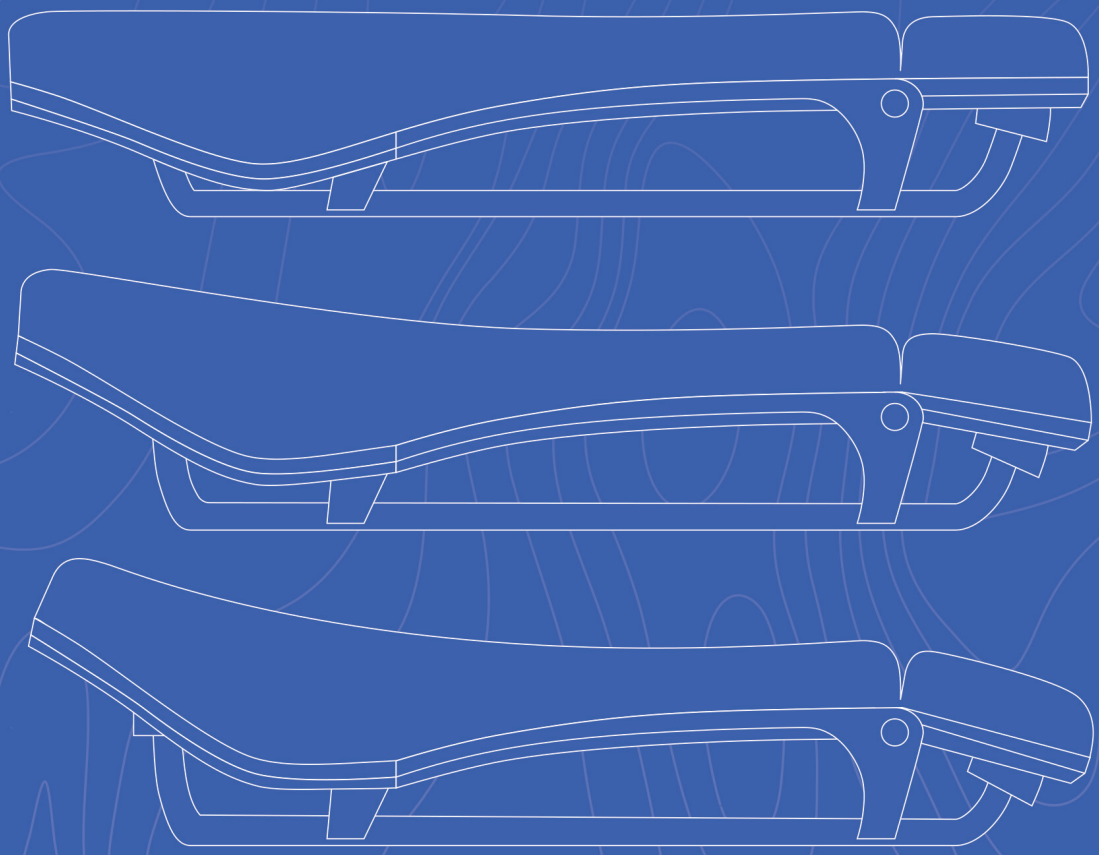
ART VAN ZUUK

SCULP

A VARIABLE PROFILE SADDLE TO PREVENT SADDLE SORES



TU Delft

SCULP

A VARIABLE PROFILE SADDLE TO PREVENT SADDLE SORES

Master Graduation Report by Art van Zuuk
Delft University of Technology
Industrial Design Engineering

2024

Under supervision of:
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READING GUIDE

A specific colour scheme was selected to highlight elements within the report.

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1. INTRODUCTION

This chapter provides further insight into the project, including what its purpose is, how it came to be, and how it is realized.



1.1 EXECUTIVE SUMMARY

Cycling, a sport with a rich history, is experiencing rapid growth in popularity (Braeckevelt, 2019). It is known for its numerous health benefits, including reducing cardiovascular risks and obesity (Oja et al., 2011).

Despite being perceived as a low-impact activity, research conducted by Delft University of Technology reveals that over one-third of cyclists suffer from saddle sores (Groenendijk et al., 1992). This prevalence is even higher among sport-cyclers, with complaints often focusing on discomfort around the perineum and sit-bones, potentially hindering participation in the sport (Napier & Heron, 2022).

Throughout this research, it became apparent that achieving a comfortable saddle experience hinges on two crucial factors: a saddle design selected to fit the purpose (cyclist's anatomy, cycling posture, and personal preferences) and a proper bike fit. Despite their significance, these aspects are frequently disregarded during the saddle purchasing process. As a result, cyclists may find themselves cycling through multiple saddles before discovering the right fit or resorting to costly professional bike fitting services.

In response to these findings, this thesis proposes the development of a bicycle saddle with a variable side profile. This way, the rider can adjust the saddle to align it with the pelvic bone. Therefore creating an optimal pressure distribution, leading to less saddle sores. This has been done by introducing a hinging frontal and rear part, covered by a specially designed padding that makes sure that a smooth profile is established. Additionally, bike and saddle fitting items and a simple guide are provided to the customer and should help find a better bike fit at home.

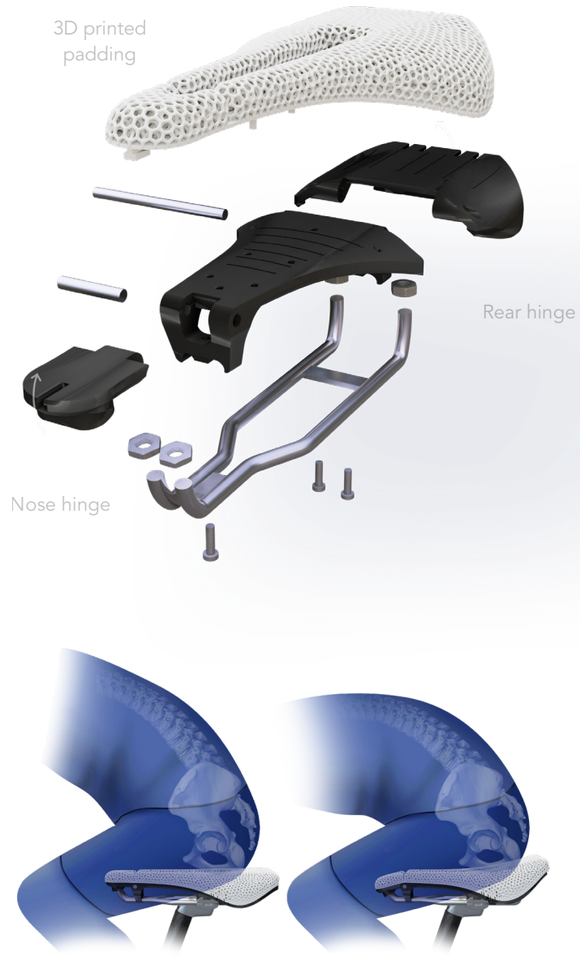


Figure 1: Exploded view of final design (top) and pelvic tilt on saddle in flat configuration and waved configuration (bottom).

1.2 **INITIAL DESIGN BRIEF**

The initial design brief was inspired by numerous papers suggesting that bicycle saddles with dynamic adjustability in geometry, tilt, or position could significantly enhance comfort and performance during cycling (Sequenzia, 2015; Hynd, Cooley, & Graham, 2017; Fonda, Panjan, Markovic, & Sarabon, 2011). These saddles are referred to as dynamically adjustable saddles (DAS). They have the potential to improve the experience while using it with different riding styles, anatomies, riding positions, and terrains, by adapting their positions and/or shapes accordingly.

