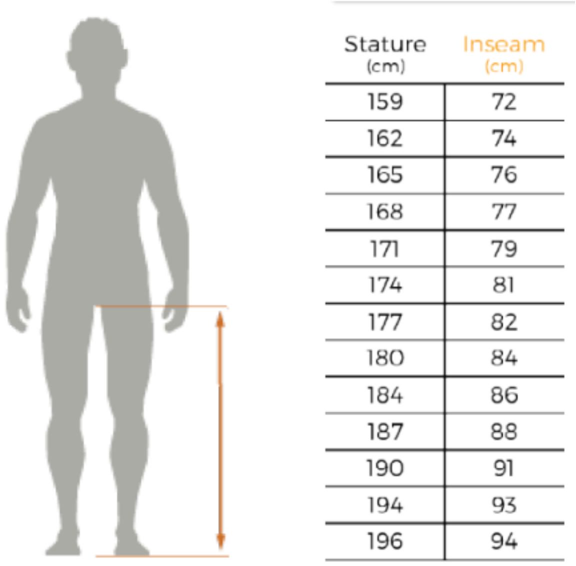
Which parts of road do we drive the bike on, how fast and how much height difference is there on average on the road.

- **Duration of bicycle ride**

The maximum comfortable distance to ride the bike will be 45 minutes (SWOV, Bovag onderzoek, User interview, Spaac).

2.3.4 Determine Bicycle lay out (Specs/ demands/criteria)





Stature (cm)	Inseam (cm)
159	72
162	74
165	76
168	77
171	79
174	81
177	82
180	84
184	86
187	88
190	91
194	93
196	94

Geometry of the bike (lay out)

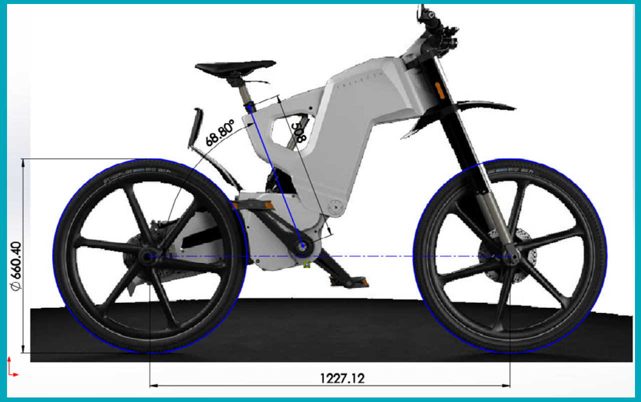
Wheel base
Finding the balance between space for the engine and still being able to corner the bike.
Also the maximum outer size of the bike must be

Tires size
Probably as big as possible, yet, smaller tires make space for more battery and engine/
Gyroscopic effect? Weight vs cornering vs centrifugal force vs diameter
Air resistance adds up with increasing speeds and widening tires
Big tires that are strong enough become too heavy
Bigger

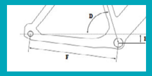
Bottom bracket to ground distance:
Mtb's have 30 cm to ground, normal bikes have 27cm, spaac has 29cm
A lower bottom bracket provides easier reachability of the ground but a biggers chance to hit the ground, the smaller front sprocket means the bike will not hit a curb, a short research on bicycle users shows that common users with the pedal in a corner, wider tires and slightly narrower

Frame geometry rake trail and head angle
See dimensions of two current bikes on the right page.

A small survey by Whitt and Wilson (1982) found that touring bicycles should have head tube angles between 72° and 73° and trail between 43 mm and 60 mm.



Specifications of the trefecta DRT speed pedelec:
Left we see the lay out of the trefecta DRT speed pedelec, in solidworks it is traced and the measurement



Stromer st2 sizes

Seat tube

The position and length of the seat tube is the base for any bike generally the seat tube ranges between 70° for and 75°
The height of the seat strongly depends on the size of the rider, On current bicycles, the seat is adjustable in height and from front to back it can already been said that the Spaac S7 will probably have adjustable seating to enable (p5 - p95) Dutch males and females age 30 to 65 to ride on this bike. For this measurement the length and angle of the users legs are used.

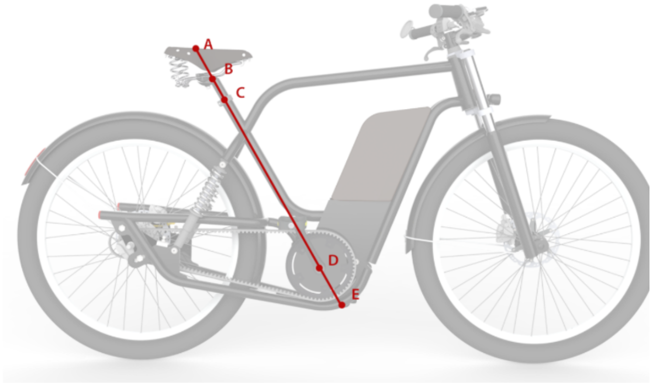
Handlebars position

The handlebars position the upper body of the rider on the bike, they also determine the look of the bike. The top tube distance is important in the design, a longer top tube will position the rider more forward, also making the angle of the back stronger.
The height of the handlebars compared to the height of the seat also influences the posture. Most touring bikes have the handlebars at the same height as the seat or higher (comfortable position), racing bikes have the handlebars lower than the seat lowering the frontal surface of the complete bike and thus lowering the air resistance of the bike. This is often experienced as less comfortable for non trained riders.

The picture above shows different riding postures for

stretched while the crank is in the lowest position. Taking the inner leg length and subtracting the crank length will provide us the saddle height. The inseam also shows how comfortable the standover is for different users.

The sizes for the smallest, biggest and average users are displayed in fig xx.
The corresponding inseam lengths are 72cm, 82cm and 91cm
The inseam length corresponds with the person sitting on the bike while the crank is in the lowest position. A-E Assuming the cranks are 17cm each, this can be subtracted from the inseam to get the desired Saddle top to bottom bracket length. These are 55, 65 and 74cm A-D
The preferred saddle is the Brooks flyer, together with the attachment bracket it adds 7cm to the assembly. (A-B) the desired length for C-D is now 48cm, an average sized person will ride with the saddle tube (B-C) extended 10 cm and a P95 user will have the saddle tube extended 19cm



2.4 Technical analysis

In this chapter the conclusions of various technical explorations are listed, these conclusions form the basis of the design and list of requirements, Appendix C and D further explain some decisions.

The system of motor, drive, gears and hub/wheels that is chosen for a pedelec strongly influences the driving characteristics. Brands have different types of drive-trains. In this section the most common or outstanding ones will be discussed to give a general overview of the specifications and characteristics.

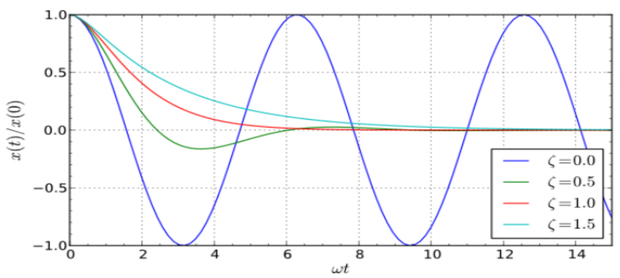
Wheel size and Tire size

The wheels for the Spaac S7 determine a large part of the lay out and feeling of the bike, analysing relevant literature, we see wheel size increase to add comfort, but bigger wheels are also heavier and add unwanted angular momentum that makes the bike behave unpredictable.

Wider tire adds increases comfort and grip, they also add some resistance. An analysis is made on all the bicycles that are checked in appendix C on which Wheels and tires there are used, essentially all the bikes have 24, 26 or 28 inch rims, the bikes that are focussed more on comfort have wider tires, the Schwalbe big ben is a good option for road use but still keep the option of keeping grip on gravel of uneven surfaces. When the details of wheel suppliers are checked on weight and speed allowance of the wheels is it noticeable that the 28 inch wheels are not suitable to speeds up to 70Km/h. A 26inch wheel might do the job but more space is needed for suspension travel. The wider tires also add size. The best option is a 24inch wheel, is it light and strong and in combination with a big tire mimics the outer diameter of a normal 26inch tire.

Comfort and Suspension

Riding a high speed pedelec may not lead to discomfort as this might affect the safety. It is therefore important to reduce the vibrations caused by the roads as much as possible. This can be achieved by using a front and rear suspension system and one or more pivot points. To compare the vibrations of a frame with and without a suspension system that are felt at the saddle and the steer, Liu et al (2013) made a very detailed numerical model of the bicycle and the human body. Vertical vibrations up to 50 Hz were analyzed for a smooth and a rough road when cycling 12 km/h. Accelerations up to 10 m/s2 were felt. The suspension system was clearly damping the frequencies above 10 Hz and thus increasing the comfort.

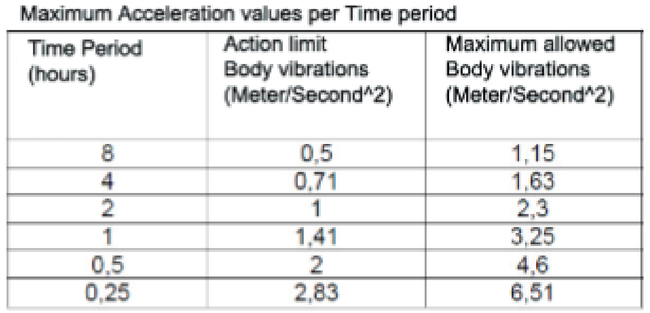


It is clear that when cycling 70 km/h the frequencies become higher but, it is unknown what the amplitudes of the accelerations will be for the different frequencies. No studies on the vibrations of pedelecs were found.

The goal of a suspension system is to dampen all the frequencies that are felt at the saddle, feet and, hands. MTB terrain bikes were the first bikes were the suspensions were applied. Some of these were inspired by the suspensions that are used by motor cross bicycles. To dampen the large accelerations caused by the rough terrain complicated suspensions were developed via trial and error methods. To dampen the accelerations of the steer, oil-air suspensions are generally used in the front fork (Levy & Smith, 2005). To dampen the accelerations of the saddle there is no generally accepted system of the spring and pivot point. Note that the accelerations caused by the pedals are less of a hinder as the legs can dampen these to an acceptable level. The differences in duration and comfort between off-road cycling and road cycling can be large (Macdermid, Fink, & Stannard, 2015).

As the Spaac S7 is developed for paved roads the damper/pivot is simple and the design is lead by the ergonomics (similarities with the motorbikes developed in the early 1900s and simplicity (2 pivot points and only the swingarm that moves). It is recommended to measure the accelerations as described in Vanwalleghem et al (2012) and if not acceptable levels are measured to model numerically variations of the suspension system as in Liu et al (2013). Loads due to non-smooth road surfaces as well as due to the pedal force and braking force are difficult to predict when using models. Speelberg (2012) also recommend to measure accelerations on the bike and the rider.

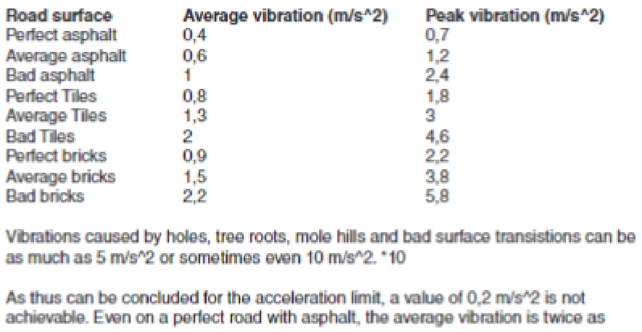
Acceptable levels of comfort in relation to acceleration magnitudes are given in Damgaard et al (2009) that are based on the ARBO and “Fietsen Bond” measurements, see the tables on the right page (Figs. 2.28 & 2.29).



Maximum Acceleration values per Time period

Time Period (hours)	Action limit Body vibrations (Meter/Second^2)	Maximum allowed Body vibrations (Meter/Second^2)
8	0,5	1,15
4	0,71	1,63
2	1	2,3
1	1,41	3,25
0,5	2	4,6
0,25	2,83	6,51

Fig. 2.28: *ARBO limits for body vibrations (Damgaard et al, 2009)*



Road surface	Average vibration (m/s^2)	Peak vibration (m/s^2)
Perfect asphalt	0,4	0,7
Average asphalt	0,6	1,2
Bad asphalt	1	2,4
Perfect Tiles	0,8	1,8
Average Tiles	1,3	3
Bad Tiles	2	4,6
Perfect bricks	0,9	2,2
Average bricks	1,5	3,8
Bad bricks	2,2	5,8

Vibrations caused by holes, tree roots, mole hills and bad surface transistions can be as much as 5 m/s^2 or sometimes even 10 m/s^2. *10

As thus can be concluded for the acceleration limit, a value of 0,2 m/s^2 is not achievable. Even on a perfect road with asphalt, the average vibration is twice as

Fig. 2.29: *Vibrations on different types of surfaces (Damgaard et al, 2009)*

As the high speed pedelec reduces the travel time, the maximum acceptable magnitudes of acceleration can be higher when compared to normal cycling speeds.

When using a suspension the bicycle might start to resonate at certain frequencies. This is an unwanted situation as it might lead to loss of control. This resonation frequency is called the “eigenfrequency” f and can be calculated from the equation:

$$2 \pi f = \sqrt{(K/m)} \quad [\mathrm{Hz}]$$

where K is the stiffness of the spring and m the mass of the bicycle and the rider.

In Liu et al (2013) the following numbers were used. A spring stiffness of front fork is 17.2 N/mm and the damping coefficient is 1.15 N-s/mm. The rear suspension has a spring stiffness of 97.5 N/mm (557 lbs/in spring rate) and a damping coefficient of 2.05 N-s/mm. The estimated weight of the Spaac S7 is approximately 40 kg. Assuming the cyclist weights 80 kg, then the eigenfrequencies are 1.9 and 4.5 Hz for the front and rear suspension respectively. These are not interfering with the pedaling frequencies that are an order of magnitude higher.

If the road would have the shape of a sinusoidal curve where the wavelength would be 2 m, then a speed pedelec would start to resonate at about 14 km/h and 33 km/h due to the front and rear spring respectively. This can be calculated from the equation:

$$\lambda f = v \quad [\mathrm{m/s}]$$

where λ is the wavelength and v the speed of the bike. It is expected that the speed pedelec is mainly used on asphalt roads, tiles, or bricks. The latter two might have small vertical displacements every 10 or 30 cm. When cycling 54 km/h these give disturbances with frequencies of 50 and 150 Hz and are therefore not introducing unwanted resonance as these are much higher than the eigen frequencies.

The front and rear springs are connected to the same mass, the eigenfrequency of the rear spring may never be a multiple of the front spring. This to prevent double resonation due to harmony.

It is expected that road disturbances do not have the shape of a sinusoidal curve but, are more likely to have the shape of a small bump and then a flat surface. If the length of the flat surface is much more than the length of the bump, the damper of the suspension has sufficient time to completely damp the vertical acceleration. This “rebound time” depends on the damping coefficient of the damper. If it is less than the critical damping (underdamped) the bicycle will start to oscillate after a bump in the road. If the damping coefficient is larger than the critical damping (overdamped) the bicycle will more slowly go to the state before the disturbance. Ideally the damping coefficient should be equal to the critical damping (critically damped. The critical damping coefficient cr can be calculated from the equation

$$cr = 2\sqrt{(K\ m)} \quad [\mathrm{kg/s}]$$

Using the above numbers cr is 0.4 and 0.3 for the front and rear suspension respectively. This is underdamped and would lead to unwanted oscillations. Critical damping can be achieved by selecting a damping coefficient of 2.87 N-s/mm and 6.84 N-s/mm for the front and rear spring respectively (given the above numbers for the stiffness of the spring and the mass of the bicycle and rider).

Note that the above calculations were done for only one rear spring. In the current design the Spaac S7 is equipped with two rear springs, these two together should have the same behaviour as the one spring calculated before.

For many springs and forks the stiffness is adjustable and therefore the eigenfrequencies can be changed. This gives a wider range for selecting standard springs. Keoghs could be a good rear spring (2 * 100 USD) while the DNM USD-8A could be a good fork (449 USD). Both are air suspensions and adjustable (preload, rebound, air pressure).

Motor

The motor of the pedelec is one of the most important characteristics, the amount of Watts often determines if it is suitable for a speed pedelec or even a super pedelec. The average and maximum normal pedelec has a 250W engine take for example the Van Moof Electrified S. Speed pedelecs use engines up to 500W, some even 750W. When we take a look at the super pedelecs there are some that have a 1000W engine. Like the Stromer st5 that is being launched soon. The location of the motor is an important factor for the road handling.

Three types can be distinguished:

- **Motor in the hub of the front wheel** (Fig. 2.30), easy to construct, easy to adapt existing bicycles but not optimal for road handling. A good example here is the Van Moof Electrified S.

- **Mid (in frame) Motor** (Fig. 2.31), (Bosch, Yamaha, Brose, Panasonic, Shimano, Continental) When the motor is integrated in the frame of the pedelec, the frame is often designed with a bottom bracket specifically for that specific engine. One advantage is that the relatively heavy motor is located central and low in the frame. Some mid motors also provide internal gearing. This prevents the front sprocket of the bike to become extremely large when a user wants to pedal at a comfortable pedaling rate (50-70 rpm) whilst reaching speeds over 45km/h. Continental provides a mid motor with continuous gearing. This motor has a great feature: the continuous internal gearing is directly linked to the speed of the bike. The rider just sets a pedal rate and starts cycling. The roller gearing system sets the pace and the speed of the bike is controlled with the power the user sets to the pedals.

- **Motor in the hub of the rear wheel** (Fig. 2.32). This system is proven to be simple and effective. Yet the gears are very important here. There is demand for a rear motor with gears in the hub but such a product does not exist.

Fig. 2.30 - 2.32
top: motor in the hub of the front wheel,
middle: mid motor,
bottom: motor in the hub of the rear wheel
(author, 2018)

Transmission

For the drive there are 3 options:

- Normal chain drive (Fig. 2.33). A chain is light in use but high in service. The cost price is relatively low.

- Belt drive (Fig. 2.33). This is gaining interest. The resistance is somewhat higher and also the price is a bit higher. But on the positive side is that this belt drive is totally maintenance free. One important notice is that belt drives are often sensitive to the alignment of the rear wheel and sprocket. Otherwise the belt runs off the sprocket.

- Cardan drive (Fig. 2.34). Almost no bikes use this type, its complexity leads to high costs and high resistance. This drive could possibly be a solution for a super pedelec, it is used in the motorcycle industry

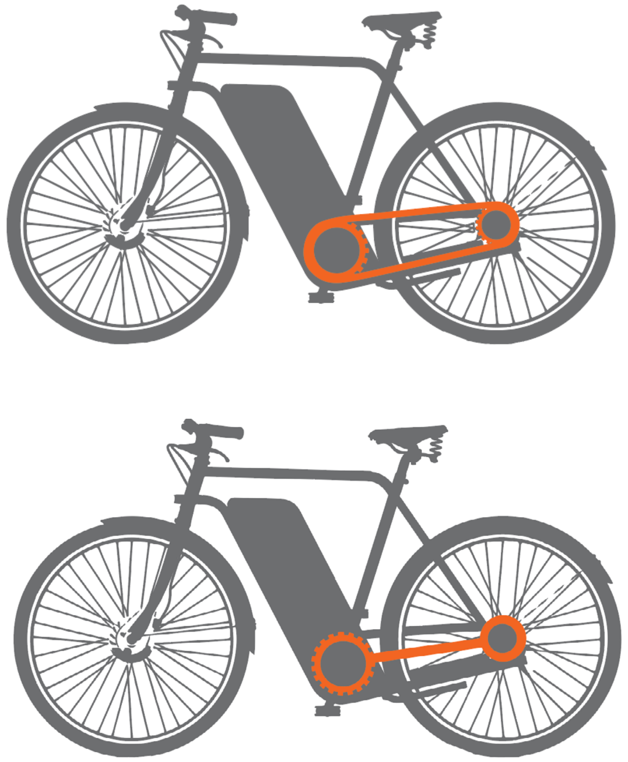


Fig. 2.33 - 2.34
top: normal chain drive or belt drive (same position),
bottom: cardan drive
(author, 2018)

Gears

Several gearing systems can be distinguished:

Derailleur (Fig. 2.35)

- A derailleur is the most common system for gearing. The downside is that the external system is sensitive to dirt and can easily be damaged while parking or storing the bike.

Rear hub gearing (Fig. 2.36)

- 3-, 5-, 7-, 8 speed rearhub (shimano/ sturmey archer)
- The current Spaac S5 uses an automatic internal planetary 2 speed SRAM. hub. It works perfectly smooth but is not suitable for the forces in a speed pedelec.
- Rolhoff makes heavy duty rear hub systems with internal gearing
- Nuvinchi has a promising system with internal roller gears. It is maintenance free and made for heavy duty. It is expensive.

Mid gears (Fig. 2.37)

- the pinion system, this is a small gearbox that is located around the crank of the bike. It cannot be combined with a mid motor. It is also relatively expensive so only possible on a high-end pedelec. There are some mid motors that also provide gearing,
- Continental created a mid engine with continuous gearing. Called 48V
- Schlumpf drive is a great system that has a set gearing in the front sprocket. This is a direct alternative to a really large sprocket

In the design of a pedelec, besides the drive train also other decisions need to be made, which brakes, tires and battery are needed for a particular design? These parts are of secondary importance for the driving characteristics. Often the battery is selected together with the engine. The design of the frame is often adapted to the battery and the motor. Then the braking system is selected to complete the drivetrain.

The car industry shows that kinetic energy can be stored back into the battery. So an interesting question is if generative braking can be applied successfully to an E bike (the Knighthawk Bomber has it already).

Fig. 2.35 - 2.37

top: classic derailleur,
middle: gearbox - Pinion,
bottom: mid gear - the Schlumpf
(Wikipedia, Pinion, Schlumpf, 2018)

Drivetrain sets explained

A pinion front gearbox followed by a belt drive and a rear wheel engine. Although the pinion is an expensive part (approx 1000 euro minimum) it leaves room for the rear motor, there is a wide variety for rear hub motors available. A rear motor that is originally intended for the scooter business can be spoked in a rear bike wheel.

The next option could be a front motor with internal gear or internal motor with the Nuvinchi rear hub. The great feature about this setup is that the gearing system can be set to a certain pedaling rate and the user will keep pedaling at that rate. When accelerating on a Speed pedelec it is quite a hassle to get through all the gears.

ABS system

Frontal view can easily be changed with fork legs that stretch up to the handlebars.

It seems that 2018 will be the year of brake innovation in the E-bike market. Big companies like Bosch but also smaller ones like, Blu brake and Break force one are getting ready for a market demand of small light and flexible ABS systems. What possibilities do we have for a "smart bike"?

Engine type and size

The electric engine of this bike will be a mid or a rear motor. The size required to reach 70 km/h will is between 1000 and 2000 Watt for the two fastest and most popular available speed pedelecs, i.e., the Stromer st2 and the Klever X Speed (Fig. 2.39 below).

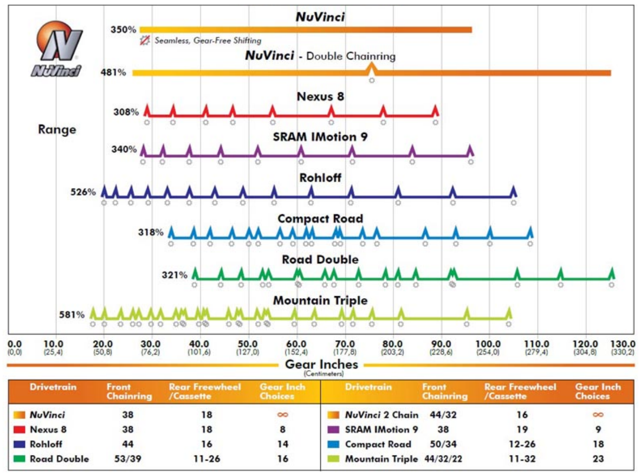
Fig. 2.39

Klever X Speed (Klever, 2017)

Battery size

Depending on the engine, the battery pack can be determined, the most powerful battery packs are assembled from Samsung-18650 cells (cylindrical li-ion cells that are stacked to fill the shape of the bike as much as possible).

A standard battery pack will save production costs but, will not give full form freedom. The current Spaac S5 has a custom battery pack, the new Spaac s5 bikes will have a standard battery pack that reduce the cost.



Drivetrain	Front Chainring	Rear Freewheel /Cassette	Gear Inch Choices	Drivetrain	Front Chainring	Rear Freewheel /Cassette	Gear Inch Choices
NuVinci	38	18	∞	*NuVinci* 2 Chain	44/32	16	∞
Nexus 8	38	18	8	SRAM IMotion 9	38	19	9
Rohloff	44	16	14	Compact Road	50/34	12-26	18
Road Double	53/39	11-26	16	Mountain Triple	44/32/22	11-32	23

Fig. 2.38

NuVinci Range and Gear Inch Comparison. All comparisons done with a 26" wheel (NuVinci, 2016)

Selecting the drivetrain

Taking into account the previous analyses for different types of drives for the Spaac S7, 3 serious sets can be selected:

Note: there are more options especially when drive component are adapted but regarding the possibilities of Spaac, a proven complete system is necessary

TQ-Drive 120S (920W) drive motor with Nuvinci N380 hub and harmony automatic shift unit (winner)

- Looks: 5/5 rigid, manly and fits spaacs form language
- Ease of use: 5/5 being a complete system it comes with controls and possible battery
- Price: 3/5 This motor might cost more then the luna but is worth the money
- Technical reliability: 5/5The Nuvinci hub is known for the great technical standard, the

Rear wheel motor with pinion C1.12 gearbox

- Looks: 5/5 rigid, manly and fits form language
- Ease of use: 3/5 Shifting is still clunky, the gears have resistance and the pick up for the power and interface need to be integrated
- Price: 4/5 costs are average
- Technical reliability: 4/5 pinion is known for technical reliability, yet there are no 1000W complete pedelec motor systems available, it is all self built

Luna front motor (1000W) with nuvinci N380 hub and harmony automatic shift unit.

- Looks: 4/5 rigid, motor looks okay but mounting plates might look flimsy if not integrated correctly
- Ease of use: 3/5 system is not complete integrated
- Price: 4/5 affordable motor but maybe too cheap
- Technical reliability: 3/5 the motor seems budget and there is need for a reliable known motor

2.5 Conclusions of research

In the SWOT on the bottom of this page (Fig. 2.40) is highlighted what are the most important strengths and opportunities for the target of selling 100 safe and comfortable Spaac Super/Speed-Pedelecs in 2020.

2.5.1 Design visio

A timeless but unique product with which the owner can distinguish himself from others. The product should complement the users identity and lifestyle. In reaction of the current disposable tendency, this product needs to resist fashion trends and deterioration. The product should have a long term character: a bicycle for life.

Fig. 2.41 *A product for life (Spaac, 2016)*

2.5.2 Product vision

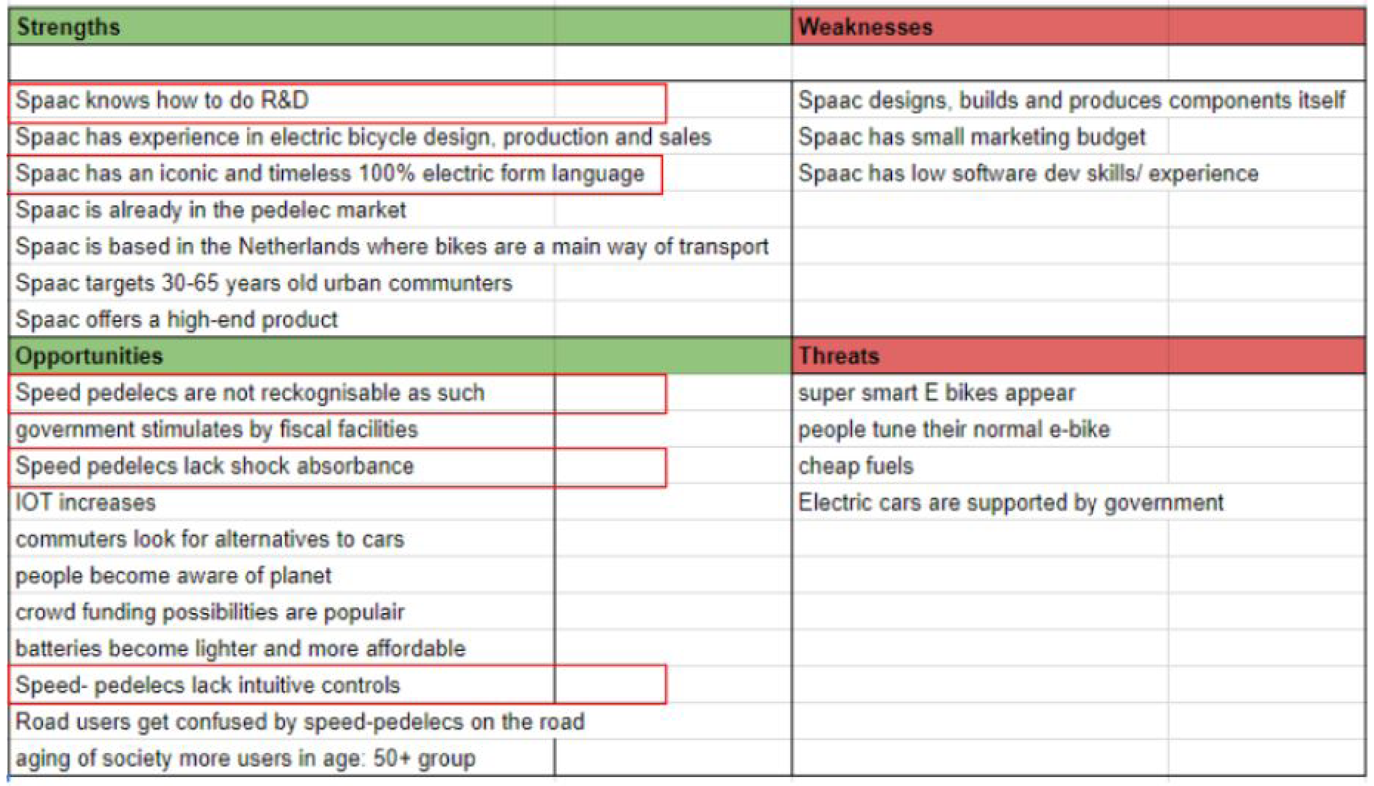
To create a high-speed-pedelec that improves the travel comfort of commuting per bicycle and increases the action radius of urban commuting cyclists.

Visibility options
- Front and rear lights need to be bigger, higher and further apart
- Recognizability of its speed by appearance (between regular bicycle and a moped), as the position of the suspension in figure xx below demonstrates.

Safety options
- Having oversight on the road, sitting upright, higher seating position
- Which ABS system to integrate, what are the details on wiring, energy and space

2.5.3 List of requirements

See page right.



Strengths	Weaknesses
Spaac knows how to do R&D	Spaac designs, builds and produces components itself
Spaac has experience in electric bicycle design, production and sales	Spaac has small marketing budget
Spaac has an iconic and timeless 100% electric form language	Spaac has low software dev skills/ experience
Spaac is already in the pedelec market	
Spaac is based in the Netherlands where bikes are a main way of transport	
Spaac targets 30-65 years old urban communters	
Spaac offers a high-end product	
Opportunities	**Threats**
Speed pedelecs are not reckognisable as such	super smart E bikes appear
government stimulates by fiscal facilities	people tune their normal e-bike
Speed pedelecs lack shock absorbance	cheap fuels
IOT increases	Electric cars are supported by government
commuters look for alternatives to cars	
people become aware of planet	
crowd funding possibilities are populair	
batteries become lighter and more affordable	
Speed- pedelecs lack intuitive controls	
Road users get confused by speed-pedelecs on the road	
aging of society more users in age: 50+ group	

Fig. 2.40
SWOT - Selling 100 safe and comfortable Spaac Super/Speed-Pedelecs in 2020. (author, 2018)

Performance
- 900-1000(O)W engine
- 80 Battery cells (18650 type) 1000Wh minimum
- Gear switching to keep pedal rate between 30 and 90 rpm while riding
- Drivetrain handlebars and frame must withstand impact of urban bike parking and bike tipping over
- Users p10-p95 Dutch male must be able to use bike comfortably (159-198cm)
- Bike must be strong enough to carry a Dutch P95 male adult (93Kg)
- Bike must last 5 years of normal day use in an urban environment
- Bike must last 50.000 km with original motor and drivetrain
- Bicycle must have a single or double standard for stable placing
- Battery must be dismountable for charging

Service
- Tires, wheels, seat, bars and accessories must be serviceable by a normal bicycle repairman
- Motor, power system and battery must be serviceable by spaac
- Broken parts must be replaceable

Use
- 2 x 45 Minutes driving
- Drive 60-70 km/h white pedaling 60 rpm
- Service once a year by Spaac service plan

Form
- Fit Spaac form language
- Fit form language appealing to user

Comfort
- 26 Inch wheels
- 4 Inch tires
- 5-8 cm Shock absorbance
- Suspension must be adjustable from stiff to flexible for driver in a few seconds
- Handlebars must be adjustable in height and forward position

Safety
- Lighting: amount of lumen
- Height to road surface
- Watertight IP15 parts and connectors moisture may not cause malfunction or oxidation
- Disc brakes will be fitted on both wheels
- ABS brakes will be fitted
- Vibrations of the use must not loosen screws, parts or even cause cracking in the frame

Dimensions
- Bike must not exceed 40 kg
- Bike must not be wider than 70cm
- Seat height must be adjustable from 55-74 cm
- Wheel base must be 120cm?Seat tube angle 60 degrees
- Stem angle 72 degrees
- Follow-up must be 4 cm
- Top tube length must be ...cm

Retail
- 6000 - 10000 euro
- Initial batch of product will be 50 pieces

Production
- The bike must fit spaac and it production facilities.
- A tubular frame will mainly be used with sharp bends and straight lines combined with metal plating and welded joints.

Optional requirements
- Integrated locking system
- Suspension adjustable from handlebars
- User is able to personalize some parts of the bike

3. PRODUCT DESIGN

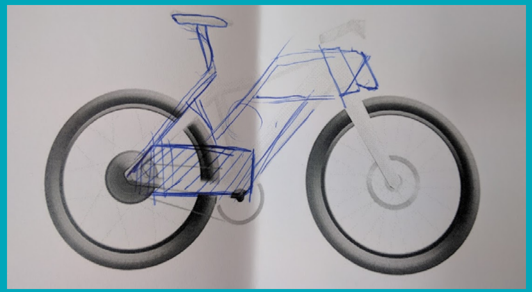
3 PRODUCT DESIGN

In this chapter the ideation and concepts will be discussed. Ideation guided loosely by the list of requirements and with the main goal of developing lots of differing idea's, the concepts and the final concept are more focussed towards a final feasible design and checked specifically to the list of requirements.

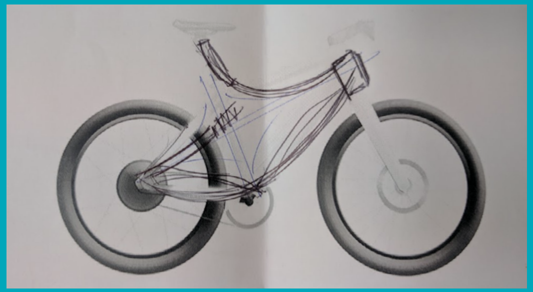
3.1 Ideation

The initial idea generation for the Spaac s7 started with a framework that contains the wheels, motor and a range image of where the handlebars and seat could be. The under layers were printed out and handed out to several participants to draw their impression of what a fast, comfortable and, safe urban commuting bike would look like. There was a big variety in the direction of the ideas, some thought about cargo, some about suspension, visibility and some about how to control the bike. The following sketches show side views of the bike or frame. These were subsequently used to develop the layout and placement of the different components.

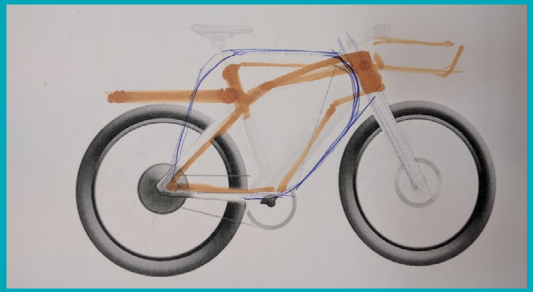
Fig. 3.1 - 3.4:
Sketches with different form language and shapes (author, 2018)



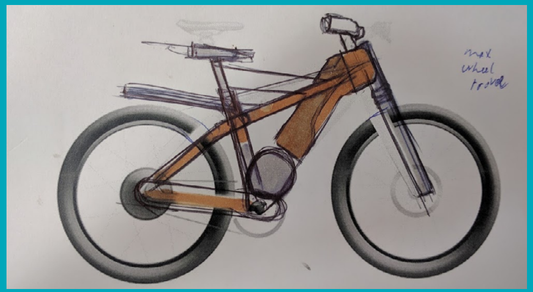
This frame was developed to create a more technical look. The bike loses the Spaac line and at the same time looks unnecessary complex. This might scare new drivers since is does not look friendly.



This frame concept was developed to see what a more softer look would do to the Spaac bikes. Already from the first sketches it becomes clear that the bikes lose the Spaac lines and look less serious.



This design was created to find the minimum and maximum lines for a skinny looking frame and a bulky looking frame, the final design of the bike has to fit somewhere in between.



This design was developed to have a strong and reliable look. Doing so, it lost some elegance needed for a real Spaac.

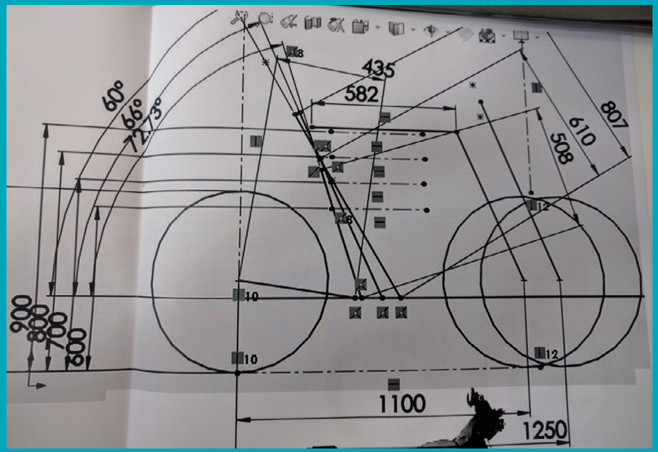
Dimensions and proportions
When detailing the ideas further into concepts, several Solidworks models were generated to set all the different proportions of the bike out. The model was later printed on A3 paper (Fig. 3.5) to have an under layer that allows further detailing. The different components that could possibly be used on the bike were also examined. Size, weight and shape gave an idea of the final shape of the bicycle. The wheel travel was also taken into consideration to create a frame that has enough space for the suspension. Inseam length (crotch height) is also added in the underlayer. Users can then test the developed designs on comfort.

Seating position
Before the idea generation, different seating positions were examined to get an overview on the different aspects. A recumbent bike (Fig. 3.6) is a great and innovative concept. Ergonomy and wind resistance are overall very positive. There are some negative sides that make the stance less suitable for the S7:

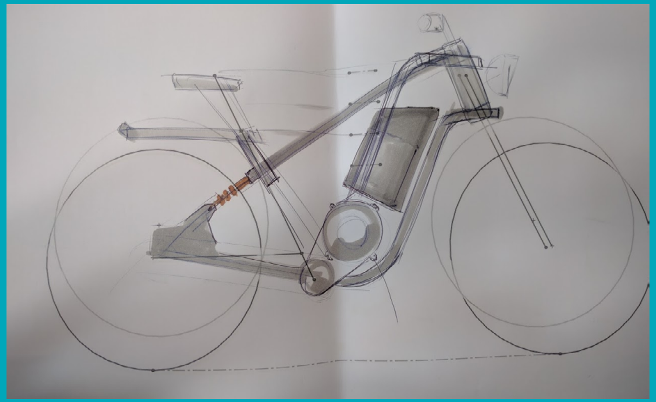
- Because of the lower seating posture, the user is less visible and has less oversight than the average bicycle with an upwards position.
- The recumbent bikes often have such a relaxed position that the pedals are raised from the ground. The rider has to reach further down for a stable standstill.
- The average pedelec rider is not easy to convince. Also the step to a recumbent bike is too big for the average Spaac rider.

Gears
This is the last stage before precise concepts, the motor here was designed to drive a separate gear mechanism, later on the choice was made to use the internal hub gears from nuvinci.