Existing saddles often remain static and non-responsive to these dynamic needs. Hence, the primary objective of this graduation project is to explore the potential benefits of DAS in various scenarios. The scope of the assignment begins with a broad exploration, aiming to identify numerous opportunities for implementation. Once a promising opportunity is identified, the focus shifts towards refining and testing a specific concept within that context.

ASSIGNMENT

Design a bicycle saddle that enhances the cycling experience. This design will be based on an exploration of the potential of a bicycle saddle that can dynamically adjust its properties during cycling.

NAVIGATION CANVAS

According to the navigation canvas of Jeroen van Erp, this graduation project is a typical example of impact open, manifestation fixed (see Figure 2) (Erp, 2020). While it is clear what the project is about, namely dynamically adjustable bicycle saddles, the problem it will solve is yet to be found.

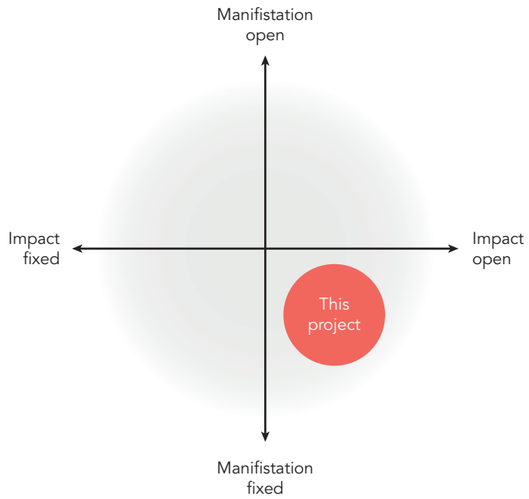


Figure 2: Navigation Canvas, Jeroen van Erp (2020).

1.3 **INSPIRING DAS**

A distinction can be made between saddles that can be adjusted before or during a ride. Down below a selection of the most inspiring research, concepts or products that can be categorized as DAS is shown.

BEFORE

Several studies aim to compare various saddle designs to determine which shapes are considered most comfortable. These comparisons include long vs short, cutout vs closed, wide vs narrow, pear-shaped vs T-shaped and more (Bressel & Larson, 2003; Schrader, Breitenstein, & Lowe, 2008; Bakker, 2015). While much of the research tends to suggest particular shapes to reach comfort, the reality is more nuanced. Factors such as the individual cyclist's anatomy and personal preferences significantly influence comfort levels.

Based on this given, there is a company called BiSaddle that produces saddles with an adjustable front and rear width to accommodate the persons needs ands wishes. Similarly, a concept of a Modular Saddle System (van Montfort, 2022) proposes a saddle with interchangeable padding.

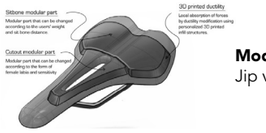
DURING

Especially a lot of research is done to bicycle saddles that can adapt to uphill versus flat conditions. One study proposes the concept of a variable geometry bicycle saddle that can modify its rear width and nose angle through a mechanism located beneath the saddle, as shown in Figure 3. When compared to a standard saddle, the researchers discovered that the adjustable saddle could help prevent neurological issues during uphill cycling (Sequenzia, 2015). Next to that, research has also concluded that adjusting the angle of a bicycle saddle can enhance comfort and performance when cycling uphill (Hynd, Cooley, & Graham, 2017; Fonda, Panjan, Markovic, & Sarabon, 2011). Based on the latter, Aenomaly made a system that allows the cyclist to change the angle of the saddle during the ride.

Other products include the Switch Aero; a system positioned between rails and seatpost, enabling to switch between aerodynamic and touring position, the Ere Research Genus Pro, a saddle with a variable shell stiffness for varying terrains, and the dropper post, which is a seat post that can extend or lower to facilitate body movement during off-road mountain biking.



Adjustable rear & nose width
BiSaddle



Modular Saddle System
Jip van Montfort



Variable geometry saddle
Sequenziia



Saddle tilt system
Aenomaly



Saddle position system
Switch Aero



Variable stiffness saddle
Ere Research



Saddle height system
Dropper Post

Figure 3: Examples of DAS. First 2 before cycling, bottom 5 during cycling

1.4 **RESEARCH QUESTIONS**

During this research, a list of research questions was formulated, which served as framework for the first phase of the research.

GENERAL

- What does a bicycle saddle do?
- What are the differences between bicycle saddles?

EXPERIENCE

- How do different bicycle saddle parameters effect the comfort, efficiency, and overall experience on the saddle?
- What other factors influence the experience on the bicycle saddle?

DAS

- How can a bicycle saddle by dynamically adjustable?
- What dynamically adjustable bicycle saddles currently exist and what problems do they tackle?

OPPORTUNITIES

- What are problems faced by cyclists on bicycle saddles?
- What methods are currently used to eliminate problems on the bicycle saddle?
- What is the most interesting opportunity to design a dynamically adjustable bicycle saddle for that eliminates a particular problem faced by cyclists?

1.5 **APPROACH**

Throughout the project, I adopt the double diamond approach, which facilitates both divergence to explore opportunities and convergence to refine options. While this approach may appear linear, many small design iterations were carried out throughout the project, as shown in Figure 4. Note that the two diamonds have distinct colours. These colours correspond to the introduction pages of each chapter, with blue indicating chapters discovering 'what is the problem?', and green indicating chapters discovering 'what is the solution?'. The diamond can be broken down into four phases:

Discover (diverge): In this phase, a deep dive into the world of bicycle saddles will be done to better understand the scope and to define interesting opportunities (Chapter 2).

Define (converge): Since the initial design brief is very broad, specific design directions will be created and evaluated by discussions with experts (Chapter 3) and by conducting user tests (Chapter 4). Based on these outcomes, a redefined assignment is created (Chapter 5).

Develop (diverge) / **Deliver** (converge): Traditionally, a differentiation between the develop and deliver phase is made. However, due to the structure of this project, these phases are highly overlapping and could therefore be considered as one. In these phases multiple design iteration are done (Chapter 7 & 8). For this, desktop research, interviews, and a lot of prototyping and testing is involved (Chapter 8 & 9).