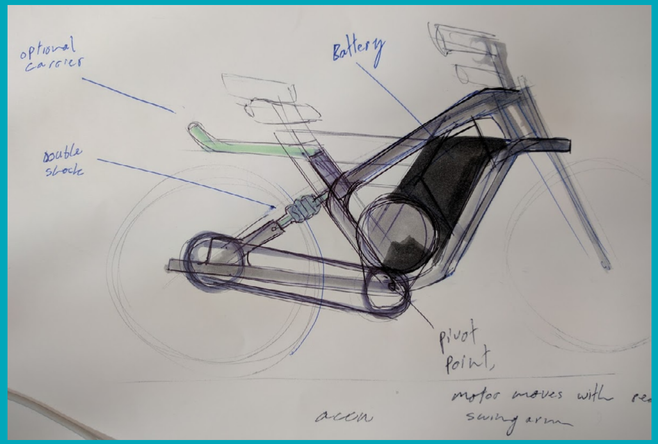
Fig. 3.5 - 3.7:
Different considerations for the design (author, 2018)



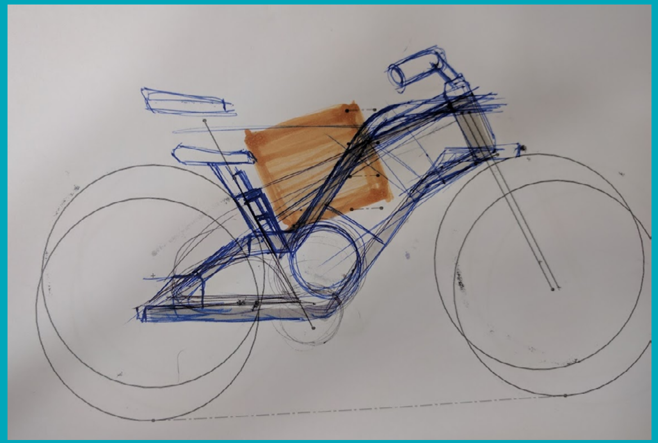
Variation of the dimensions and proportions from a SolidWorks model



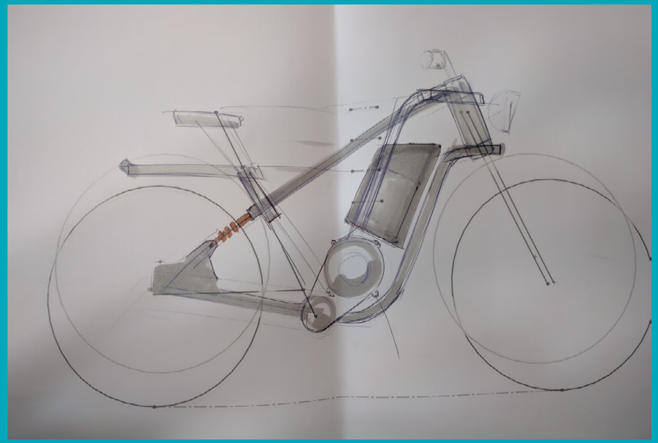
Bicycle with motor for a separate gear mechanism



The frame in this drawing has a more continuous shape, it is based on a single tube that bends around the complete bike.



The above frame is constructed with a double top tube, the design gave the option to insert a narrow bag in the frame.



A comfort model was created to enable easy access to the bike. The low step in makes the bike appear more female.

Towards the final concepts, the bike is reaching a more fine level of detailing. The bicycle on the right page (Fig. 3.8) was printed on paper (A3 size) to get the first details into place. From there a parametric model was set up in Solidworks. Information from suppliers is used to mock up parts, e.g., suspension suspension, belt drive, sprockets and motor, that fit in the bike. The battery consists of a certain amount of cells that were modelled in Solidworks to see the volume of different powerpacks. Three examples of different frame shapes that were designed in Solidworks are shown below (Figs. 3.11 - 3.13).

Left column, Fig. 3.8 - 3.10
different considerations for the design (author, 2018)

Above, Fig. 3.11 - 3.13
above: models of different frame design options (author, 2018)

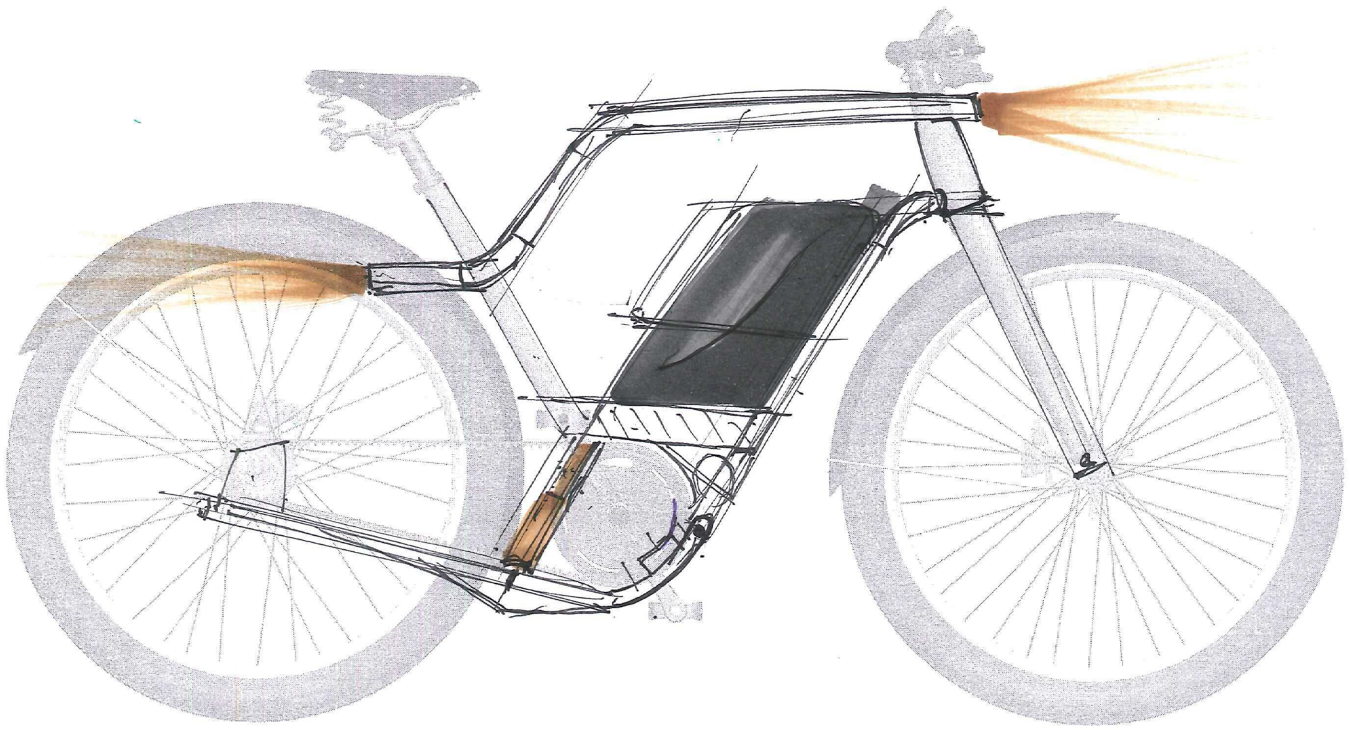


Fig. 3.14
first detailing to the design options (author, 2018)

3.2 Spaac form language

What is the Spaac form language?
The targeted customer for Spaac buys the bike for its minimal design, clear form and iconic shape. Interviews with the owners of Spaac and customers gave insights on the form language used by Spaac. Below are listed and visualised the design details that make a real Spaac.

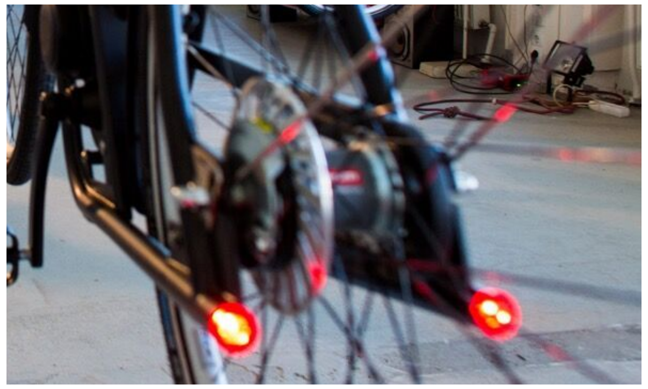
Frame lines:
- Tubular frame
- Straight lines
- Rounded curves in frame tubes
- Firm upper tube
- Mass vs Lines

Details of early 1900 bikes:
- Leather details for durable soft parts
- Air cooled engine details
- Double down tube that mimics exhaust pipes
- Multiple mounting screws for aluminium

Below, Fig. 3.15 - 3.16
Crank case of a Norton motorcycle (author, 2018),
Rear lights of the existing Spaac model (Spaac, 2016)

Right column, Fig. 3.17 - 3.21
form language elements

Page right, Fig. 3.22
collage highlighting the typical Spaac form language (author, 2018)




Clean look, parralel lines


Closed shapes
vs thin straight lines and
continuous curves

Double downtube contains
front and rear lights

Inspiration from early
1900's motorcylces


Details and overall design show
reltion to old motorcycles

3.3 Conceptualisation

Before the concept phase, several detailed designs of the frame have been made to get an idea of the possible shapes and sizes, this enabled the concepts to be created with the optimal design.

The most important elements in this Design process are the shape of the frame and the working principle of the suspension.

Many different shapes are possible for the frame of the new bike. It is important to make the connection with the current Spaac S5 and the iconic double frame tube.

For the rear suspension three different types can be distinguished:

- Mono suspension behind the motor
- Single suspension between the seat tube and rear wheel
- Double suspension

Double top tube frames

In this paragraph the exploration of frames with a double top tube are explained, it is a search for frame shapes that could create the Spaac S7.

The first Design created is a bike suspension on either side. The suspension represents the type of suspension that was used on older motorcycles and mopeds, also the shape allows the bike to have a continuous line in the design that represents the form language.

The double frame tube is now moved to the top tube. The first finding is that the combination of the double tube and a continuing front fork causes the 2 parts to touch when steering furthest to the left of right (Fig. 3.24).

After some fiddling with the lines the idea is discarded because it does not provide the strong look Spaac is after. Also the attachment from the single frame tube to the big battery provides difficulties to incorporate in a smooth design. The double down tube has more visual resemblance with early 1900's motorcycles that represent Spaac.

Fig. 3.23:
1885 Whippet safety bicycle (Wikipedia, 2009)

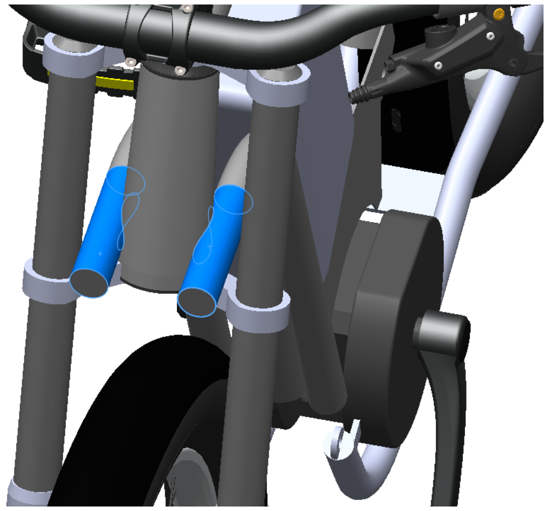
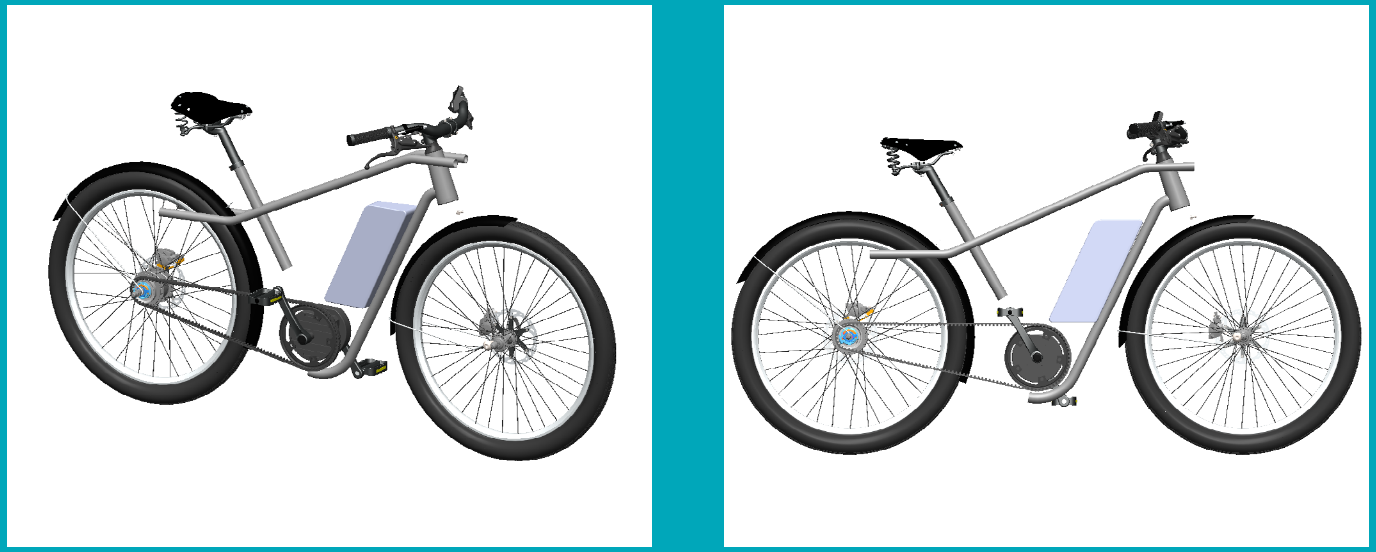


Fig. 3.24:
The blue parts are touching the front fork. In future designs this is first solved with indents but, later on in the process the two frame tubes meet just before the head tube. (author, 2018)

Page right, Fig. 3.25 - 3.28
frame shape explorations (author, 2018)

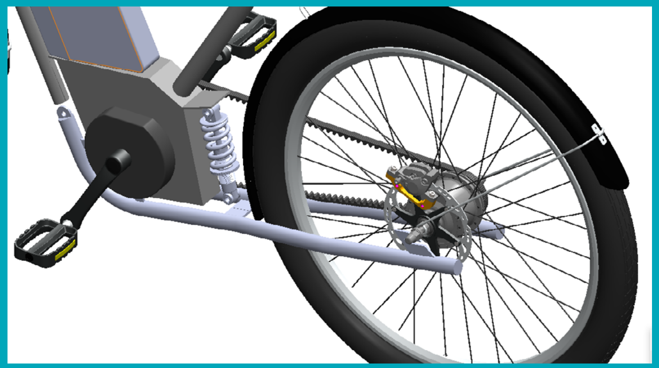
Double top tube in sport model



Double top tube in comfort model

Concept 1
Mono suspension behind the motor

The double bottom tube represents the Spaac line that we see in the S5. The suspension is "hidden" in the lower part of the frame and therefore provides an overall cleaner look. The system requires a stronger rear shock absorber. The spring is not directly adjustable by hand, adjusting system via the handlebar is required. The system is interesting to combine with a belt drive since the belt can run above the wing arm assembly without having to remove parts of the shock assembly to place the belt. In this concept there is chosen for a front fork that stops at the bottom crown plate. In other concepts a longer fork is chosen to improve visibility



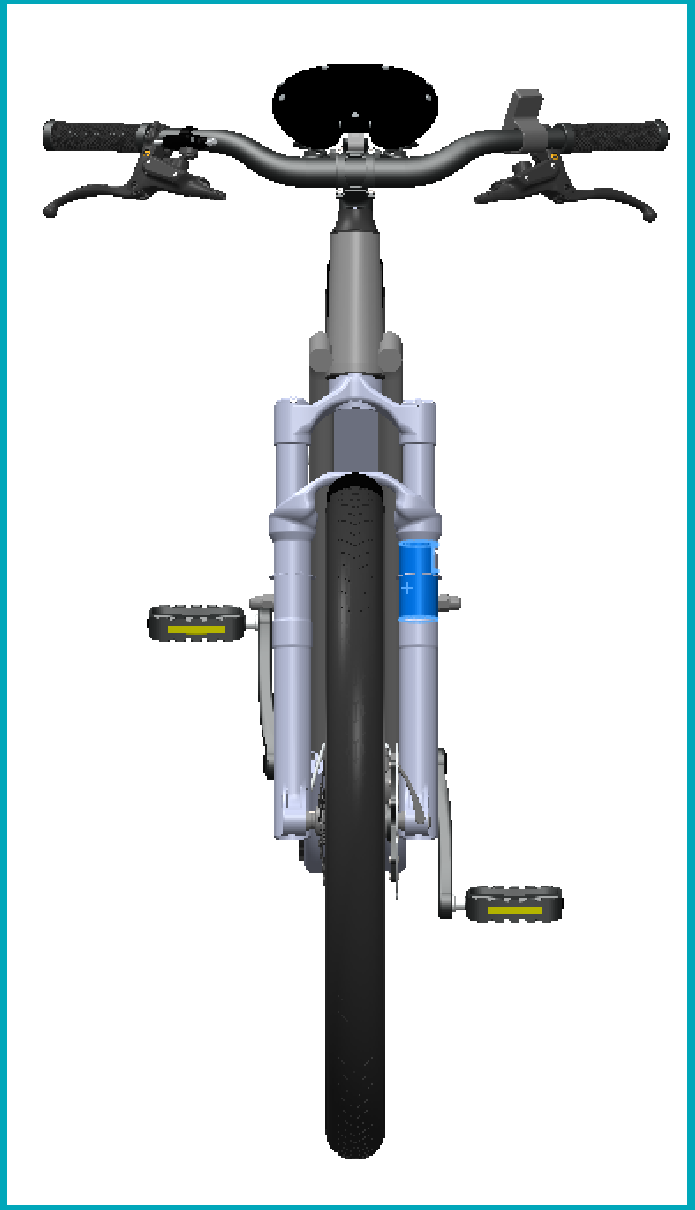


Fig. 3.29 - 3.34
images of concept elements (author, 2018)

Concept 2

Single suspension between the seat tube and rear wheel

The concept created here is evolved to keep the looks a similar as possible to the current Spaac bikes. It results from users that have a strong connection with the Spaac S5 because of the current lines of the bike. The bike has a shorter spring because there is less space between the seat tube and the wheel. There is the possibility to overcome this with a different placed spring as seen in Concept 2 the damper for the suspension is well reachable for the user but has less freedom, the maximum suspension on the rear wheel will be about 4-5 centimeters more suspension travel could be created by placing the swing point closer to the shock, for instance behind the motor.

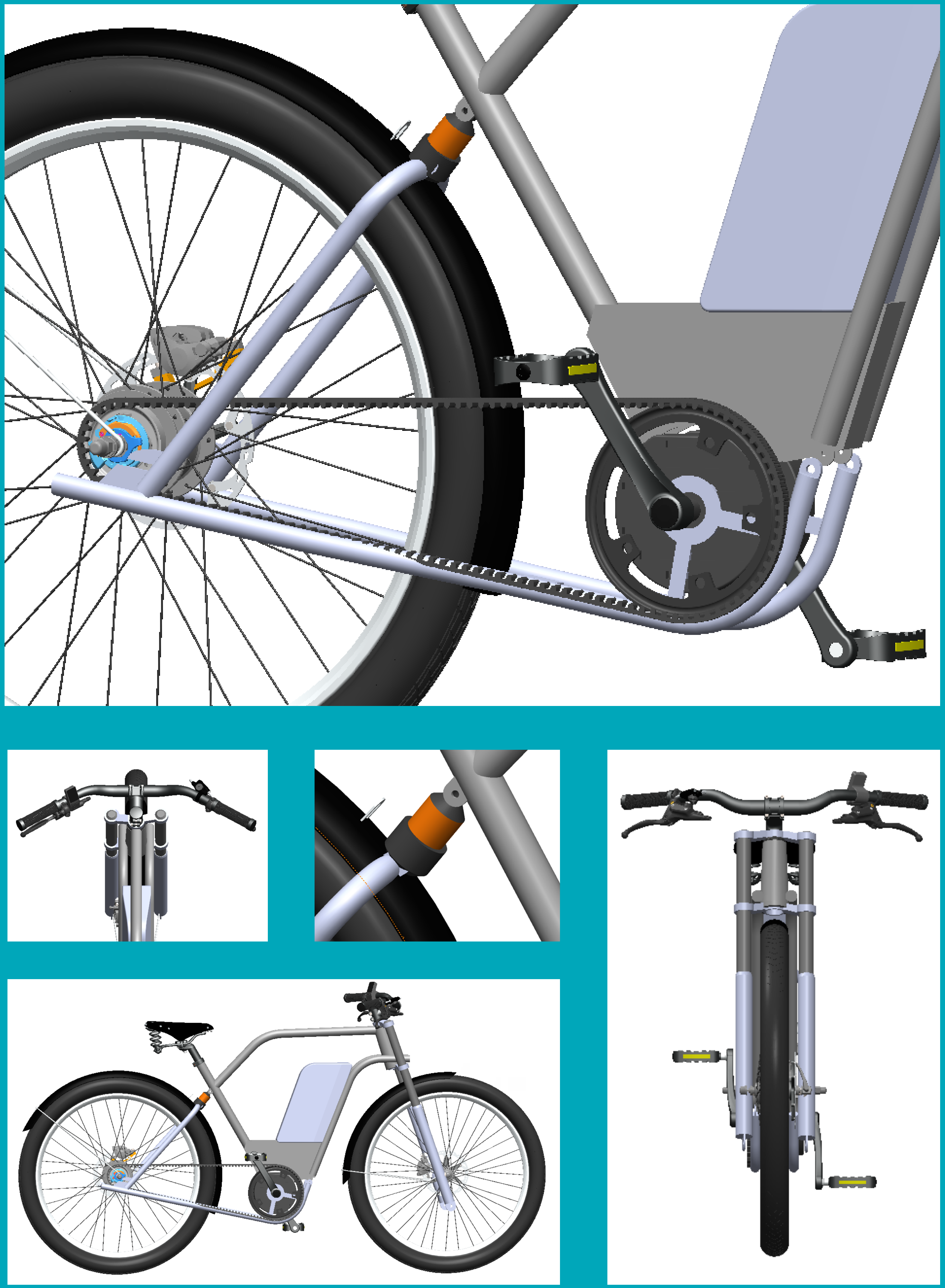


Fig. 3.35 - 3.39
images of concept elements (author, 2018)

Concept 3

Double suspension

The concept with double suspension is directly inspired by the lay out of older motorcycles and mopeds, it enables easy adjustability on the shocks

Fig. 3.40 - 3.43
images of concept elements (author, 2018)

3.4 Concept selection

Criteriteria	Weight 1-3	Concept 1 Single low shock Score 1-5	Concept 2 Single high shock score 1-5	Concept 3 Double shocks Score 1-5
Design fits spaac's from family	3	**2** * 3 = 6	**4** * 3 = 12	**5** * 3 = 15
Aesthetics appeal to user	3	**2** * 3 = 6	**3** * 3 = 9	**3** * 3 = 9
User can adjust shocks easily	3	**1** * 3 = 3	**4** * 3 = 12	**5** * 3 = 15
Cost estimation	2	**3** * 2 = 6	**3** * 2 = 6	**2** * 2 = 4
Production complexity	2	**2** * 2 = 4	**4** * 2 = 8	**4** * 2 = 8
Design complexity	2	**2** * 2 = 2	**4** * 2 = 8	**4** * 2 = 8
Weight of the system	1	**3** * 1 = 3	**3** * 1 = 3	**2** * 1 + 2
Total score including weight		30	58	61

Fig. 3.44
Weight criteria values for the three concepts (author, 2018)

Criteria topics

Looks of the bike
- Represents Spaac
- Fits the users expectation

Use
- Shocks provide enough comfort
- Shocks easily adjustable

Retail price
- Competitive with same category bicycles

Production
- Complexity attachment
- Fits Spaac's production facilities
- Assembly time

Fig. 3.45
Form study sketch for concept 1 (author, 2018)

4. DETAILING

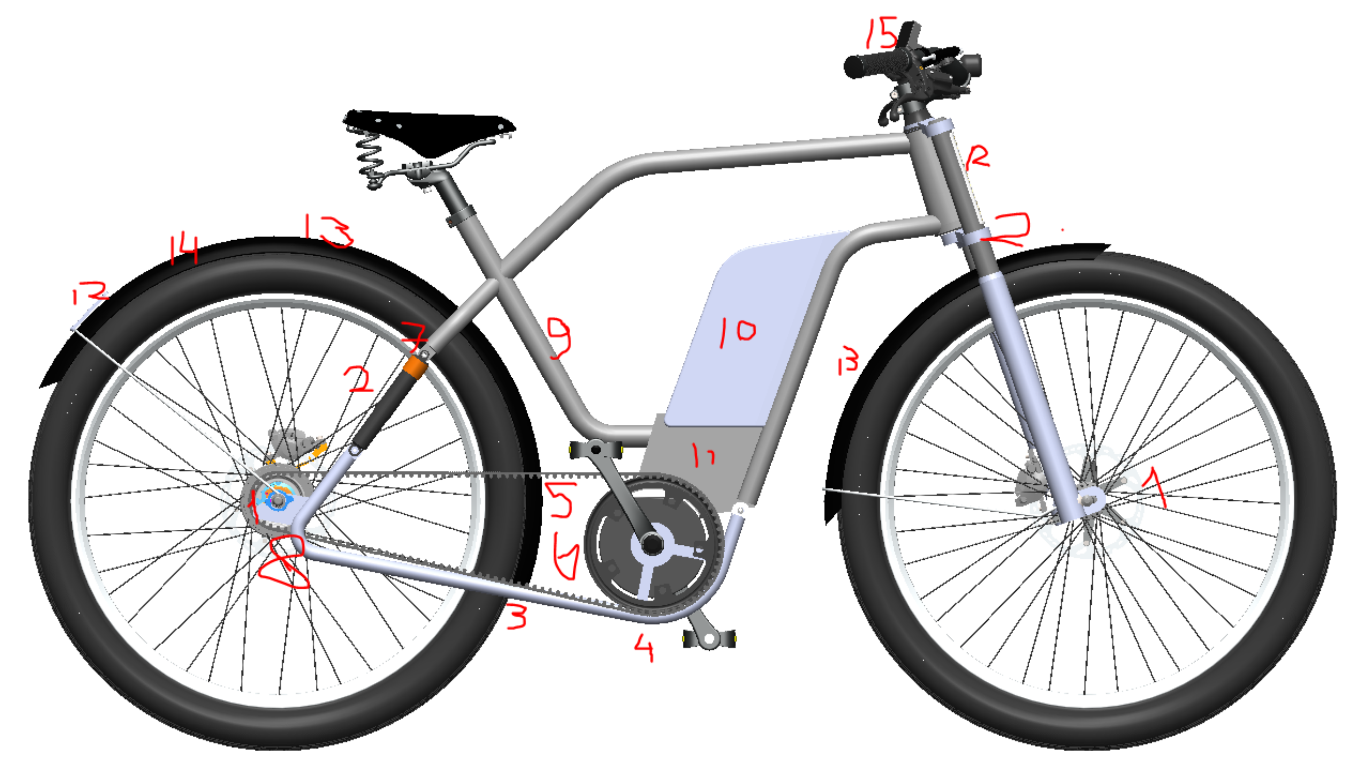
4 DETAILING

To create a detailed design, all the different parts of the bike need to be analysed further. The following parts will be discussed in this Chapter.

1. Brakes
2. Suspension
3. Swingarm
4. Motor and mounting
5. Belt and gears, attachment and installing
6. Tensioning the belt
7. Attachment of spring/dampers to the frame
8. Rear wheel attachment
9. Optimising geometry of the swing arm and pivot points.
10. Battery
11. Electronic compartment of motor management
12. Lights
13. Fenders and mudguard attachment

Below, Fig. 4.1

numbered parts of the design (author, 2018)



4.0 Dimensions of the bike

The detailed design specifications are:
- Wheelbase 1.20 meter
- Wheel size 24 inch
- Tire thickness 4 inch
- Tire type schwalbe big ben

Posture of rider translated to frame dimensions
- Seat height 60 Degees upwards, from crank)
- Handlebars position (in x-y position from crank

Integration of these components is required:
- Direction indicators, brake light and normal front and rear lighting.
- Lights will always be on to optimise visual appearance
- at least 1 rear view mirror
- Integrate ABS system
- Integrate class 1 disc brakes

4.1 Optimising the geometry of the swingarm and pivot points

To optimise the rear suspension, the desired behaviour is analyzed and designed with the modeling program “Bike Checker” (see the below picture). Also an analysis of desired road behaviour translated to the spring type should be shown here.

The first set up of the bike shows that the pivot point are not in a line perpendicular to the shock absorber.

Fig. x:

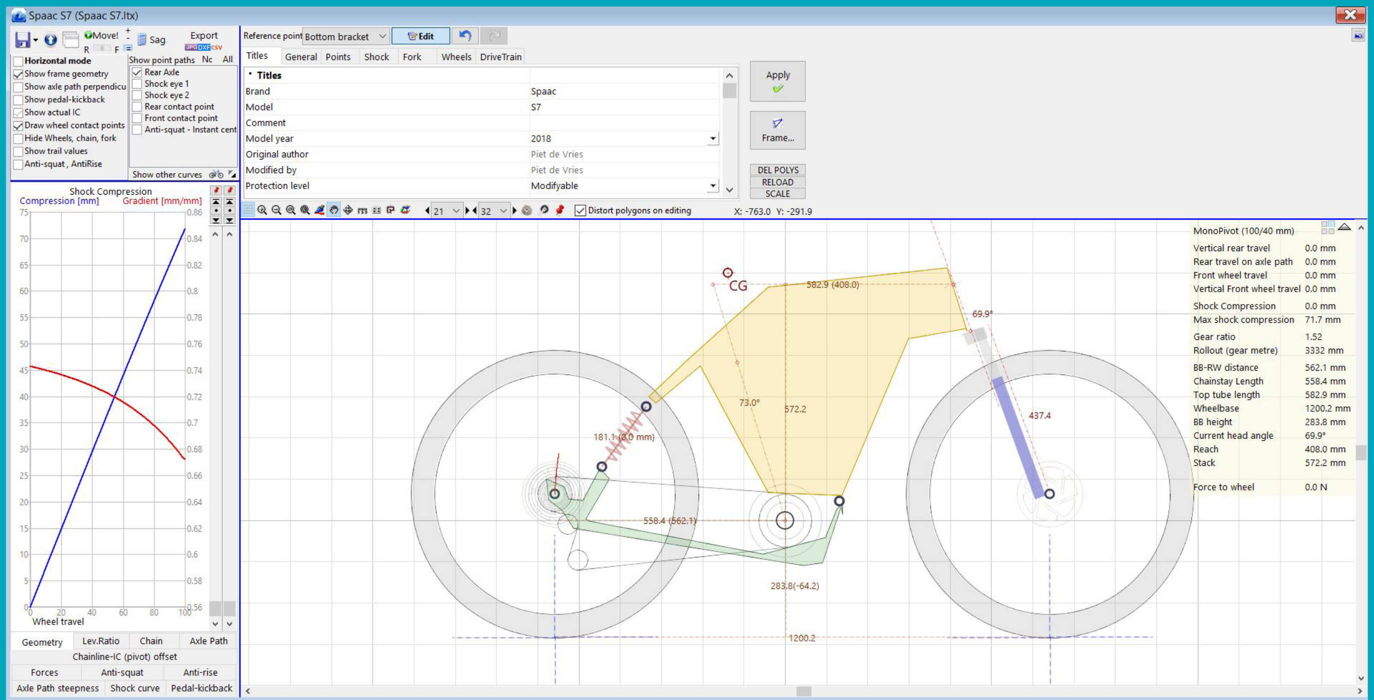
links en rechts om 10000 keer belasten met iemand van 100kg

4.2 Suspension

Rear suspension
The rear suspension of the Spaac S7 needs to add comfort to the user. It also needs to fit the form language of Spaac. The exact layout of the suspension-points in combination with the exact selection of a spring/damper system will determine the damping characteristics. The optimal characteristics were found from a suspension analysis that was made for the bike's geometry and, certain combinations of speed and road surfaces. The output of the model (from BikeChecker.com) was compared to data on which vibrations and accelerations are experienced as uncomfortable.
Also certain eigen frequencies can be found where the suspension resonates. This should be avoided. Cycling in certain pedalling rates (cadence) might cause the bike to bounce on the natural frequency. Some speed pedelecs have these resonating frequencies between 120 and 180 Hz (60 - 90 RPM).

Front suspension
Head tube: trend on bigger head tubes.
Pick the right front fork, look at wheel travel and damping

Fig. x:
model for validation


Spaac S7 (Spaac S7.ltx)

☐ Horizontal mode
☑ Show frame geometry
☐ Show axle path perpendicu
☐ Show pedal-kickback
☑ Show actual IC
☑ Draw wheel contact points
☐ Hide Wheels, chain, fork
☐ Show trail values
☐ Anti-squat , AntiRise

Show point paths
☑ Rear Axle
☐ Shock eye 1
☐ Shock eye 2
☐ Rear contact point
☐ Front contact point
☐ Anti-squat - Instant cent

Reference point: Bottom bracket

Titles
Brand: Spaac
Model: S7
Comment:
Model year: 2018
Original author: Piet de Vries
Modified by: Piet de Vries
Protection level: Modifyable

☑ Distort polygons on editing
X: -763.0 Y: -291.9

MonoPivot (100/40 mm)
Vertical rear travel: 0.0 mm
Rear travel on axle path: 0.0 mm
Front wheel travel: 0.0 mm
Vertical Front wheel travel: 0.0 mm
Shock Compression: 0.0 mm
Max shock compression: 71.7 mm
Gear ratio: 1.52
Rollout (gear metre): 3332 mm
BB-RW distance: 562.1 mm
Chainstay Length: 558.4 mm
Top tube length: 582.9 mm
Wheelbase: 1200.2 mm
BB height: 283.8 mm
Current head angle: 69.9°
Reach: 408.0 mm
Stack: 572.2 mm
Force to wheel: 0.0 N

4.3 Swingarm design

The design of the swingarm starts with the predefined measurements that are part of the geometry of the bike: the length, the location of the pivot points, the location of the dropouts for the rear wheel and the attachments for certain parts like the motor mounts and brakes.
The swingarm's main function is to enable the rear wheel to travel in an almost vertical direction while the wheel remains straight. Also the sideways travel must be minimised.
In Chapter 5 some tests will be conducted on the newly designed swingarm assembly to determine the tolerances and flex in the materials.
Initial testing shows that most rear wheels have some millimeters play when pulled sideways. The end of the swing arm where the wheel is connected can also be pulled sideways with predefined forces, this will be done in Chapter 5 to test the clearance and stiffness of other speed pedelecs with shocks.

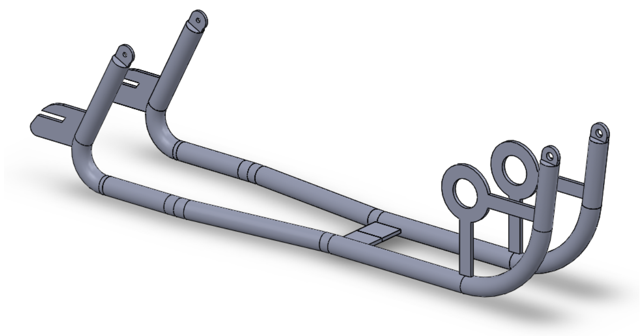


Fig. x:
Swingarm design

Fig. x:
Swingarm dimensions

4.4 Motor and mounting

As specified before the motor used in the Spaac S7 is the TQ-Drives 120S Race. The motor delivers 920 Watt and 120 Newton meter of torque (TQ-Drives 2018). This means that with a front sprocket of 20 cm the force exerted by the motor on the belt could reach up to 1200N of force.

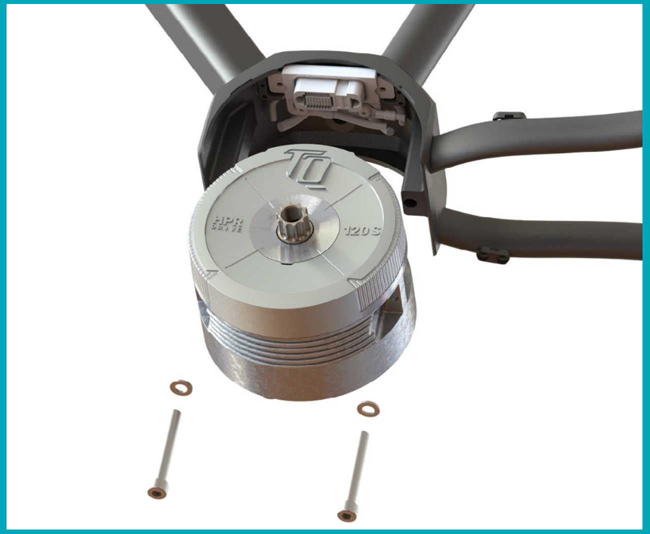
The motor is designed to be attached with 2 bolts on a mounting bracket, the bracket is located at the top of the motor as shown in the top two pictures in the right column.

The diameter of the motor is 144 mm which is smaller than an average front sprocket.

4.5 Belt and gears, attachment and installing

The belt used in this project is not separable like a chain. Many bikes have the chainstay running through the belt. But, this provides difficulties for the assembly. This problem is solved by running the chainstay bracket (part of the swing arm) below the belt (see image below).

The gears of the S7 are located in the Nuvinchi hub, an electronic stepless shifting system is installed so the rider only selects the cadence and the bike does the shifting.
Certain things have to be taken into account when designing all the details around the drive mechanism. The rear wheel must be removable by any bike shop when the bike has a flat tire. Also when the bike is assembled, there may not be plates or rings that can be swapped or installed the wrong way around.



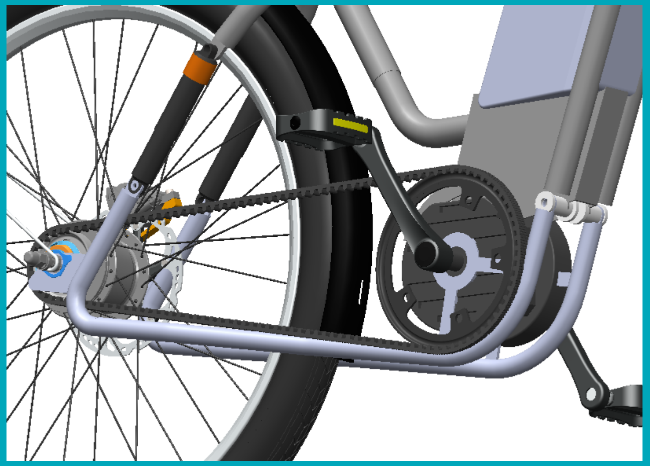


Fig. x:
top two: Motor and attachment of motor in frame

bottom two: Chain and chainstay bracket, gear position

4.6 Tensioning the belt

Most swingarm type vehicles have the motor mounted to the frame of the bike and the rear wheel attached to the swing arm. This often creates a variable distance between the motor and rear wheel when the swing arm moves up and down. Most designs compensate this with a chain or belt tensioning wheel.
Here the idea is to make a different design by attaching the motor to the swing arm. With this configuration the distance will be kept equal in any swingarm position.

The belt needs to be tensioned. The goal is to achieve this by moving or even tilting the motor slightly forward. This will increase the distance between the motor-axle and rear wheel-axle.

4.7 Attachment of Swingarm to the frame

The point where the swingarm pivots is often referred to as “the rocker”. The rocker always contains a double bearing that prevents the swingarm from having any sideway movement, instead, it allows the swing arm to swing around the pivot point mainly to let the wheel move up and down when riding over bumps. Budget suspension bicycles often have sliding bearings made out of harder plastics like PTFE or PVC. [Materials science and engineering boek]. These types of pivot points are more sensitive for wear and often have more play then pivot points that contain a good ball bearing. Most mopeds, motorcycles and mountain bikes have a set of ball bearings.

To make an estimation on what kind of bearing to use, the Santa cruz heckler is investigated, It is a top selling mountain bike by santa cruz, that is known for its off road capabilities and robustness. It has a lot of resemblance with the spaac S7 since the rear suspension has 1 pivot point and the shock absorber(s) mounted directly between frame and swingarm as seen in picture xx on the right.

The 2 bearings used in the heckler are deep groove ball bearing type R8-2RS Bearing 1/2”x1 1/8”x5/16” (12,7x28,6x7.9mm) (outer x inner x with)

Fig. x:
Bearings with rubber sealer

The bearings have a rubber sealer that makes sure no dirt can come in, the sealing of the bearing is very important, since the bearings are not even used close to the limits of their application, it is mainly dirt breaking the seal and damaging the inner workings to cause a bearing failure.

For the Spaac S7 we chose the SKF 2200-ETN9 bearing, it is selected from the SKF bearing catalogue for its size, (10x30x14mm) thick rubber seal and load resistance, the basic static load rating of this bearing is 1.8KN, which is well over the maximum force it might while driving over an obstacle.
The bearings are pressed in the frame with a press fit, the bearings are dimensioned 0.2% larger than the hole they fit in, this is enough pressure to let the bearing stay in place, yet not compressing the bearing so much it might damage.

The exact damper is not chosen yet. Most damper systems are attached by a simple lock pin or bolt. From an assembly point of view it is a logical choice to maintain the lock bolt there.

Fig. x:
Santa Cruz Heckler, with a detail of the mono swingarm (Heckler, 2018)

4.8 Rear wheel attachment

To keep the belt tensioned, there are 3 logical option:
1. Move the motor forward or backward
2. Use an adjustable belt tensioner
3. Move the rear wheel forward or backward to tension the belt.

The last option is chosen, below the advantages and workings are explained.

The rear wheel is mounted on 2 plates on either side of the wheel. These plates are called the dropout plates. They have a vertical slot that enables the wheel to slide in to place, it allows simple removal of the wheel in case of a flat tire. The bottom brackets also have the function of tensioning the belt, That happens by moving the complete plate and wheel assembly rearwards. The brake calipers are attached to the dropout plates, which ensures they are always grab the brake discs in the right place regardless if the wheel is in the most front or rear position. One of the biggest advantages is that the rear plates can easily be

Fig. x:
top and middle: "Butchers and bicycles" dropout (E-biketips.com, 2018)

bottom: Rieser muller nuevo belt tensioning mechanism (Rieser Muller, 2018)

4.9 Brakes

As described in the analyses the Spaac S5 will be fitted with ABS disc brakes. There are certain companies that deliver these brakes:
- Bosch has an ABS system, the pump is rather large but with the right design decision the pump can be fitted near the electronic compartment.
- Blu brakes is a small company in Italy that created an ABS system where the pump can be hidden in, for example, one of the frame tubes.
- Break Force One is a German company that also created an ABS system, they also have a small pump that can be integrated in the frame.