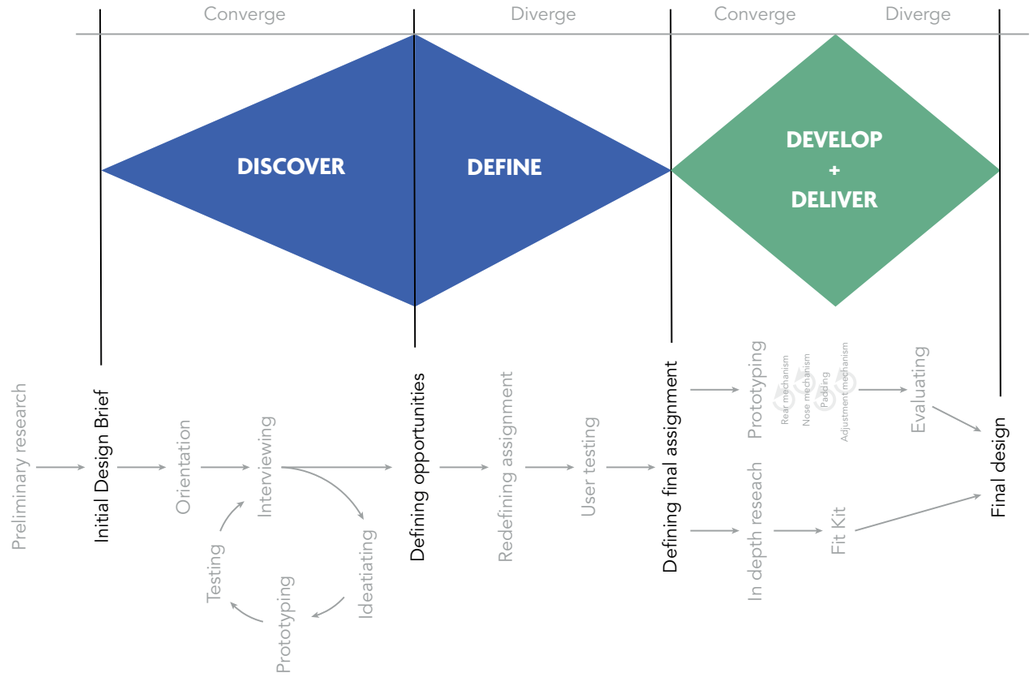


Figure 4: Double diamond approach used during this graduation project

2. INFLUENCES ON SADDLE EXPERIENCE

The bicycle saddle is the primary contact point between cyclist and bicycle. Therefore, it is considered a key component regarding the rider's experience especially when considering comfort (Ayachi, Dorey, & Gaustavino, 2015). However, the saddle extends its influence beyond comfort; it also has a significant impact on aspects such as aerodynamics, kinematics, and control, among others (Gatti, 2021; Potter & Sauer, 2008; Sequenzia, 2015). This chapter highlights the different aspects that are all relevant for the experience on a bicycle saddle to get a better understanding about the context, issues faced by cyclists, and possible solutions.

2.1 **INTERACTION MODEL**

According to the model of Dirken (1997), all product-human interaction factors can be broadly categorized into three domains: human, product, and environment. For this report, this model has been slightly adjusted. The saddle is part of the bicycle. These together form the product in this model. They both interact with the cyclist (human) and the environment, but also with each other. In the Figure down below, the adjusted model is shown. This chapter delves into these four areas.

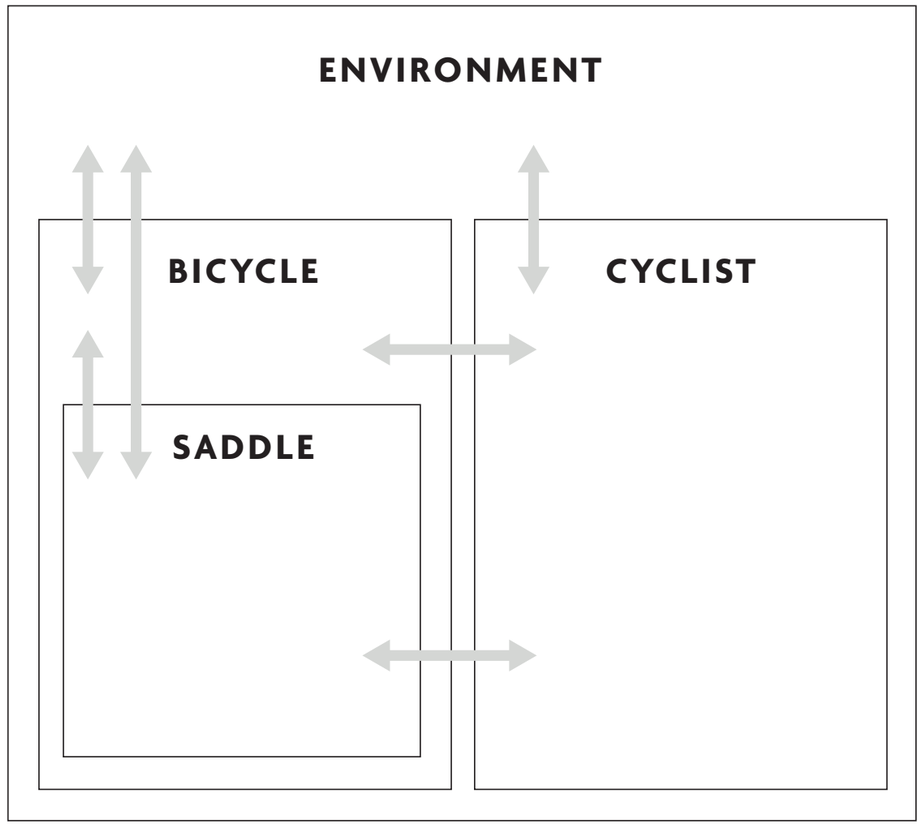


Figure 5: Adapted interaction model by Dirken (1997)

2.2 **CYCLIST**

HUMAN ANATOMY

The anatomy of the cyclist is an essential factor for the saddle choice. While there are many more, below is an overview of the key factors.

• **Sit bone distance**: The weight on the saddle should be primarily carried by the ischial tuberosity, also known as the sit bones. The width between the sit bones is dependent the natural pelvic width of the cyclist and the rider's posture on the bike. In a more aggressive riding posture, the area on the sit bones contacting the saddle is closer together due to the converging bone shape. This asks for a narrower saddle width (Sauer, Potter, Weisshaar, Ploeg, & Thelen, 2007).

• **Perineum**: The perineum is the area between the anus and the external genitalia in both males and females. Because it is comprised of soft tissue, pain and numbness are often result of excessive pressure on this area (Schrader, Breitenstein, & Lowe, 2008).

• **Natural Pelvic tilt**: In a standing position, the pelvis has a tilt that greatly varies from person to person. In a more inclined cycling position this tilt increases (Sauer, Potter, Weisshaar, Ploeg, & Thelen, 2007).

• **Lumbar Flexibility**: Personal variations in lower back flexibility affect the ability to be in a more aggressive riding posture (Sauer, Potter, Weisshaar, Ploeg, & Thelen, 2007).

• **Body Mass & Fat**: The weight of a person influences the pressure on a saddle. Also, the more fat one has, the more natural cushioning the person experiences (Vink, 2023).

• **Gender**: There is a distinction between men and women considering the sitting area. Therefore, more and more research is done to gender differences and saddle comfort (Potter & Sauer, 2008). However, some argue that there should be no women's and men's saddles, since saddle requirements may vary more between individuals in a group than between the groups themselves (Velde, Interview, 2023).

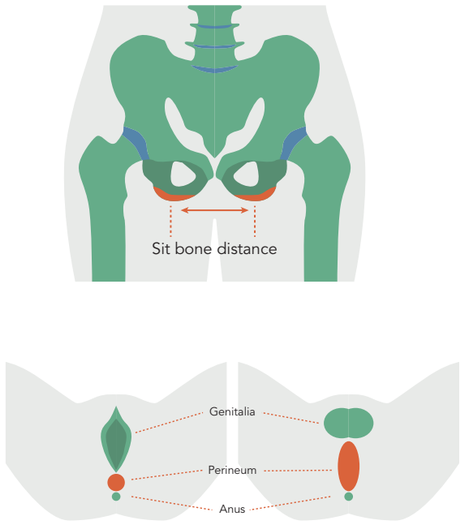


Figure 6: Important human anatomy factors for cycling. (1) Sit bone distance, (2) perineum, (3) pelvic tilt, and (4) lumbar flexibility.