To make a decision between these brands and systems a deeper analyses was done on the working, size, reliability and price (ref: Appendix). Bosch might have a somewhat bigger system that is supposed to hang on the handlebars but in return they add a lot of reliability but it does not fit the spaac form family

Fig. x:
Bosch breaking system

4.10 Battery and location

The battery housing is attached to the frame that protects it in the urban environment. The size of the battery is depending on the amount of power cells that are used. The list of requirements specifies that ...kWh power is needed to have enough range. The cells are usually clustered in packs of 8 or 10 which are then stacked on top of each other and linked to the battery's power supply. The location satisfies the Spaac form language.

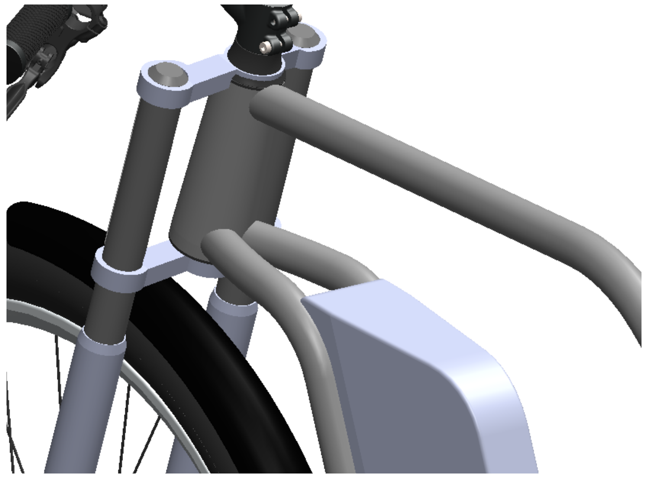


Fig. x:
Positioning of battery and electronic compartment.

4.11 Electronic compartment of motor management

The electronic system in the S7 is needs a protected place against rain or other forms of moist that post a thread during the use. Also the ABS systems has a pump that could be housed in the same compartment below the battery. The compartment must satisfy the IP15 waterproof norm. So, rubber connectors and sealing strips are needed.

4.12 Lights

A design is made to show what Spaac lighting could look like. However, for the first production cycle of the S7 it is recommended by Spaac to use standard lights to save time and therefore money in an effort to create the whole system inhouse. Also standard lights can be incorporated in the design, e.g., the lights of the S5 show the endpoints of the frame tubes.

Fig. x:
top two: Curana lights embedded in fenders (Curana, 2018)

bottom two: Blinkers on the end of the handlebars (Winglights, 2018 and Motorgadgets, 2018)

4.13 Fenders and mudguard

The fenders on the Spaac S7 are needed to keep rain and road debris away from the user. Research with current users showed that a lot of speed pedelecs lack this feature. The fenders will be located close to the tires to perform best.

Fig. x:
Stem tube

Fig. x:
Handle bars

5. TESTING

5 TESTING

Because the Spaac S7 can go faster than 45 km/hr it is required by law to do special strength tests in a lab. The safety norms as defined in DIN EN 15194:2009 and ASTM F2711-08 (a standard [5] for horizontal fatigue testing) are for pedelecs that are not allowed to go faster than 45 km/h. Passing these test successfully leads to a type approval. In this Chapter some of these tests will be simulated in a computer model (SolidWorks) where several extreme loads will be applied to the modelled S7.

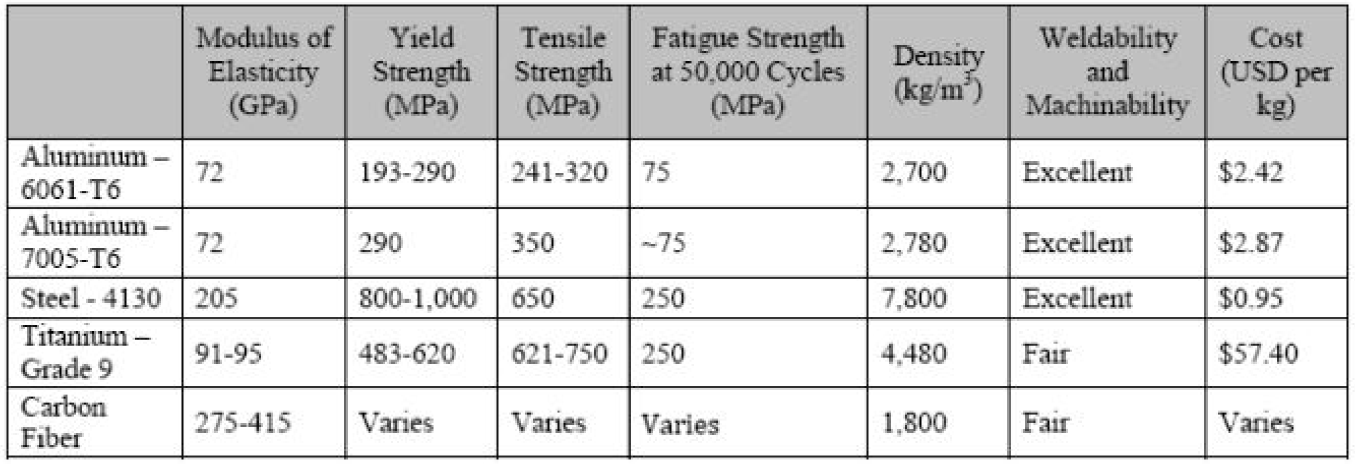
Since the S7 has three springs and a pivot point it is important to check (test) the geometry due to maximum wheel and/or sadde movements. Also these tests will be done with the aid of a computer model (Linkage X3).

It is also important to test the new design by potential buyers and to find out if they enjoy the design, is there a feeling if uniqueness and, is there a good comfort and safety feeling.

5.1 Stiffness, strength and fatigue

The aluminium 6061-T6 is often used for bicycles, see the below Table (Fig. 5.1) for a comparison with other materials (costs were in 2012).

The table shows that aluminium is more susceptible to fatigue failure than steel, titanium or, carbon. This might become an issue for mountain bikes (F. Dwyer, A. Shaw, and R. Tombarelli, 2012) but, should not be a problem for speed pedelecs. The Spaac S7 can therefore be made of aluminium.
Bossenbroek (2016) studied the consequences for his e-bike due to extreme load situations. As an example he refers to speeding on to a curb “these are relatively infrequent, but far more severe than normal loads in pedaling”. The strength of the S7 can be investigated in a computer by doing Finite Element Modeling (FEM) in SolidWorks, i.e., stresses and strains are calculated due to different loadings. Different materials have different maximum allowable stresses (see the above Table). The FEM results due to extreme loadings are a good guidance for selecting the optimal materials (computed stresses may not exceed the yield strengths of the materials) and thickness of the tubes. These results might also lead to small design changes, especially at some joints.



	Modulus of Elasticity (GPa)	Yield Strength (MPa)	Tensile Strength (MPa)	Fatigue Strength at 50,000 Cycles (MPa)	Density (kg/m^3)	Weldability and Machinability	Cost (USD per kg)
Aluminum – 6061-T6	72	193-290	241-320	75	2,700	Excellent	$2.42
Aluminum – 7005-T6	72	290	350	~75	2,780	Excellent	$2.87
Steel - 4130	205	800-1,000	650	250	7,800	Excellent	$0.95
Titanium – Grade 9	91-95	483-620	621-750	250	4,480	Fair	$57.40
Carbon Fiber	275-415	Varies	Varies	Varies	1,800	Fair	Varies

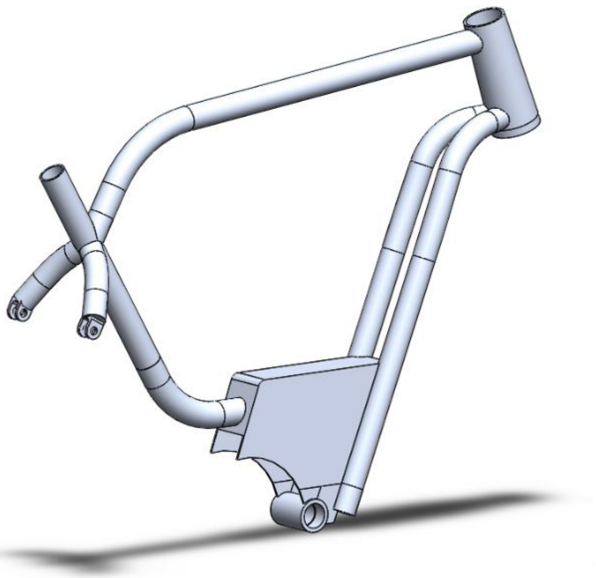
Fig. 5.1:
Aluminum characteristics (

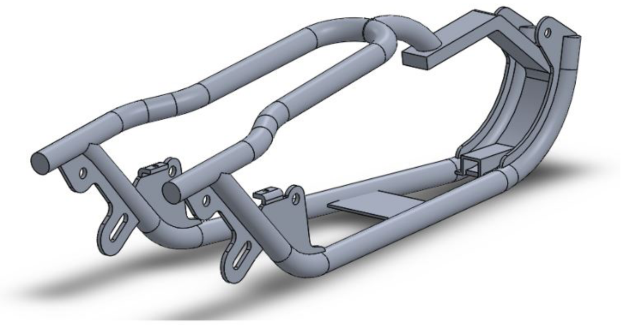
Bossenbroek (2016) also analysed how to prevent fatigue “most bicycle failures occur because of fatigue issues. Fatigue behaviour largely defines bicycle durability and is caused by repeated stress variations that create small cracks which grow larger with each cycle”. Bicycle durability is a very important aspect of the S7 as this e-bike is very expensive. As fatigue is difficult to test via computer modeling Bossenbroek (2016) proposes to test fatigue of the bicycle in a lab by applying 100.000 load cycles. However Dwyer et al. Dwyer et al. (2012) describe lab test results that are in reasonable agreement with their FEM modeling. They applied horizontal forces of 600, 1200, and 1500 N to the fork and measured and modeled a maximum strain of 1.2 millistrain. Cracks were developing at the head tube after approximately 450.000 load cycles. The applied forces are representative for mountain bikes but, are too high for a speed pedelec. Therefore it can be concluded that a speed pedelec made of aluminium can withstand much more than 450.000 load cycles before fatigue results into crack development. In Dwyer (Fig. 28) an exponential relation is shown that demonstrates that if the load is reduced by 50% the number of cycles can be multiplied by 100.000 before a crack develops. As the impact of a sudden failure is very high when riding 75 km/h it is recommended to do load cycling testing on the Spaac S7.

Following Bossenbroek (2016), Maestrelli and Falsini (2008) and, Covill (2014) the stiffness of the Spaac S7 aluminium swingarm and frame will be analyzed for the following loads:

1. a vertical load at the saddle of 2400 N (this is related to comfort) ,
2. weight move as a consequence of de-accelerating or accelerating (braking may not bend the head tube and accelerating may not bend the frame (dynamics in the longitudinal direction),
3. steering (the head tube will twist due to forces on the front fork; related to safety) and,
4. pedaling (vertical forces on the pedals should result in forward motion and not to a deformation of the frame; related to speed).

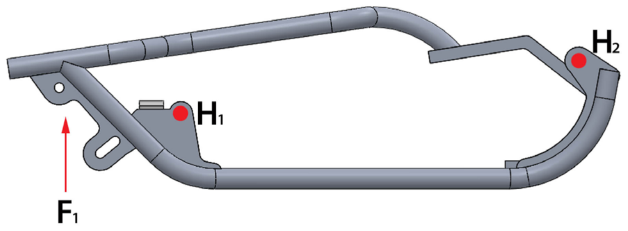
The deformation of the S7 due to the above loads depends to a large extend on the rear and front suspension as well as the location of the pivot point. For cycling with a high speed it is important to make optimally use of the human energy but, since the S7 is an e-bike there is no requirement to have a very stiff frame.



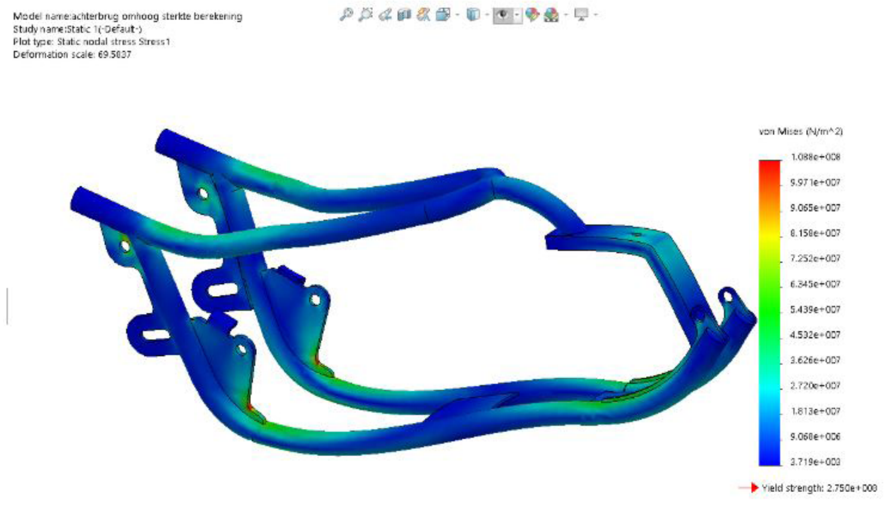


Load case 1: saddle weight

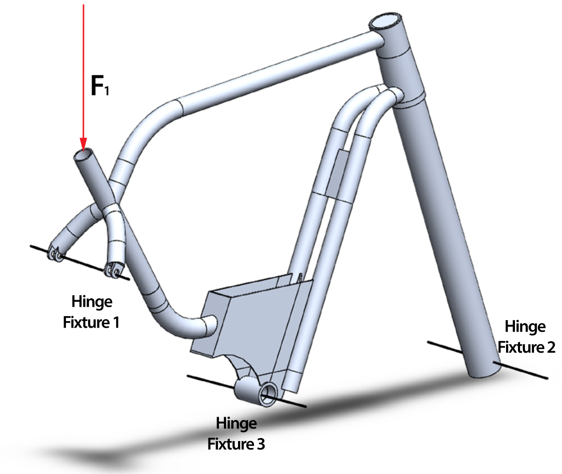
Load on saddle 2400N vertical. This is split in 50% at the rear wheel and 50% at the front fork. Results are shown in the right column for the swingarm, F1 denotes 1200N upwards due to a bump. H1 and H2 are fixed hinges.



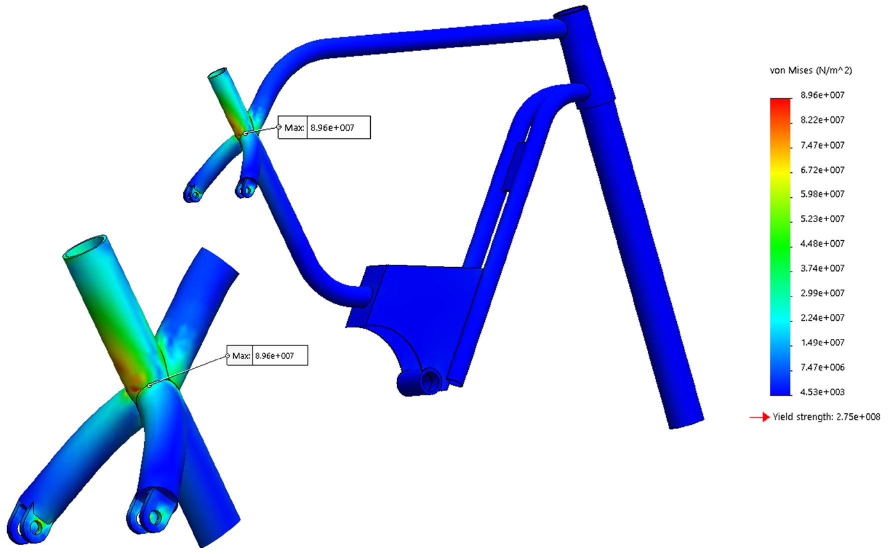
It is seen from the figure that the maximum Von Misses stress is 109 MPa which is well below the yield strength of 275 MPa.


Model name:achterbrug omhoog sterkte berekening
Study name:Static 1(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 69.5837

Results are shown below for the Von Misses stresses on the frame due to the same vertical load of 2400N on the saddle (F1). There are three fixed hinges (see figure right).

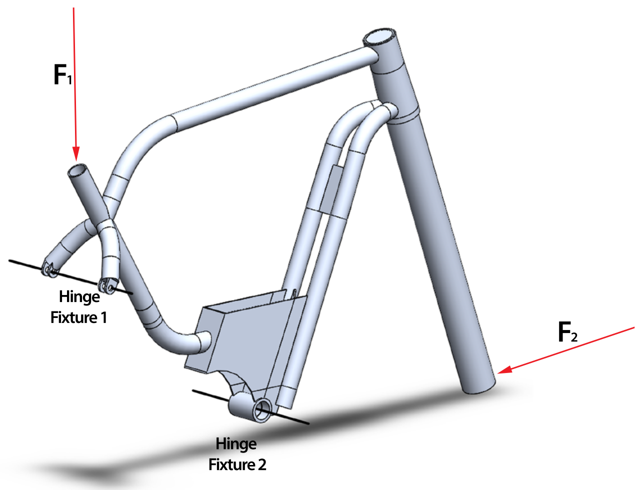


It is seen from the figure below that the maximum Von Mises stress is 90 MPa which is well below the yield strength of 275 MPa.

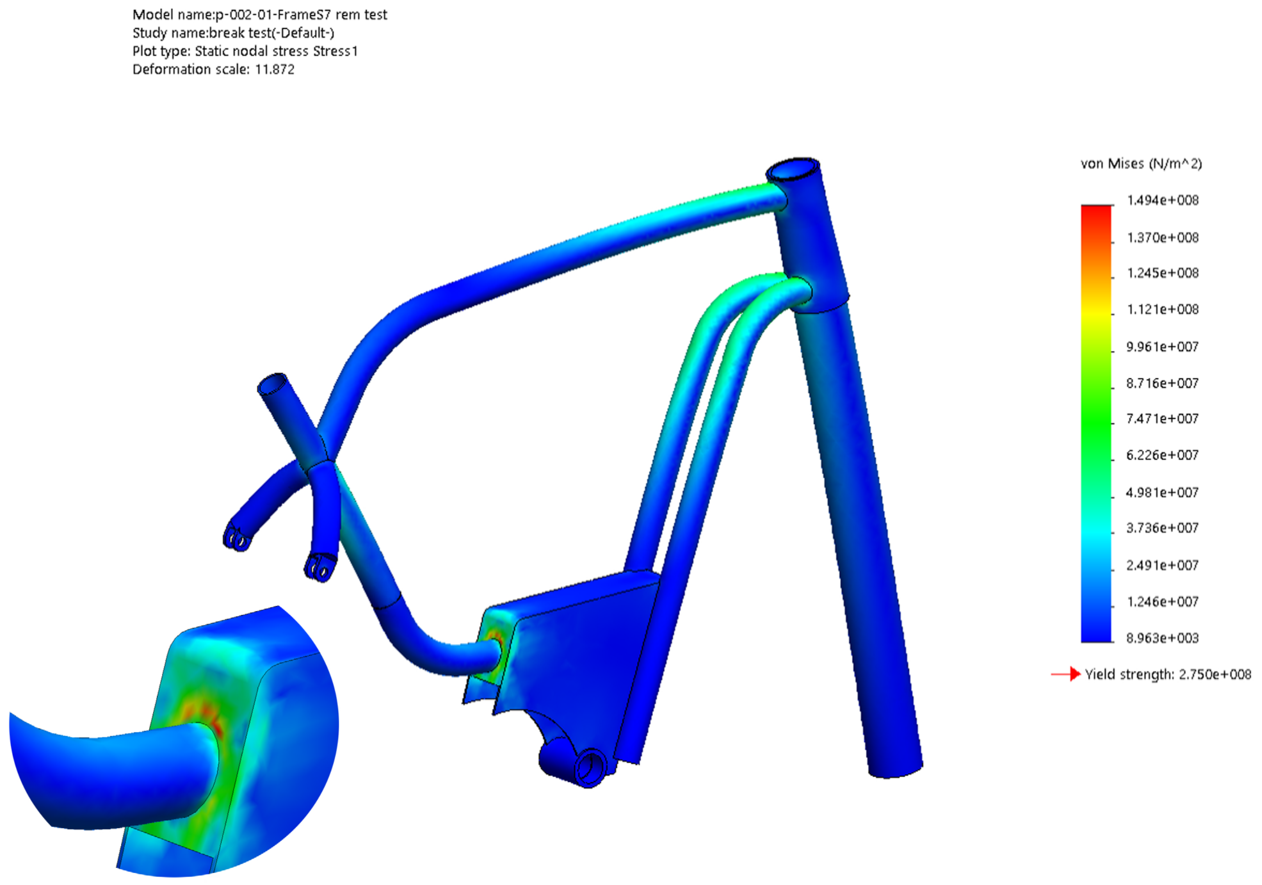


Load case 2: breaks

Load due to breaking, 800 N vertical on the saddle (F1) and 1000 N horizontal (F2) at the fore fork.