DRIVING POSITION

The riding position significantly impacts the distribution of pressure on the sit area as shown in Figure 7. City bikes tend to distribute pressure toward the sit bones, while time trial bicycles place more pressure towards the perineum (Sauer, Potter, Weisshaar, Ploeg, & Thelen, 2007). Often different driving positions require different types of saddles, which also influences the pressure distribution.

DRIVING INTENSITY

The perception of a saddle is influenced by various factors, including the duration of time spent on the bike, the degree of movement while on or off the saddle, cadence, power output, and more (Miller & Berry, 2007). Generally, the more pressure is put on the paddles, the less pressure is on the saddle.

PERSONAL PREFERENCE

Saddle selection is highly individual, as perceived comfort can vary greatly among cyclists. While some may find sitting on a simple wooden plank tolerable, others may struggle to find any saddle that provides lasting comfort. Even with thorough bike fitting, discomfort can persist, as Boon, a bike fitter states during an interview (2023).

Additionally, achieving a comfortable riding experience cannot be solely reliant on measurements. While they can provide valuable guidance, it's crucial to prioritize individual preferences and rider comfort in the decision-making process (Boon, 2023; Christiaans, 1998; Baino, 2011).

OTHERS

There are many other factors that play a role when designing a saddle, like hygiene, experience level and mental status.

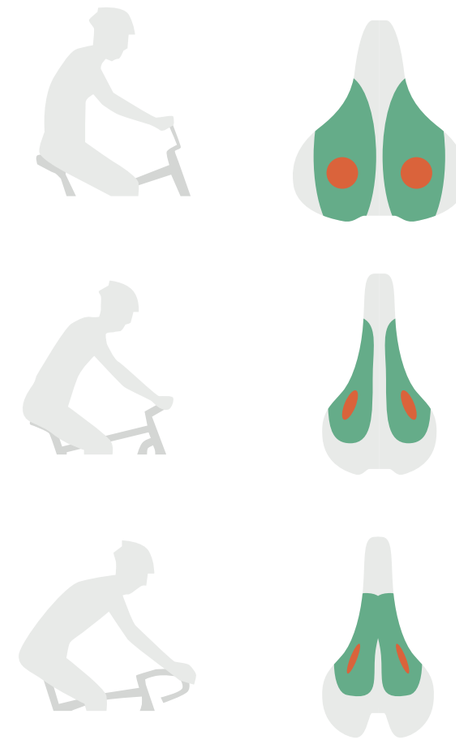


Figure 7: A saddle pressure distributions comparison on the saddle for different driving styles.

2.3 **BICYCLE**

BICYCLE TYPE

Bicycles come in various types, each offering unique characteristics and different amount of quality. Some allow for aggressive riding positions, while others focus on comfort for leisurely rides. Some have very stiff frames, while others have full suspension. All these characteristics influence the experience on the bike and the saddle (Christiaans, 1998).

BIKE FITTING

To achieve comfort and efficiency on the saddle, a good bike fit is essential (Ayachi, Dorey, & Gaustavino, 2015; Napier & Heron, 2022; Bressel & Larson, 2003). Failing to achieve this can lead to discomfort, pain, and even injuries (Boon, Interview, 2023). Overextending your legs may result in excessive movement on the saddle, while handlebars positioned too far from the saddle can exert extensive pressure on the perineum. The main settings include the following:

- **Frame Size**: Choosing the right frame size is essential to ensure a good posture on the bike, since this determines the range of the settings listed below.
- **Handlebar Height**: The height of the handlebar determines the posture on the bike. The lower this is, the more inclined the rider sits, resulting in more perineal pressure.
- **Handlebar reach**: This is dependent on the length of the torso and arms. And should be set so that there is a slight bend in the arm and pressure is well distributed between the arms and the saddle.
- **Saddle Fore-Aft Position**: This setting determines the saddle's forward or backward placement, impacting the distance between the saddle and handlebars. Furthermore, time trial riders often shift the saddle forward for a more efficient pedal stroke.
- **Saddle Height**: The saddle's height plays an important role in ensuring the efficiency of the pedal stroke.
- **Saddle Tilt**: Typically, saddles are set in a level position, but tilting the saddle forward can provide advantages, especially in more aggressive riding postures or to alleviate pressure on the perineum.

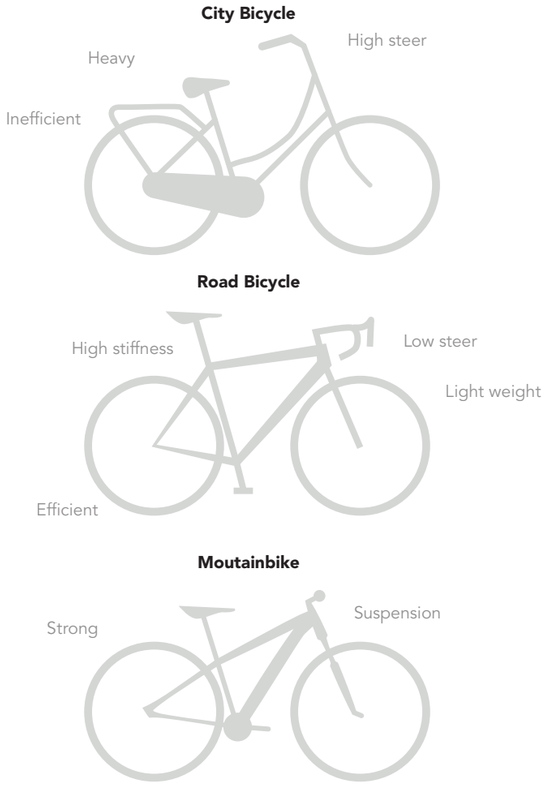


Figure 8: Different types of biycles.

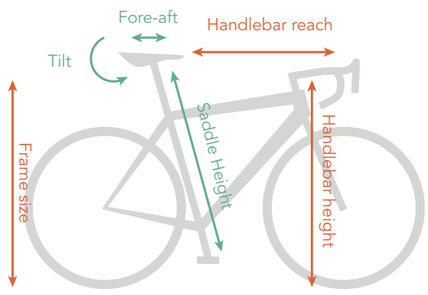


Figure 9: The most important bike fitting parameters.

2.4 **SADDLE**

With some exceptions, bicycle saddles have a relatively standard design, generally comprising of a shell, rails, padding, and a cover. Some saddles, particularly cruisers and city bicycle, feature suspension for more comfort. This is illustrated in Figure 10.

Cover: The saddle cover protects the padding and holds it in place while also providing the rider with grip and stability.

Padding: The padding is responsible for delivering a more spread-out pressure distribution on the saddle. It is generally made from materials such as foam, gel, or a 3D printed structure. Premium saddles often incorporate padding with varying stiffness levels across the seat to enhance pressure distribution. It is commonly believed that thicker padding links to better comfort. This may hold true for short rides. However, on longer journeys, a firmer saddle is often favoured because it primarily distributes pressure to the sit bones, saving the softer tissues from discomfort (Bakker, Interview, 2023).

Shell: The shell is the main construction of the saddle. It is frequently made from leather, (reinforced) plastic or carbon. Stiff saddles are often more efficient, but they compromise on comfort.

Suspension: Suspension on the saddle often involves a spring connecting the shell to the rails. It is incorporated into a saddle to reduce impact between the seat and the cyclist's sitting area, enhancing comfort. Too much suspension reduces efficiency, because energy is transferred to the flexibility of the material instead of to the pedals.