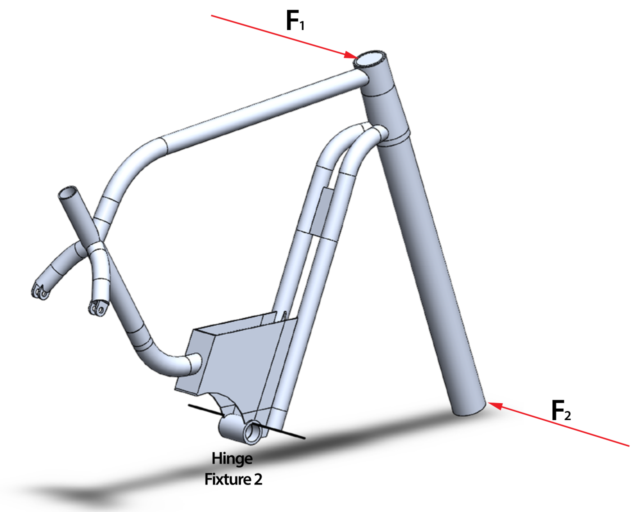
It is seen from the below figure that the maximum Von Mises stress is 150 MPa at the joint between the seat tube and the electrical box. As this maximum is more than half the yield strength (138 MPa) a small modification was made. The seat tube was extended through the electrical box and ending at the side of the box that is connected to the double down tube. This stronger design gave a maximum Von Mises stress of ... MPa at the same joint (see the following figure). This is below 138 MPa and therefore satisfying the yield strength with a safety factor of 2.


Model name:p-002-01-FrameS7 rem test
Study name:break test(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 11.872

The computed strains of the S7 are in this case at most 1.1 millistrain (results not shown). In [5] (p. 60) strain levels of 1 millistrain were reported from lab testing and FEM modeling when a horizontal force of 1200 N was applied to the front fork. The maximum strain of the here used aluminium is 2 millistrain.

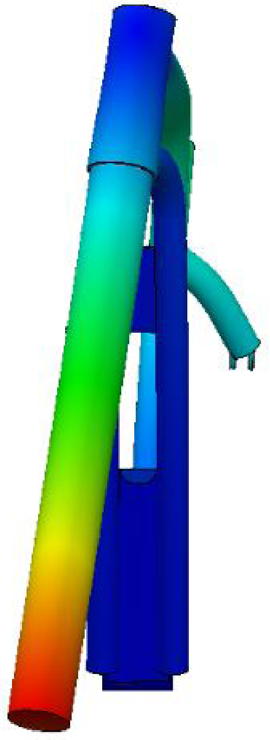
Load case 3: steering

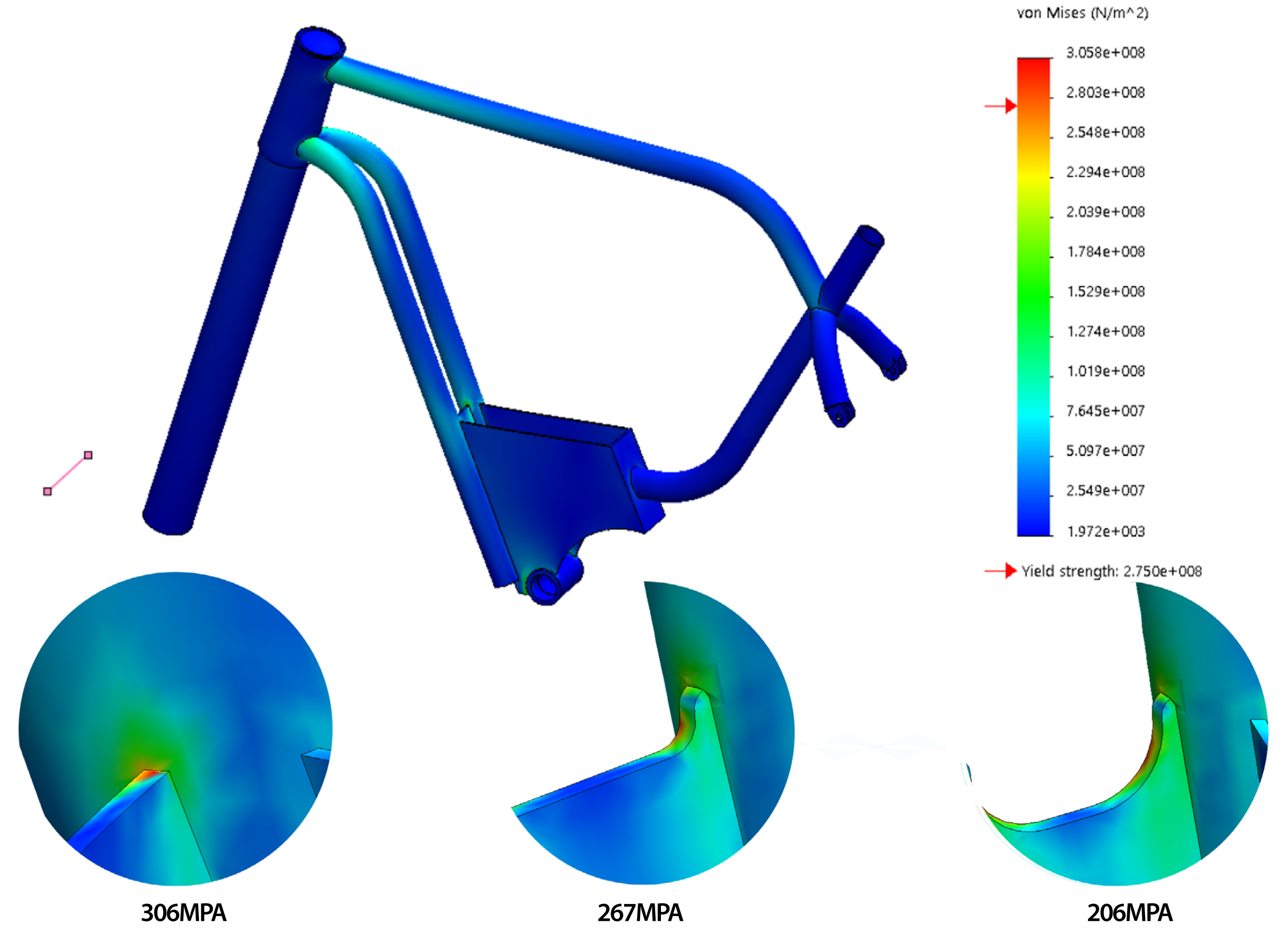
A load of 500 N horizontal (F2) on the wheel axle. The counter force F1 is meant to hold the headtube in position while F2 creates a momentum on the head tube.

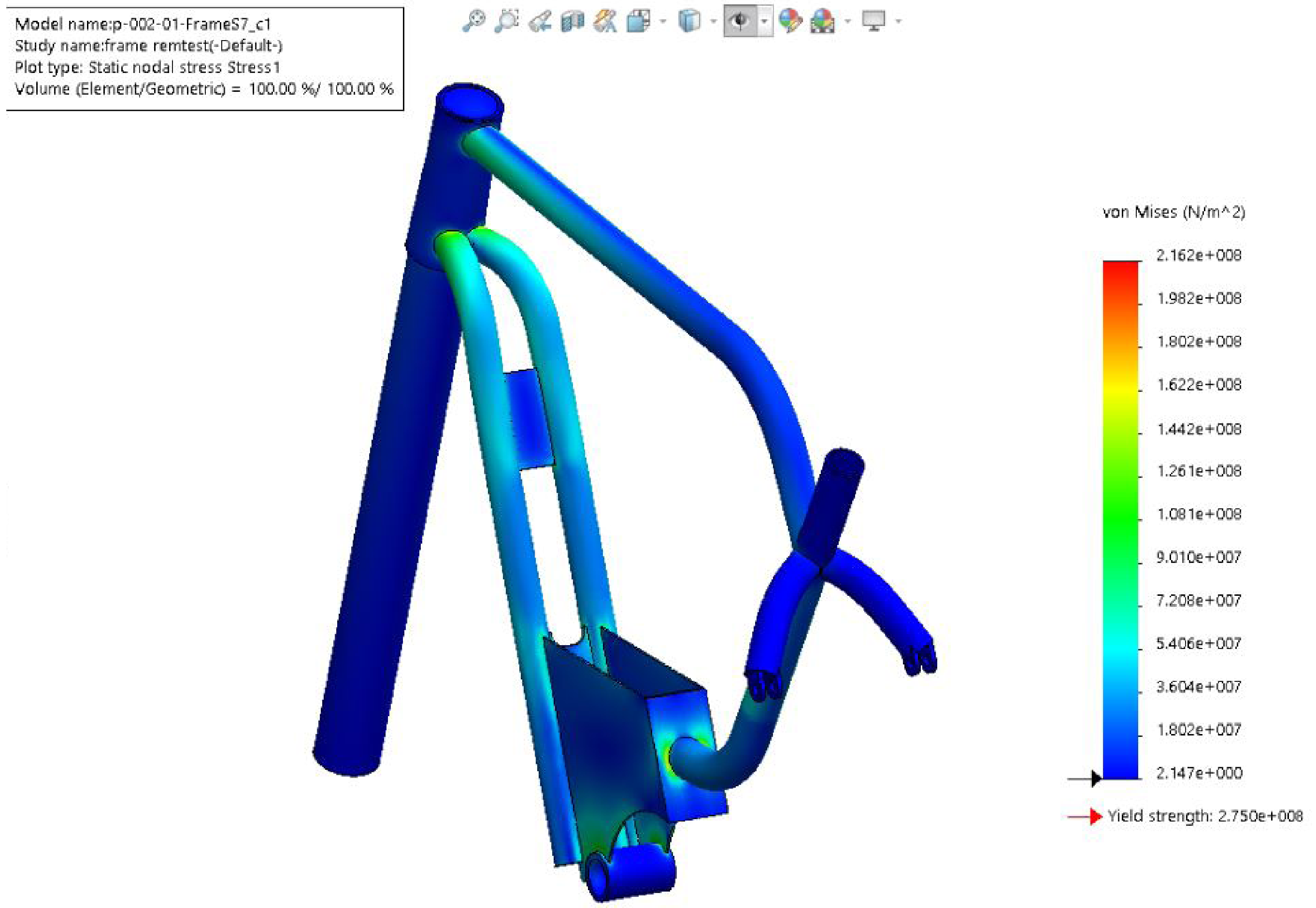


In the figures on the right page we see that the maximum Von Mises stresses are more than the yield strength of 275 MPa. This is not safe and requires a modification. The figure also shows the effect of the design changes on the stresses. The area where the plate is attached to the frame tubes is rounded off to spread forces over a wider area and therefore the Von Mises stresses will decrease at that location. Because the largest rounding (shown on the right) still has a maximum of 200 MPa more measures need to be taken such that the final Von Mises stresses will be below half the yield strength. Therefore, a second plate is welded between the down tubes to avoid them from sheering (see the second figure). This method proves to be effective, the maximum Von Mises stress now is (in the same area) 120 MPa

The below figure shows the horizontal displacement. The maximum is 3 mm.

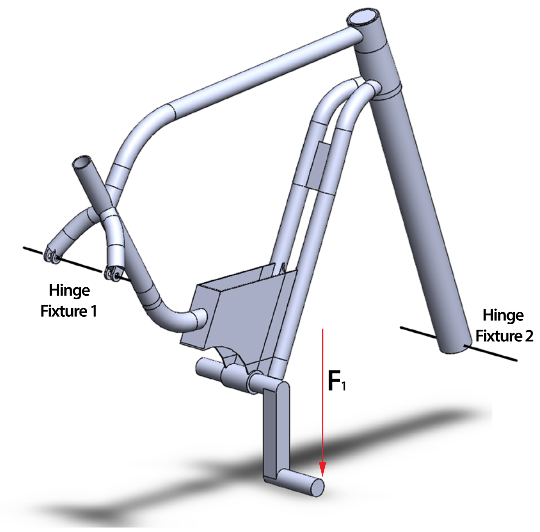






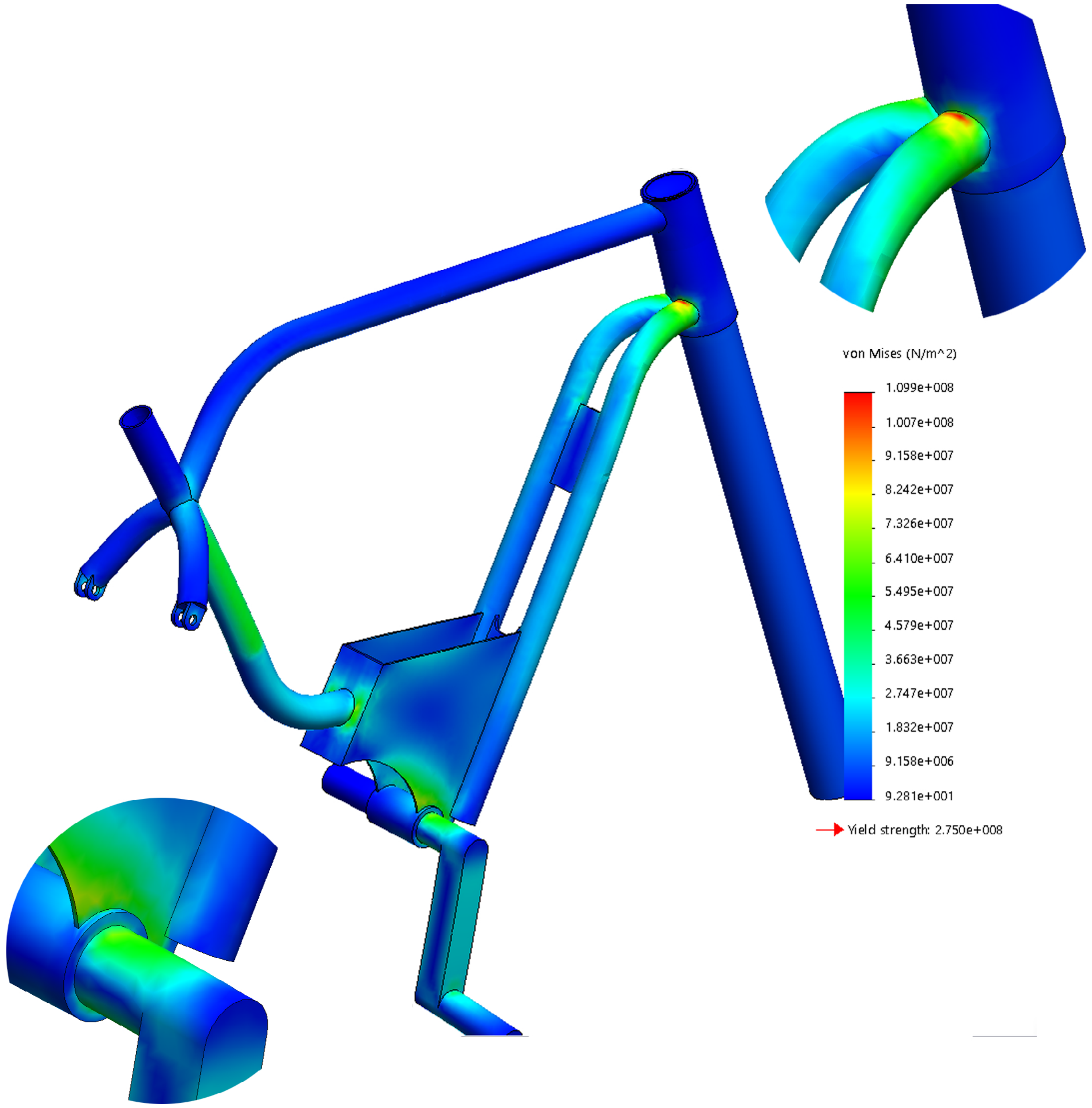
Model name:p-002-01-FrameS7_c1
Study name:frame remtest(-Default-)
Plot type: Static nodal stress Stress1
Volume (Element/Geometric) = 100.00 %/ 100.00 %

Load case 4: pedaling power
A vertical load of 1200 N is applied on the outside of the pedal while the front wheel axle and the rear spring attachments are fixed.



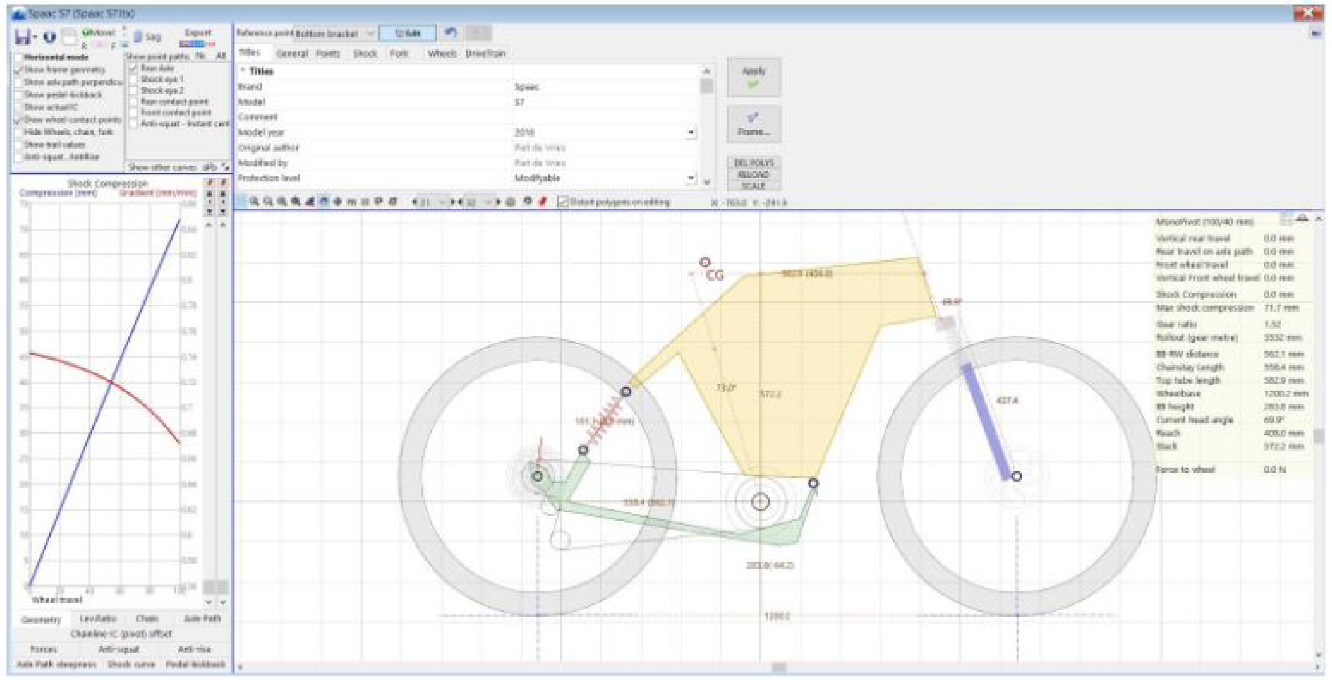
The precise location of the paddle is slightly different from reality, this was done for simplicity such that the computations in SolidWorks could be done relatively fast.

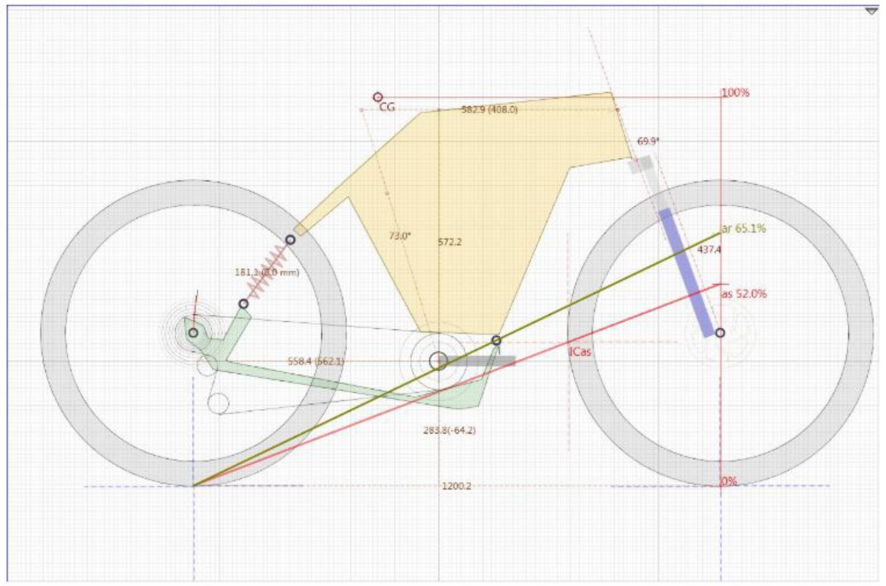
The below figure shows a maximum Von Mises stress of 110 MPa at the connection between the head tube and the down tubes. This is well below half the yield strength.

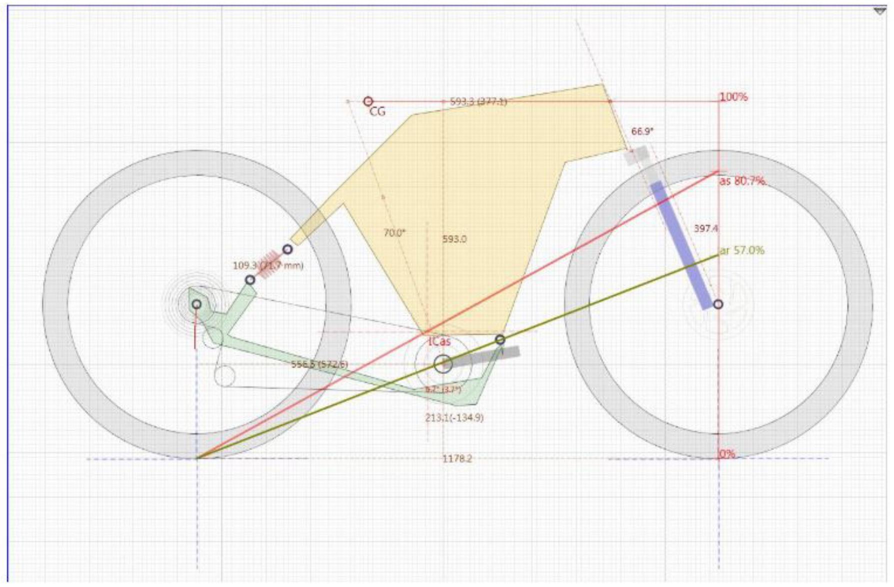


5.2 Geometry check

The Spaac S7 has not got a rigid frame where the complete geometry is fixed. Due to suspension in the front fork, two springs at the rear and, a movable swingarm the geometry is dynamic and varies with the weight and movement of the rider and, sudden variations of the road. Therefore a thorough check is needed on the dynamics of the geometry. This is done with the 2D modeling program “Linkage” (version X3). The Linkage program allows to import the raw 2D sketch of the Spaac S7, make geometry changes and, to assign properties of the suspension (stiffness and damping). It further allows to compare the results with other bikes. The below picture shows a typical input (right side) and output results (graphics on the left side and a table on the right side).
Unfortunately, in Linkage the bottom bracket is connected to the frame. This is not correct, it should be connected to the swing arm. As a consequence, not all results of Linkage are accurate.







MonoPivot (100/40 mm)	
Vertical rear travel	0.0 mm
Rear travel on axle path	0.0 mm
Front wheel travel	0.0 mm
Vertical Front wheel travel	0.0 mm
Shock Compression	0.0 mm
Max shock compression	71.7 mm
Gear ratio	1.52
Rollout (gear metre)	3332 mm
BB-RW distance	562.1 mm
Chainstay Length	558.4 mm
Top tube length	582.9 mm
Wheelbase	1200.2 mm
BB height	283.8 mm
Current head angle	69.9°
Reach	408.0 mm
Stack	572.2 mm
Chain Growth	0.0 mm
Total chain growth	0.0 mm
Minimal required chain length	1458.1 mm
	115 Chain eyes
Pedal-kickback / Frame (a1)	0.00°
Wheel rot. (BB dist.change)	0.00°
Force to wheel	0.0 N
Current anti-squat (a1)	52.0%
A(x)	150.17 N
Anti-rise (ar)	65.1%

MonoPivot (100/40 mm)	
Vertical rear travel	100.0 mm
Rear travel on axle path	100.6 mm
Front wheel travel	40.0 mm
Vertical Front wheel travel	36.8 mm
Shock Compression	71.7 mm
Max shock compression	71.7 mm
Gear ratio	1.52
Rollout (gear metre)	3332 mm
BB-RW distance	572.6 mm
Chainstay Length	556.5 mm
Top tube length	593.3 mm
Wheelbase	1178.2 mm
BB height	213.1 mm
Current head angle	66.9°
Reach	377.1 mm
Stack	593.0 mm
Chain Growth	+10.5 mm
Total chain growth	+21.1 mm
Minimal required chain length	1479.2 mm
	117 Chain eyes
Pedal-kickback / Frame (a1)	+3.66°
Wheel rot. (BB dist.change)	-0.31°
Force to wheel	4223.3 N
Current anti-squat (a1)	80.7%
A(x)	216.25 N
Anti-rise (ar)	57.0%

Important aspects of a dynamic geometry with suspensions are, the pedal kick-back (grey pedal bar), anti-squat (red line) and anti rise (green line) that are shown in the above animation. The numerical results of the above movement are shown in the table on the left page, the rest position on the left and the action or uplift (10 cm) results on the right.

The amount that the suspension is compressed can be expressed with percentage. When an average sized rider takes a seat on the bike is called "sag". A preload on a suspension system can minimise the sag but, it also brings the point of maximum suspension closer to the limit. The "Canfield balance formula" advises 25-33% of sag. (canfield-balance-formula.com/glossary/)

When the rider accelerates a compression of the suspension occurs due to the weight movement. This is counteracted by the chain tension due to the pedalling force. This counter effect is defined as "anti-squat" and can be used to compare the pedalling characteristics of different suspension designs. There are two extreme characteristics:

- 0% "anti-squat". The chain tension does not cause any extension or compression force in the suspension. The suspension system will compress under acceleration, due to weight transfer alone.
- 100% "anti-squat". The extension force caused by chain tension perfectly balances the compression force caused by weight transfer. The suspension system doesn't extend or compress under pedalling.

Linkage calculates an anti-squat of the S7 between 52 and 81%. This means that the chain tension of the S7 not completely balances the compression force caused by weight transfer. So, the riding behaviour of the S7 during acceleration is comfortable. Note, that anti-squat values larger than 100% are seen as typical positive values for mountain bikers when climbing.

Anti-rise or brake-squat occurs when the rear suspension compresses due to the momentum of the rear brakes on the swingarm while braking. Almost every bike that has the rear brake mounted directly on the swing arm experiences anti-rise. When the distance between the pivot point and the axle of the wheel increases the anti-rise will also increase. More than 100% anti-rise implies that pulling the rear brake only would cause the rear suspension to compress, while less than 100 percent anti-rise implies it would extend. Linkage calculates for the S7 an anti-rise between 57 and 65% of the so, it would extend. This is seen as a more natural bicycle characteristic.

All bikes with rear suspension experience a so called "pedal kickback" (or pedal bob). This is that the (rear) suspension bounces on the frequency of the riders legs. Linkage calculates for the S7 a pedal kick-back of almost 4 degrees. This needs to be compensated. If the chain path of the bike is extended when the suspension is compressed, pedal bob can be compensated. Anti rise does this. A lot of suspension bicycles increase the anti-rise value as a trick to compensate for pedal bob. Also the anti-rise value of the Spaac S7 could be increased to avoid pedal bob since this is a hazard (Chapter 4.5). In real life this would mean moving the pivot point backwards and upwards to increase the cain growth when the suspension bounces in.

The Spaac S7 has the bottom bracket connected to the swing arm, therefore the anti-squat is 0. This is not seen as ideal and requires a change in the design. This can be achieved by connecting the bottom bracket to the frame (as Linkage already assumed) and also to move the pivot point backwards.

6. IMPLEMENTATION

6 IMPLEMENTATION

6.1 Production

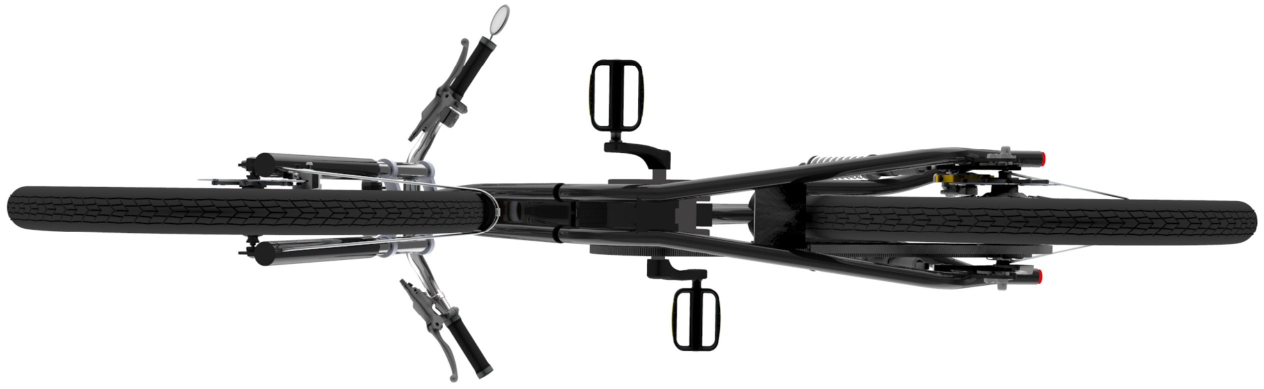
Throughout the design process of the S7 the different parts are all designed to be fabricated by the suppliers that Spaac has right now. The tubes are cut to length and with simple pipe holders the sub assemblies are welded together. Parts like the electronic compartment arrive pre folded and cut with precision to the right shape. It is only a case of welding together and preforming quality checks in between to ensure frames are straight.
Next step is powder coat and assembly.
The bearings need to be pressed in the frame and then the swing-arm can be assembled. Pre drilled holes are filled with a wiring harness and lighting modules that connect to the battery.
Wheels and fenders assemblies are fitted and torqued to the right NM.
Finally the handlebars and Brooks flyer saddle are fitted to complete.

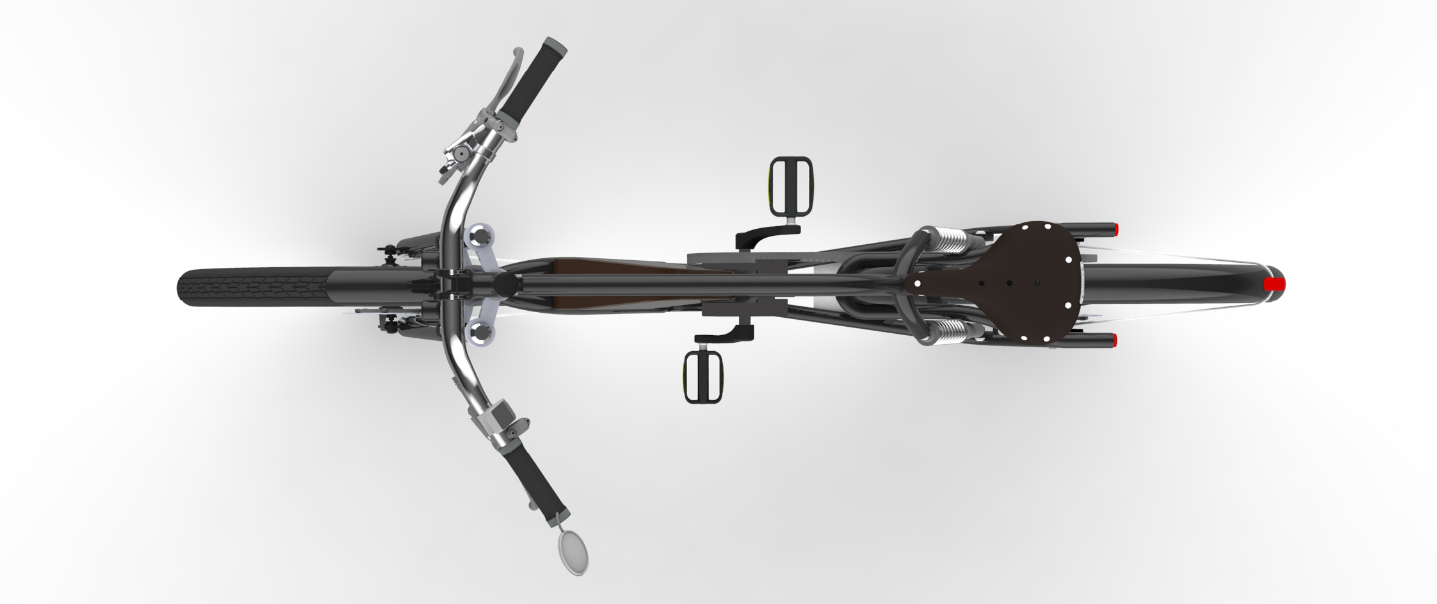
name		Part costs
Steering assembly		25
Rear wheel assembly		100
Front wheel assembly		100
Front fork assembly		300
Motor+E-system		1000
Nuvinci hub+shifter		200
Belt + sprockets		100
fenders		80
lights		170
Brakes		180
Saddle and seatpost		160

7. FINAL DESIGN

7 FINAL DESIGN

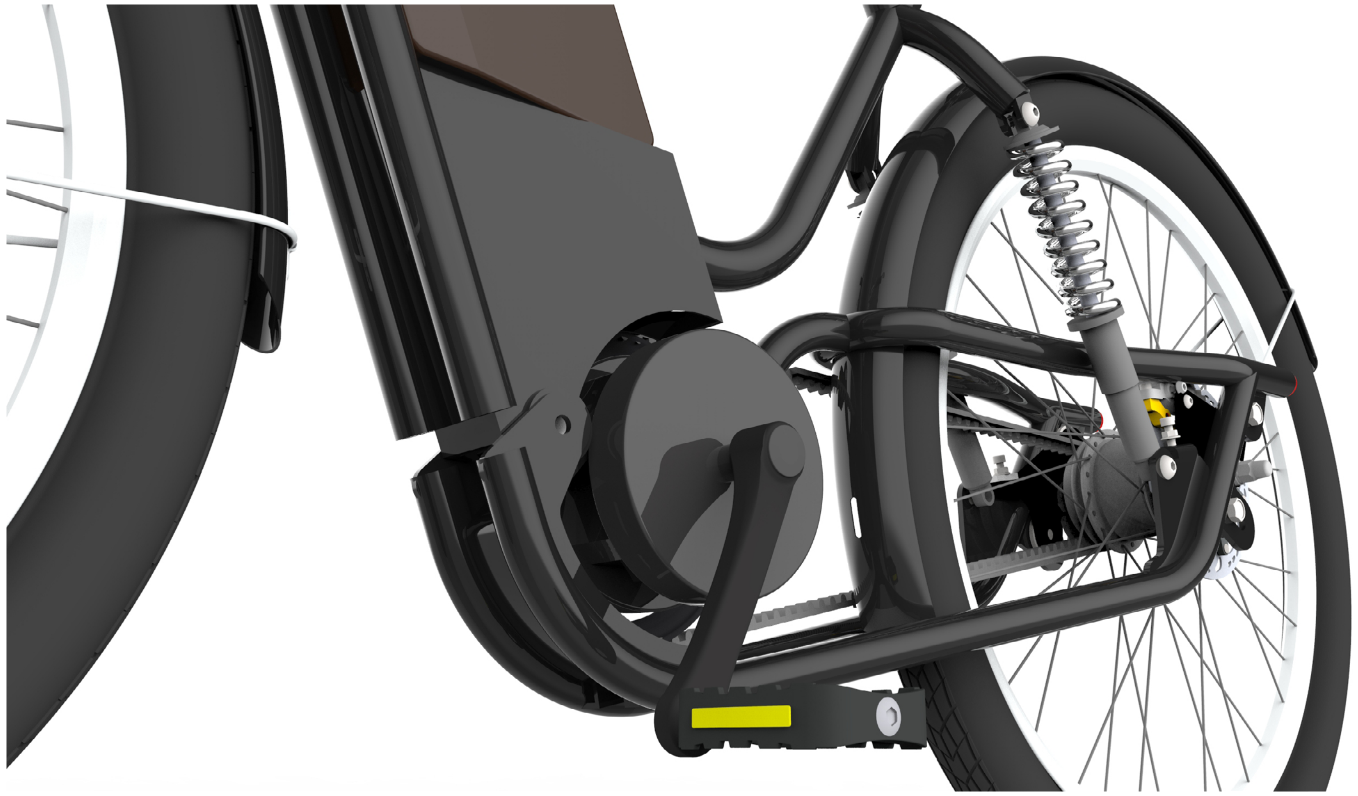
The following pages show the model and rendered images of the final design the design is ready for prototyping and further testing, the frame consists out tubes with continuous bends, the plates that connect the frame tubes to other parts are made to be ordered at 247taylorsteel.com a weld mould is necessary to get a straight and symmetrical frame. The prototype can be build with basic metal processing tools that are available at the PMB in IDE. If the design would not only be used for testing but also as a showcase model, it would advised to powder-coat all the parts to make them scratch resistant.



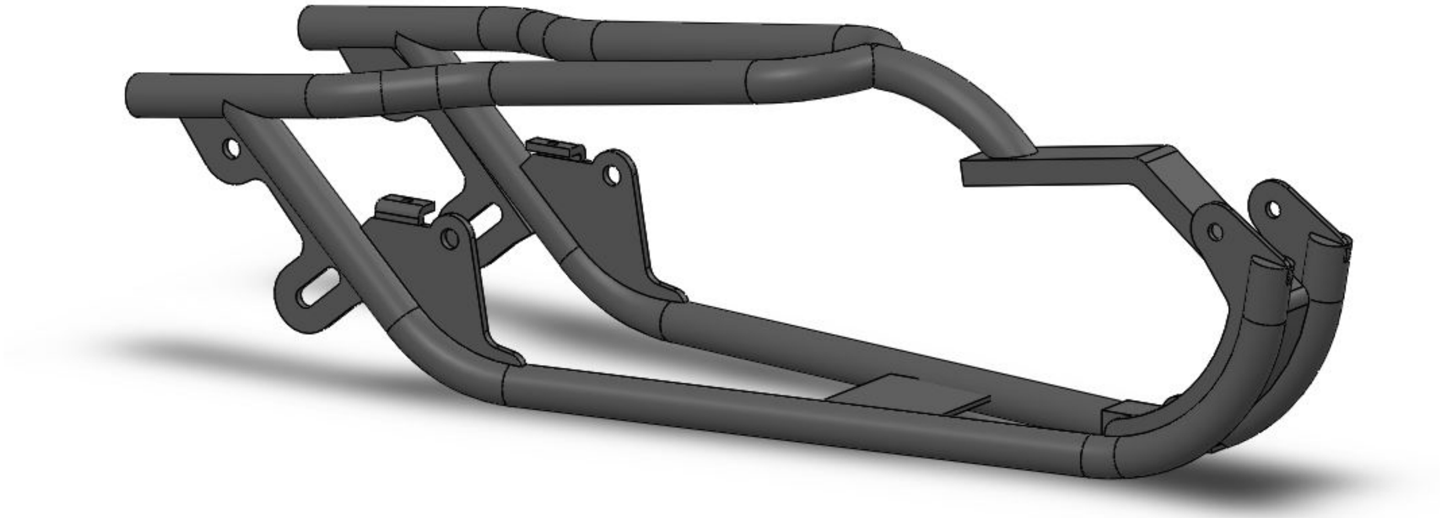


Pivot point

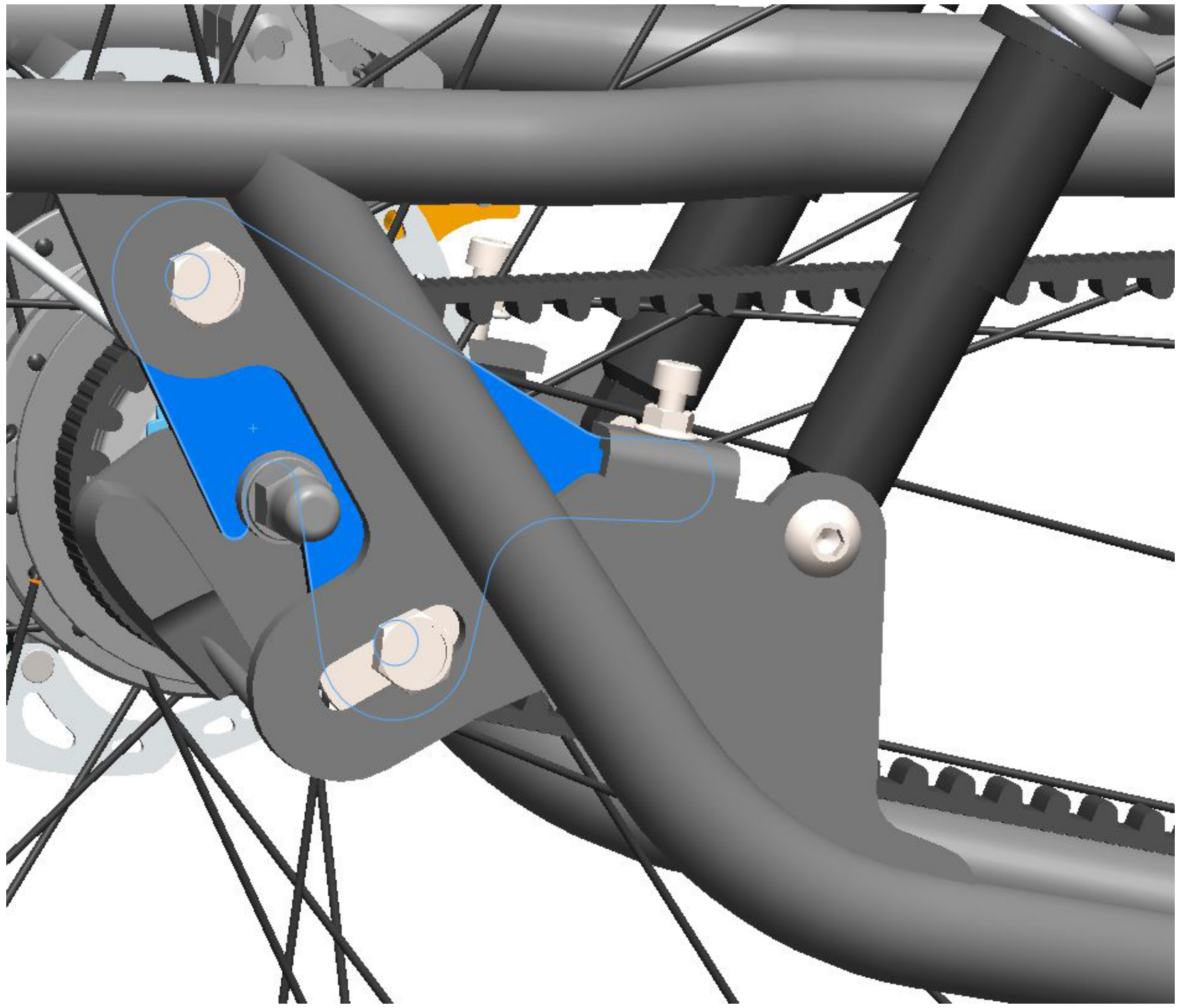
The pivot point is designed to protect the bearings that are placed in the frame, it is also designed to minimise flex in any unwanted direction.