Rails: The rails connect the saddle to the seatpost clamp and provide stiffness to the saddle. Rails are typically available in standardized measurements and are commonly constructed from materials such as steel, aluminium, or carbon.

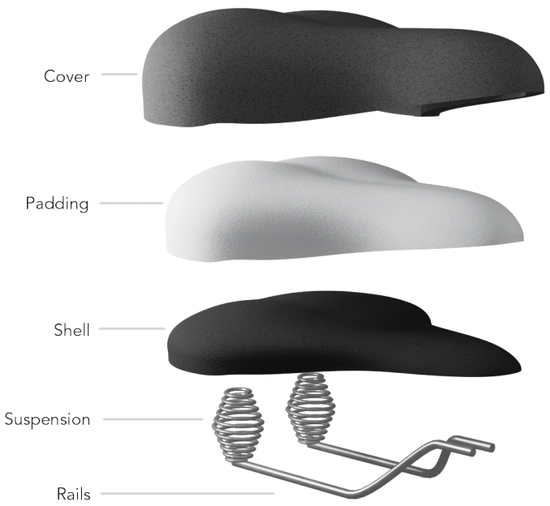


Figure 10: Main components on a standard bicycle saddle.

TYPES OF SADDLES

The properties of a bicycle saddle are closely linked to the specific type of cycling it is intended for. Time-trials bicycles are all about speed, therefore allow for an aggressive driving position while being as lightweight as possible. On the other hand, city bikes are more comfortable and durable, which is beneficial for short trips through an urban environment.

Bakker (2015) placed various driving styles along a single axis based on driving posture. This is relevant since the posture on the bicycle is an important factor for bicycle saddle design. A simplified variant of this one-line graph is shown in Figure 11. In this graph, examples of bicycle saddles are placed to show the differences between the saddles for different driving styles.

Although saddles within a given category may show many variations, it is possible to identify common, overarching features. The terms used to explain these differences are explained on the next page.

Typically, saddles designed to accommodate a more aggressive (inclined) riding position are narrower, feature a pronounced waved side profile, have minimal padding, and feature a larger frontal cutout. Saddles tailored for extremely aggressive positions also tend to be shorter. Both city bike saddles and race saddles often have significant curvature, while positions in between tend to have a comparatively small curvature.

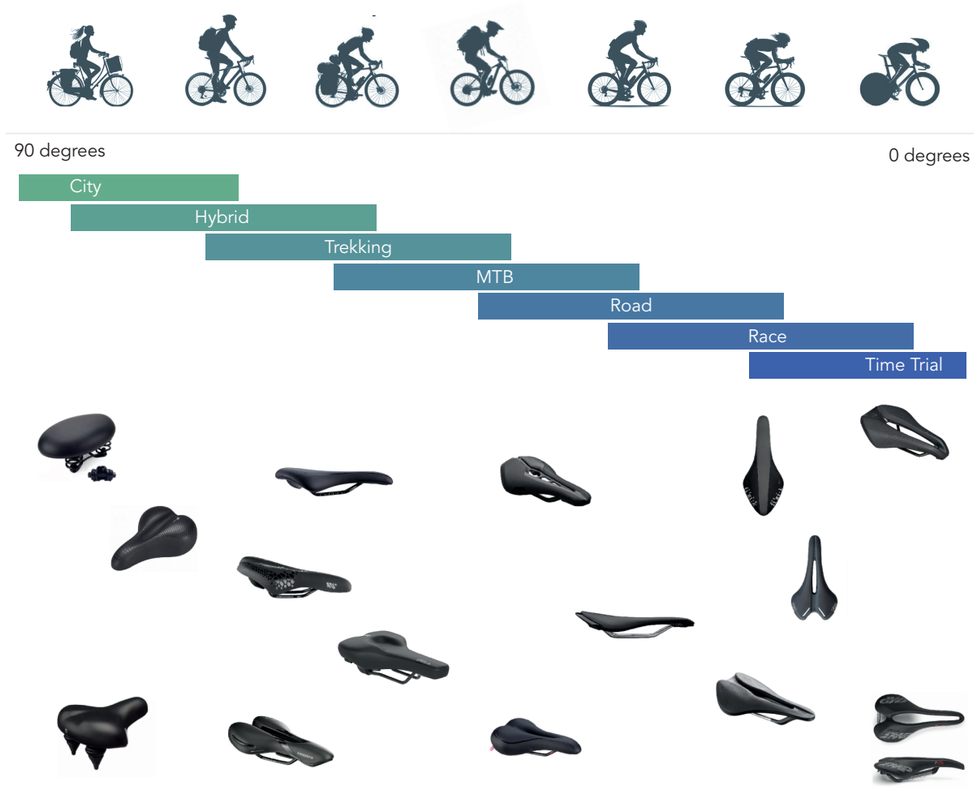


Figure 11: Saddle designs for different types of cycling based on driving position.

SADDLE PARAMETERS

There are many differences among saddles. Down below the most important parameters for saddle design are listed.

Saddle width: In the context of city bicycles, the width of the saddle holds less significance, provided it exceeds the width of the rider's sit bones. However, for sportier bicycles, the saddle's width becomes a critical consideration. It should offer support to the sit bones without being excessively wide, which could hinder the rider's movement and introduce rubbing and chafing (Miller & Berry, 2007).

Saddle shape: Two types of saddle shapes are often distinguished: pear-shaped, characterized by a larger rear area that allows for comfortable adjustments in riding position, and T-shaped, which provides additional space for the thighs, preventing rubbing and chafing.

Nose length: A saddle with a shorter nose permits a more aggressive riding posture while minimizing pressure on the perineum. However, as the nose shortens, one's control over the bicycle decreases (Schrader, Breitenstein, & Lowe,, 2008).

Saddle profile: A bicycle saddle's side profile can be waved, flat or anything in between. A flat profile allows for movement on the saddle, which is useful when driving in various positions. It is typically favoured for an upright riding posture. In contrast, waved saddles maintain a more constant riding position. Additionally, the presence of a kicktail at the saddle's rear aids in tilting the rider's pelvis forward, allowing for a more aggressive riding posture or helping people with low lumbar flexibility (Bakker, Interview, 2023).

Saddle curvature: From a rear perspective, the curvature of a bicycle saddles can be either flat or curved. Typically, flat saddles allow subtle adjustments in seating position. However, a well-matched curved design can keep the driver centred and enhance control. Next to that, a curved bicycle saddle will provide more sideways hip movement, ideal for less flexible riders (Montfort, 2023; Schrader, Breitenstein, & Lowe, 2008).

Cutouts: A cutout, often referred to as a pressure relief, is a recessed channel along the centre of a bicycle saddle where material is removed to alleviate pressure on sensitive soft tissue areas (Bressel & Larson, 2003). Typically, the cutout's position is adjusted to correspond with the rider's posture; it is shifted more towards the front for aggressive riding positions and towards the rear for more upright postures.

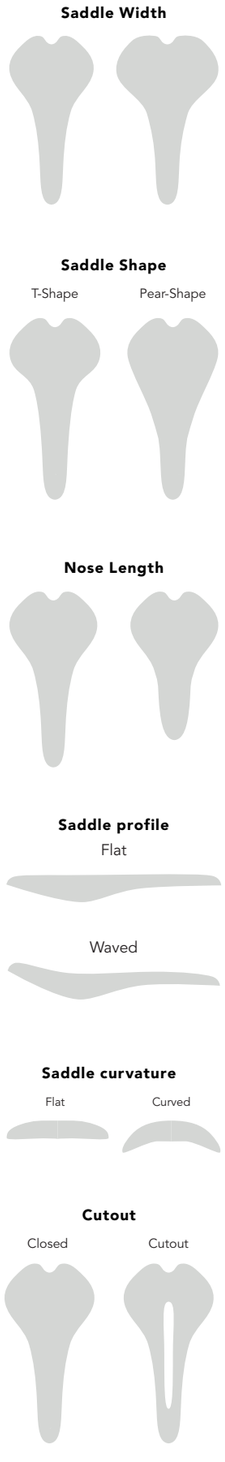


Figure 12: The most important saddle design parameters.

2.5 ENVIRONMENT

There are several environmental influences that impact the experience on a bicycle saddle. These include weather, driving dynamics, and terrain. Also, the type of clothing a cyclist is wearing can be considered as an environmental influence. The type of clothing is very important because it can prevent, sores, chafing, and other types of discomfort (Napier & Heron, 2022).

2.6 CONCLUSIONS

CYCLIST-SADDLE INTERACTION OVERVIEW

Below, you'll find an overview of the main parameters that are influential for the experience on the bicycle saddle, divided in the four topics of the adapted Dirken model: cyclist, bicycle, saddle, and environment. Arrows are added between catagories that are closely related. An important triangle can be made between bicycle settings, saddle shape and human anatomy since these are factors that are highly related to one another.

KEY TAKE-AWAYS

- Different anatomies require different saddles to ensure comfort.
- Different driving styles require different saddles to ensure comfort.
- While data and measurements of the human body can offer valuable guidance in selecting the right saddle, achieving a comfortable experience is also a matter of personal preference.
- A good bicycle fit is essential for a comfortable experience and efficient ride.

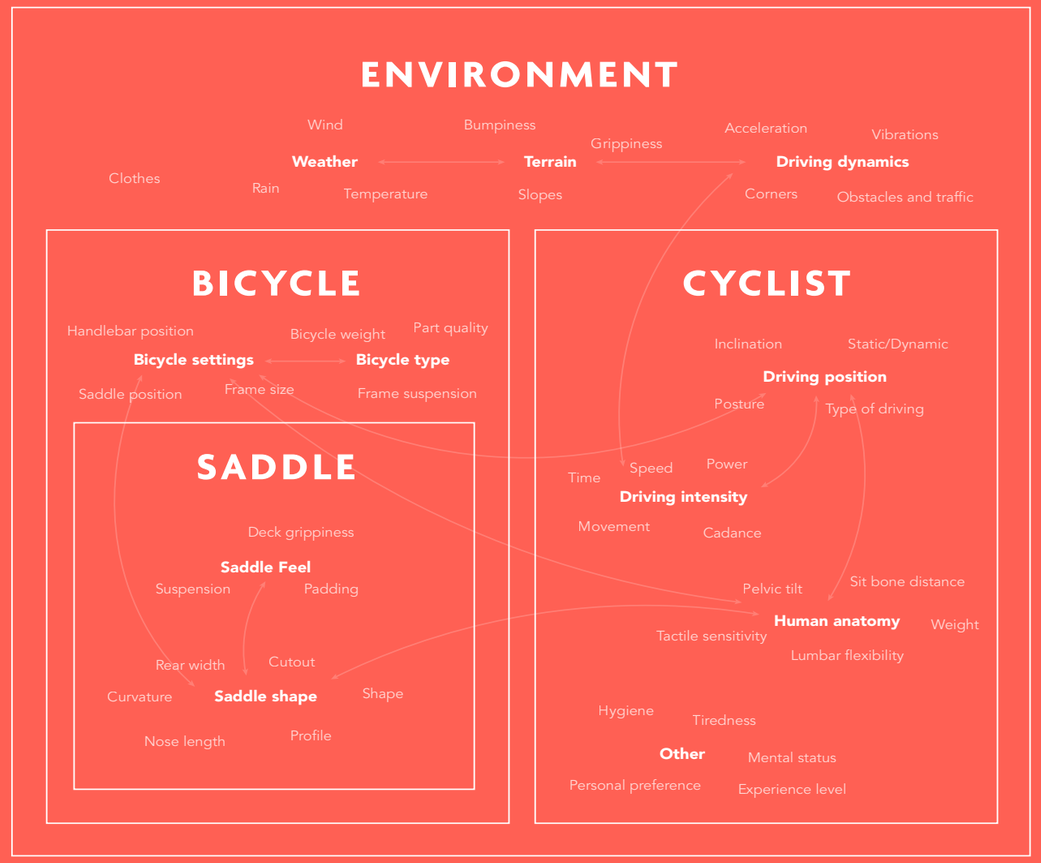


Figure 13: Cyclist, bicycle, saddle, and environment parameters influential for the experience on the bicycle saddle.

3. FINDING OPPORTUNITIES

To create a novel bicycle saddle that fulfils the needs of the user, the user needs to be understood. This chapter explains how opportunities were found by research, brainstorm sessions, and interviews with experts in the cycling community.

3.1 **BRAINSTORM SESSION WITH CYCLISTS**

After an individual brainstorm session, of which outcomes can be found in Appendix 1, a session involving three recreational cyclists was conducted. The goal was to gain insights into common issues faced by cyclists in relation to bicycle saddles. This session encompassed four key components:

1. **Flower association**: Participants were encouraged to write down their immediate thoughts and associations with bicycle saddles. This exercise aimed to stimulate their thoughts and retrieve memories related to their experiences with saddles.
2. **Scenarios**: The cyclists were asked to document at least three instances in which they had either positive or negative encounters with their saddle.
3. **Interview**: A series of questions were asked about personal experiences and perceptions regarding bicycle saddles.
4. **Brainstorming**: Cyclists brainstormed and proposed ideas for enhancing various aspects of the bicycle saddle experience.

INTERESTING FINDINGS

• Saddle discomfort may arise due to various factors, including chafing against the nose, prolonged periods of inactivity, extended cycling sessions, discomfort in an aerodynamic position, infrequent breaks, and rough MTB tracks.

• The most commonly affected areas are the perineum and sit bones.

• Some cyclists opt to stand out of the saddle to alleviate discomfort.

• Overall, participants reported relatively low levels of pain experienced during short trips. However, discomfort increased on longer trips.

• Participants noted they currently use the saddle that came with their bike and indicated a preference for basing future saddle purchases on user reviews rather than seeking professional advice.

• The participants also did not consult professional help for setting their bicycle saddle. They rather relied on rules of thumb and “what felt right”.



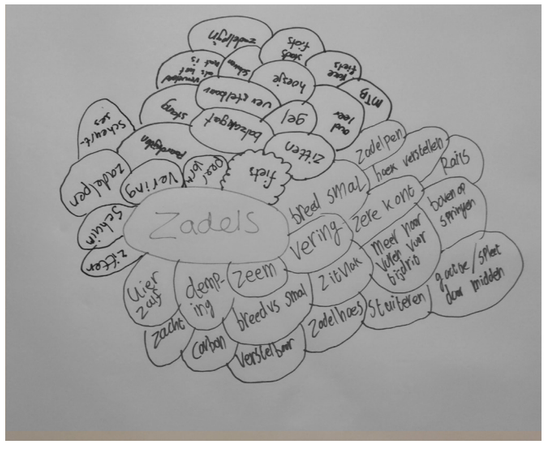


Figure 14: Brainstorm session with cyclists. Session itself (left) and results from Flower Association (right).