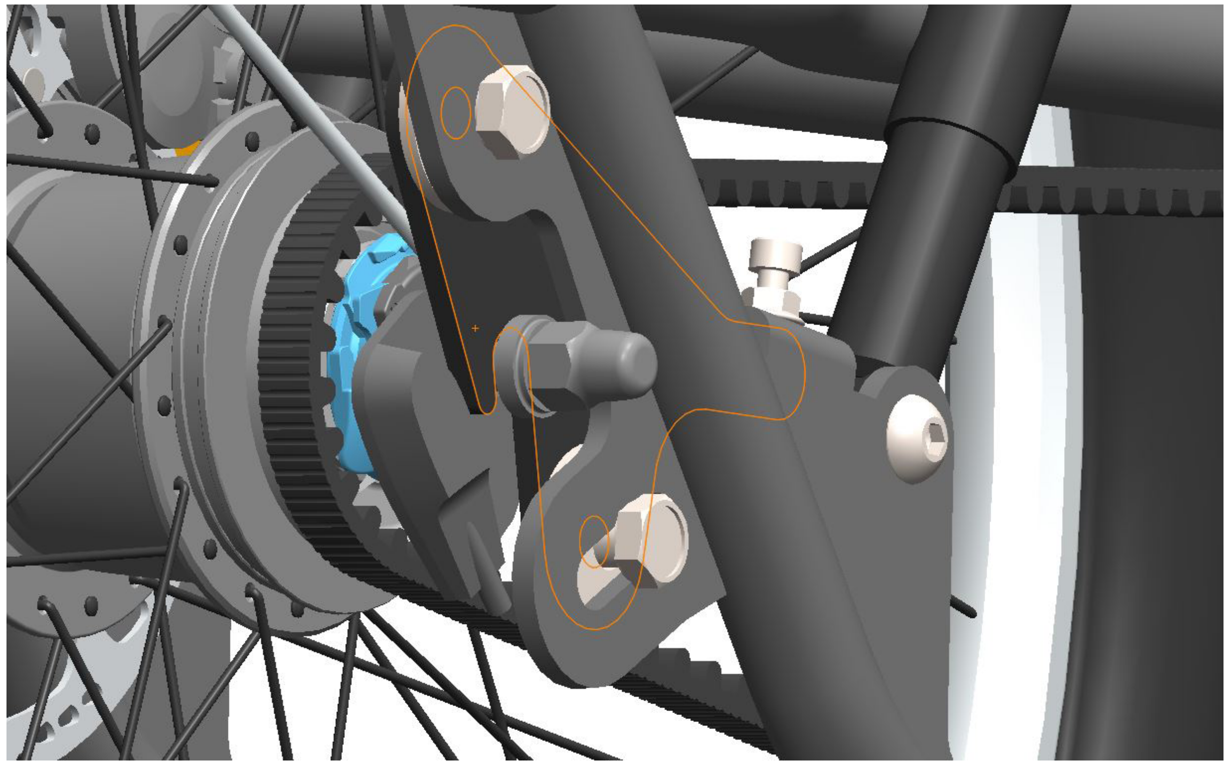


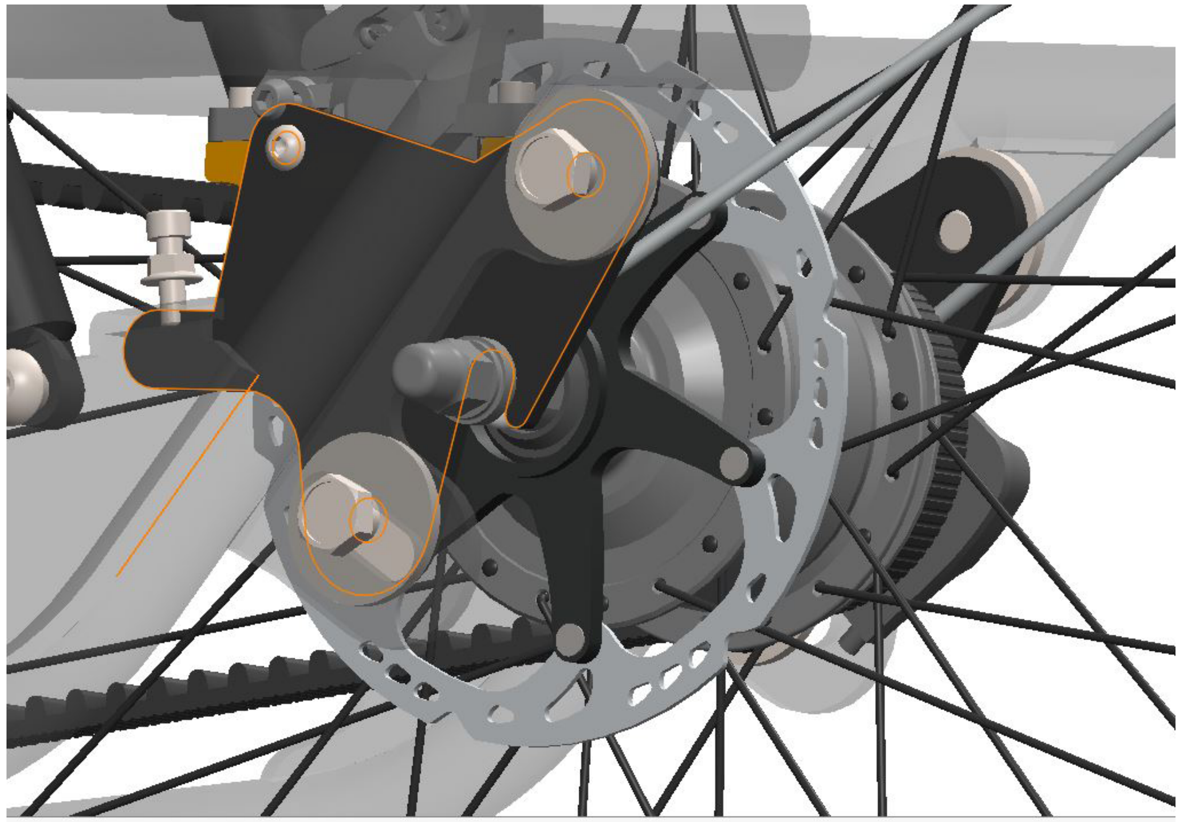
Swingarm

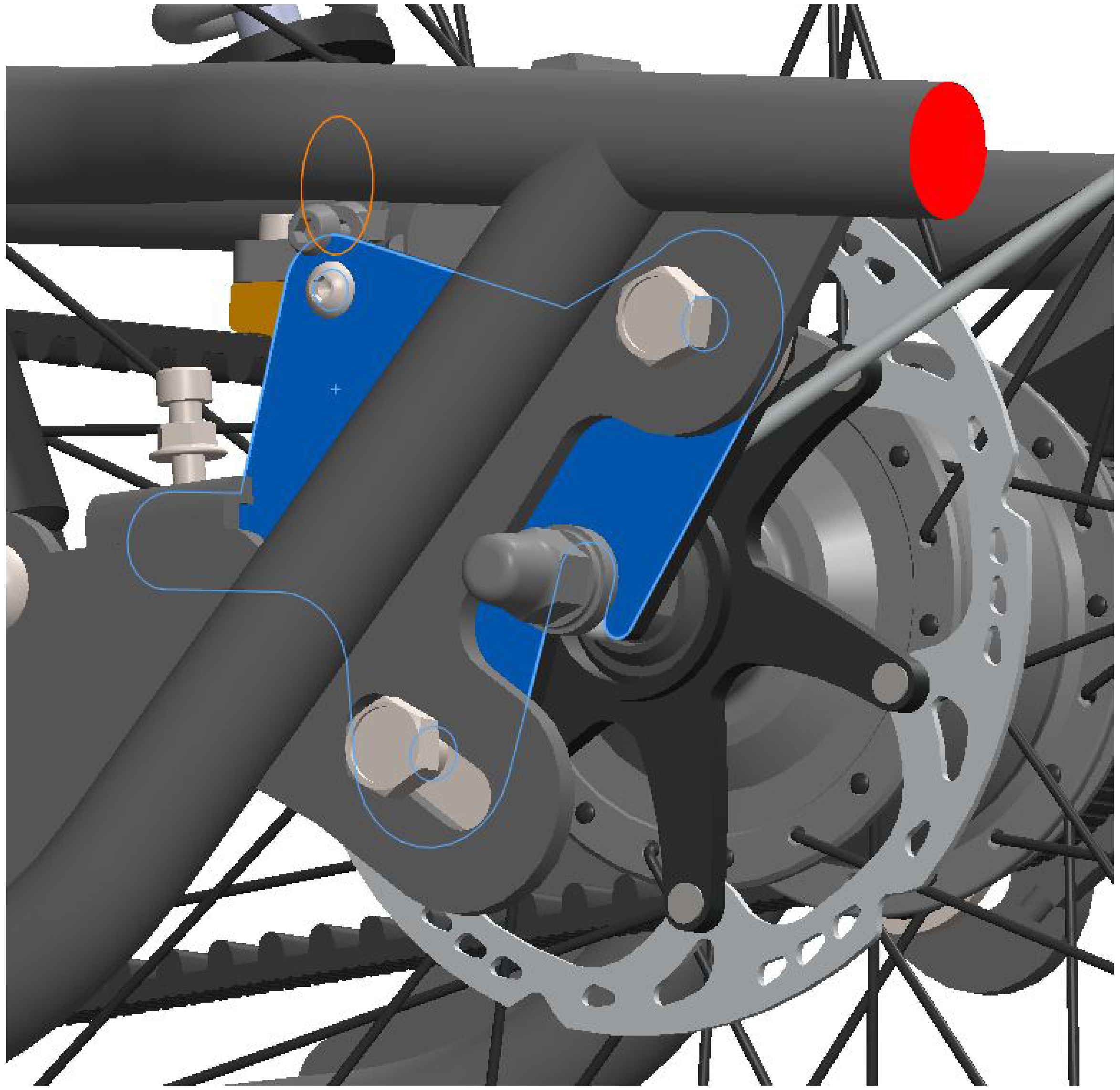


Rear wheel dropout plate









7.1 Conclusions

Chapter 1.1 starts with one of the most fundamental questions in this theses: “Imagine a Speed-pedelec that was designed for much greater speeds than just 45 km/h, could this lead to a better and safer bike?” In this Graduation project the possibilities of a “Smart Super-Pedelec”were investigated for Spaac. The company has 3 main pillars according to the owners: aesthetics, ease of use,and robustness. These pillars are resembled by the different chapters of the thesis. The conclusions for each of these pillars are discussed below, the general question is answered in the end.

Aesthetics

The Spaac S5 needs to appeal to the customer that is looking for a unique electric bike with a retro twist to. Incorporating retro details and choosing a setup with double spring suspension in the rear add to the retro look. The engine is encased by thick tubes to protect it during all day use in an urban environment. Don’t let looks fool you, the frame is made out of aluminium tubes to save weight, the tubes are covered with a few thick layers of powder-coat.

Ease of use

Resembled by ergonomics and comfort. The design is optimised with a pre defined track between Leiden and Den Haag that contains all the obstacles that create discomfort or hazardous situations:
- A pedestrian zone; the bike is designed to steer smoothly around objects or people at speeds below 15km/h. The reclined seat post makes it easyer to reach the ground for the user.
- Speed bumps and other uneven road conditions are no problem for the S7, note that it is no problem to slow down for a speed bump but other road users often don’t slow down too much so the S7 must not be the only one to brake.
- Unclear junction, the upright position ensures a clear overview on any traffic situation
- 50Km/h road where traffic often drives 60+Km/h. This is where the extra power comes in necessary the Spaac S7 can reach speeds up to 70Km/h to keep up with other traffic without being pushed of the road.
- Bumpy pavement is no hazard for the S7 since the shock absorbency damps out any hazardous frequencies that could cause unwanted road behaviour
- If someone at the latest moment still decides to step in front of the bike, the class 1 brakes make sure it stops in time.

Robustness

Important factors in the design of this Super-pedelec are fatigue and stiffness analysis. The bike might have been designed as a rigid bike but how well does it cope with bumps, turns and brake forces?
In any of these situations a load case is designed to test the parts numerically on or stiffness.

7.2 Recommendations

The Netherlands are known as a bicycle country, but that does not mean that other countries don’t have the potential customers for Spaac and their S7. There are lot of countries where bicycles are less popular because the countries are to warm (South europe) or where the elevation differences make it heavier to ride to a preferred destination(North europe). These countries. On a governmental level, the Netherlands are not ready for a super pedelec, there are enough indications to assume a shift towards electric vehicles is happening right now. However it will be very hard to receive a type approval on the S7. Individual approval is possible. And with the 1000W engine the bike will probable be listed as a class A1 motorcycle (up to 11KW) and a motorcycle helmet is required to be allowed on the road.

Seat position vs wind: The upright seating position might be comfortable but is causes more wind drag. The bike has 1000W, wind resistance is by far the biggest resistance holding the speed back. Not only would the bike be faster with a more sportive position, the wind resistance also causes discomfort for the rider. Since the position can be compare with that of a moped or motor scooter, A windscreen might add the comfort for the rider.

So the Speed-pedelec was designed for much greater speeds than just 45 km/h,did this lead to a better and safer bike?

The increase in speed did not lead to a safer bike. Looking at crashes and the intensity with increasing speeds. However the increased power to travel along with other vehicles or momentarily get out of a dangerous situation can add safety. Practice tests with A real Super-pedelec in traffic conditions and speeds above 45KM/h need to be done to answer this question.

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https://www.tq-e-mobility.com/en/TQ-HPR-120S/Technical-Specifications

Review of relevant literature not referred to directly in the report

https://endless-sphere.com/forums/

The endless sphere forum is about anything E-vehicle related, there are specific discussion groups on Speed pedelecs and super pedelecs. Also a lot of knowledge is found on specific details and suppliers of batteries, motor, gear systems etc.

https://www.swov.nl/feiten-cijfers/factsheet/elektrische-fietsen-en-speed-pedelecs

The SWOV is an organisation in the Netherlands that gathers scientific information and places it on their website.

https://www.electricbike.com/10-fastest-ebikes/

Great sources of inspiration in the design process

https://en.wikipedia.org/wiki/Electric_bicycle#S-Pedelecs

Shows the speed that pedelecs are allowed to go

https://www.volkskrant.nl/binnenland/ongeval-met-e-bike-vaak-ernstiger-dan-met-gewone-fiets~a4495551/ (Mei 2017)

https://www.rijksoverheid.nl/documenten/rapporten/2017/12/07/bijlage-3-onderzoek-veiligheidnl-fietsongevallen-in-nederland

https://www.bosch-ebike.com/nl/service/actieradius-calculator/?setLanguage=8

https://www.swov.nl/publicatie/speed-pedelecs-op-de-rijbaan-observatieonderzoek (Nuttig onderzoek over speed pedelecs op de weg)

http://www.spabicicletto.com/en_US/ (Mooie high speed fiets)

http://hiconsumption.com/2016/08/scrambler-e-bike/ (Scrambler e-bike)

http://www.fietsberaad.nl/index.cfm?section=nieuws&lang=nl&mode=detail&newsYear=2018&repository=Hoger e+snelheid+gewone+e-fiets+mogelijk+maken

http://www.fietsberaad.nl/index.cfm?section=nieuws&lang=nl&mode=detail&newsYear=2018&repository=Achter wielmotor+veiliger+voor+oudere+e-fietser

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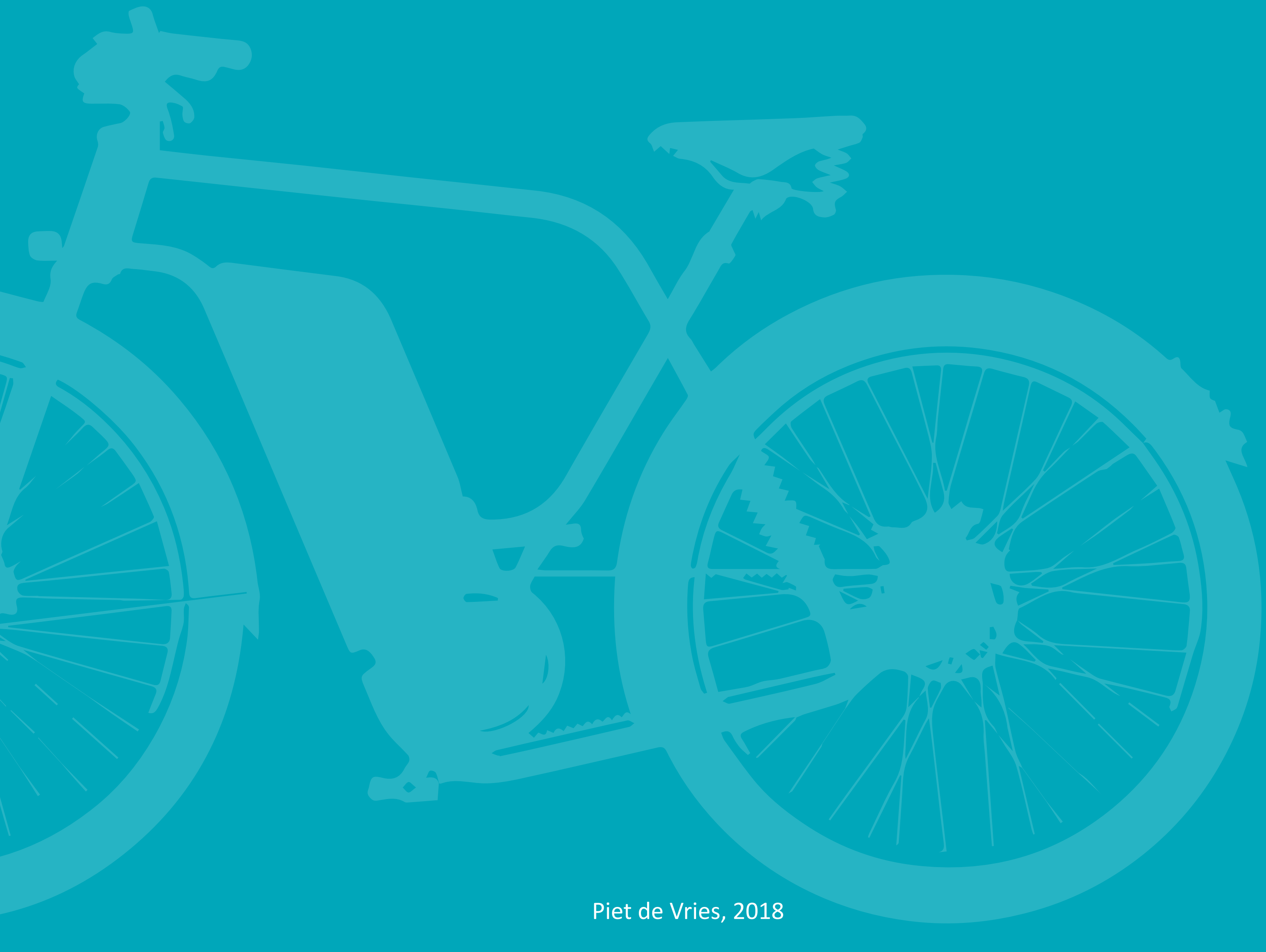

Piet de Vries, 2018