3.2 **EXPERT INTERVIEWS**

To comprehend the challenges and requirements of designing a bicycle saddle, I conducted five interviews including a professional cyclists, bike fitter and designers specialized in bicycle saddles. The first objective was to identify common issues cyclists face while cycling on their saddles. Next to that, three ideas were created to form a discussion. Some of the questions asked in this interview can be seen in Appendix 2.

INTERESTING FINDINGS

• Saddle sores are often a result of having the wrong pressure distribution on the saddle.

• Saddle comfort is very subjective. Everyone has a different anatomy and a different personal preference.

• Many people are not well informed about what type of saddle is ideal for them. Most people base their saddle choice on look and feel.

• There are many cyclists buying multiple saddles before finding the right one.

• A good bike fit is essential for a comfortable saddle fit.



Figure 15: Expert meeting with BBB.

PROPOSING 3 IDEAS

Three diverse ideas have been created to form a discussion with experts. These have also been prototyped and tested. More on this can be read in Appendix 3.

1 | BISTABLE COMPLIANT SADDLE

Many people experience saddle sores when spending an extensive time on the saddle (Miller & Berry, 2007). For trips over 64 km, most cyclists experience perineal and genital numbness and/or ischial tuberosity pain (pain around sit bones) (Leibovitch & Mor, 2005) (Dettori & Norvell, 2012). Research on car seats shows that movements in the seat relief pressure points during long sits. This idea proposes a bicycle saddle that can be transformed during cycling to relief and relocate pressure points for long trips.

2 | EMBROIDERED PRESSURE SENSORS

More and more data is gathered during sports. Pressure sensing saddle covers exist; however, these are mostly used during bike fits to improve comfort, rather than to track performance. A pressure sensitive saddle could identify bobbing and swaying, wrong positioning, and track posture. This idea proposes a bicycle saddle with integrated pressure sensors that tracks data about posture and posture variation to create a more efficient ride.

3 | RENTAL BICYCLE SADDLE

Nowadays many companies that design bicycle saddles try to find ways to create padding with variable stiffness throughout the saddle to 'perfectly' support the bodyweight on the right spots. Rental- and shared-bikes saddles are used by many people with different anatomies and wishes, and therefore, ideally have a variable stiffness throughout the saddle. This idea proposes a bicycle saddle with adjustable stiffness throughout the padding to accommodate multiple anatomies.

IDEA PROPOSAL CONCLUSION

Appendix 4 delves deeper into the desirability, feasibility, and viability of the three ideas based on the meetings and research. In conclusion, idea 1 emerged as the top scorer across all three criteria. **Nevertheless, the discussions revealed another exciting use case: a saddle that offers adjustability to better accommodate the driver's anatomy, driving style and preferences.**

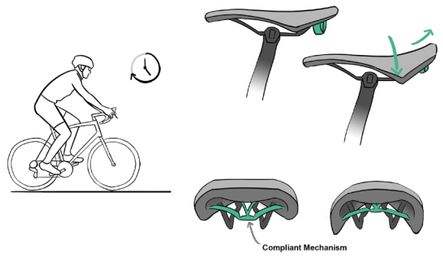


Figure 16: Illustrations explaining the ideas.

3.3 CONCLUSIONS

KEY TAKE-AWAYS

- Many recreational sport cyclists experience saddle sores at the perineum and sit bones. Especially on longer trips.
- Many cyclists base their saddle purchase on look, feel, and reviews.
- Many cyclists buy multiple saddles before finding the right one.
- Most cyclists do not do a proper bicycle fit.

OPPORTUNITY DIRECTIONS

From the research, seven opportunity directions were derived. More information and solution examples are shown in Appendix 5.

- Reduce discomfort over extended time.
- Reduce discomfort in different driving positions.
- Allow for different anatomies on one saddle.
- Allow for different driving conditions.
- Practical solutions.
- Provide feedback to the user.
- For fitting purposes.

OPPORTUNITY CHOICE

Interestingly, conclusions from Chapter 2 showed that choosing the right saddle and doing a proper bicycle fit is very important to accomplish a comfortable saddle experience. However, the interviews conducted with cyclists and experts showed that this is not what currently happens. Often people purchase a saddles based on look, feel, or review, and set their bicycle to 'what feels right' instead of looking at the cyclist's anatomy, driving style or preferences. This explains why so many cyclists experience sores. During an interview (2023), saddle designer Piet van der Velde said the following:

> *As a saddle manufacturer, you can incorporate options into the saddle so that users can customize it according to their preferences. The more choices available, the better. [...] Many individuals try multiple saddles before finding one that suits them, sometimes purchasing up to 10 saddles in search of optimal comfort.*
>
> - Piet van der Velde, Interview, 2023

Therefore, it has been decided to design a bicycle saddle with a variable geometry that can be set after purchasing, just like other bicycle settings. This way the saddle can be tweaked to fit to the cyclists needs and wishes, resulting in more comfort. Therefore, eliminating the need to buy multiple saddles until the right one is found or do an expensive professional bike fit. More om this is explained in Chapter 5. This falls into two opportunity directions; allow different anatomies on one saddle and reduce discomfort in different driving positions. What parameters will be adjustable will be explored in the next chapter.

Design a bicycle saddle with a variable geometry

4. TESTING VARIABLE GEOMETRY SADDLES

As shown in Chapter 2, there are a number of properties of a saddle that can be adjusted. Therefore, user tests have been conducted to find which property has most impact. To validate and refine my assumptions, two types of user tests have been conducted: evaluating the perceived shape differences for variable geometry saddles and outdoor cycling tests. A more extensive explanation on the methods, results and discussions for these tests is shown in Appendix 6.

4.1 MINIMAL PERCEIVED SHAPE DIFFERENCEE

To understand if cyclists could even feel a noticeable difference between changes in a particular property of a saddle, a user test has been conducted. For this, 10 participants have been asked to cycle on three different variable geometry saddles. Every 30 seconds the setting of the saddle would change, and the participant was asked to rate the saddle between two extremes on a Likert-scale (for example: from too flat to too round). An adapted method from van Veen (2016) was used. The assumption by Van Veen is that if a participant scores two settings of the same saddle differently, they feel a difference. Next to quantitative data, qualitative data was gathered by means of interviews.

Three different variable geometry saddles were created, as shown in Figure 17. Each saddle has a single parameter that is adjustable namely, curvature, profile, and nose-width. These parameters have been chosen based on the expected high impact that it has on comfort and on conclusions of discussions with bicycle saddle designers.



Figure 17: The variable geometry saddles used during the tests.





Figure 18: Participant during the test

QUANTITATIVE RESULTS

In Figure 19, the average scores and standard deviation per setting of each saddle can be seen. On the vertical axis are the scores of the Likert-scale. On the horizontal axis are the four different settings for each saddle. The red line shows the neurtal score (for instance for the curvature saddle, right in between too flat and too round).

There is significant highly negative correlation for both the curvature- and profile-saddle. However, there is no significant correlation found between settings and scores for the width saddle.

From the one-way repeated measured ANOVA, a similar outcome is present. The within-subject effect tests show that significance for both the curvature- and profile-saddle. For the curvature-saddle 61.5% of the scores is accounted for by the setting of the saddle, this is 46.2% for the profile-saddle. For the width-saddle no significant results were found.

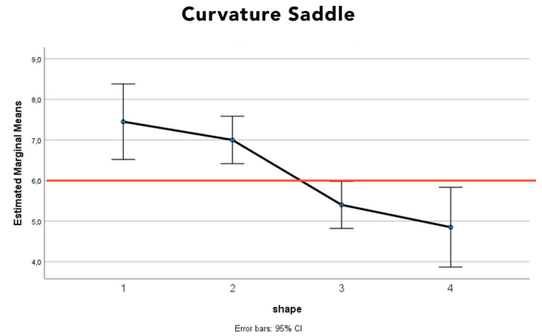
More interestingly, paired T-tests between each setting per saddle shows that for both the curvature- and profile-saddle there is a significant difference between all settings that are at least two steps apart. Next to that, there is a significant difference between settings 2 and 3 for the curvature saddle and settings 3 and 4 for the profile-saddle. Again, for the width-saddle no significant results were found.

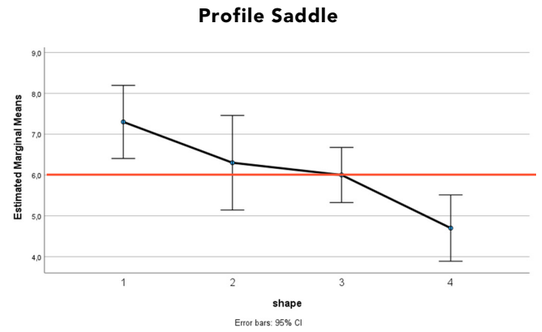
QUALITATIVE RESULTS

Generally, the interviews backed up the results of the quantitative research. For both the curvature- and profile-saddle, many participants were able to distinguish between a one-step difference, and most between a two-step difference. There was a difference recognizable between settings of the width saddle, however, perceived setting difference did not consistently correspond to the actual setting difference.

For each saddle the preferences between different settings of each saddle was large. While some liked a fairly flat saddle, other disliked it and vice versa.

For the profile-saddle, some participants highlighted that in tops and drops position, a different setting would be preferable.





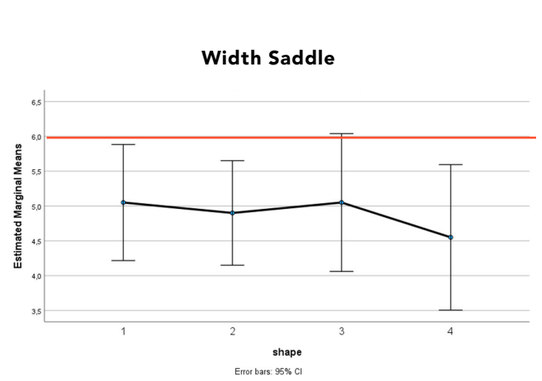


Figure 19: Average scores of all 10 participants for each setting for the three saddles. Vertical axis shows the scores, horizontal axis shows the setting. The vertical bars show the standard deviation.

4.2 OUTDOOR CYCLING TESTS

The tests described before only evaluate discomfort in a short time span. Comfort may drastically change on longer trips. Therefore, a 50km and 80km trip were done using the curvature-saddle and profile-saddle respectively. The findings of these tests have been summarised in the list down below.

RESULTS

• For both saddles there is a clear difference between saddles settings even on longer rides.

• There is a clear optimum in saddle setting for comfort. For both saddles the extreme flat position was uncomfortable.

• For tops and drops position, a different setting might be beneficial, this was most clear on the profile-saddle.



Figure 20: Image of me cycling during the outdoor cycling test.

4.3 CONCLUSIONS

TAKE-AWAYS

• Especially for the profile saddle, there is a large difference in preferences between people, as shown by the large standard deviation.

• For both the profile- and curvature-saddle a 1 step difference was perceived by a lot of participants, and a 2 steps difference by almost all participants.

• Tops and drops may require a different profile setting.

SADDLE TYPE CHOICE

The first test showed that there is generally a higher standard deviation per setting for the profile-saddle, while still seeing a significant correlation between score and setting. This means that the preferences between people differ greatly. This was also mentioned during the interviews. Next to that, personal preference between settings for tops and drops positions were also clearer for the profile saddle. This could be backed up by the outdoor cycling tests.

Therefore, the profile is chosen as the main property to be adjustable.

Design a bicycle saddle with a variable profile

Many participants noticed a one-step difference in the rear mechanism for the profile saddle, which were increments of 5 degrees. These increments are rather large. Therefore, it is expected that a smaller step size, namely at least 3 degrees would result in finding an even better fit.

For the nose mechanism, which also deformt 15 degrees, the participants noted a less notable difference between settings, therefore it is expected that 5 degree increments is sufficient.

Having continuous adjustablity would probably result in an even better fit.

Rear mechanism should have increments of 3 degrees or smaller (Need 2)

Nose mechanism should have increments of 5 degrees or smaller (Need 3)

The rear and nose angle should be adjustable without steps (Wish 1)

5. REDEFINING THE ASSIGNMENT

Based on the information gathered in earlier chapters, a redefined assignment can now be formu-lated. This chapter summarizes the most noteworthy discoveries, concluding with an assignment and research questions, as well as summarizing the most significant needs and desires identified throughout the research process.

5.1 **REDEFINED ASSIGNMENT**

In summary, it's common for cyclists to overlook their anatomical and driving style needs and preferences when choosing a saddle, even though these factors are crucial for a comfortable riding experience.

Currently, there are two main approaches for addressing saddle discomfort as a customer: either purchasing multiple saddles until finding the right fit or investing in a professional bike fitting, both of which can be expensive and cumbersome. However, a saddle with adjustable geometry offers a practical solution, bridging the gap between these options. By providing various adjustment options, such a saddle can accommodate different anatomies, riding styles, and preferences. Previous research showed that especially a variable profile saddles has a significant impact on the experience on the saddle. Besides, this property was also mentioned by multiple experts as an important parameter for comfort.



Figure 21: Traditional options of either buying many saddles or doing a professional bike fit to resolve saddle sores and the option of buying a variable profile saddle.

Many cyclists lack sufficient education on bike fit. By introducing a new variable to the bicycle, namely saddle profile, it is even more important that customers understand how these parameters influence their cycling experience. Therefore, the user should be educated so he or she can benefit most from it.

TARGET GROUP: RECREATIONAL CYCLISTS

The target audience for this product are recreational cyclists. This choice comes from the fact that this group frequently encounters saddle sores. This issue arises primarily because they often lack access to or the financial means for professional bicycle fittings and good information, unlike their professional counterparts. Nevertheless, they frequently engage in long tours where proper bicycle and saddle fittings are essential for comfort. Additionally, the weight of the saddle plays a less important role for recreational cyclists compared to professionals, as the saddle is expected to be more heavy compared to other saddles.

ASSIGNMENT

Design a road-bicycle saddle for recreational cyclists that has a variable profile to accommodate different anatomies, driving styles, and preferences.

SUB-ASSIGNMENTS

Educate users on bicycle and saddle fit

RESEARCH QUESTIONS

The following research question were asked;

- How does saddle profile relate to the anatomy, driving style and personal preference of the cyclist?
- How to design a saddle with a variable profile?
  - o How to morph the profile of a saddle while keeping it durable and comfortable?
  - o What range of saddle profiles is required?
  - o What other saddle parameters are required?
- Does the new design work like intended?
  - o Create a working prototype and evaluate it by doing user tests
- How to educate customers on bicycle and saddle fit?

5.2 **NEEDS & WISHES**

Based on the research outlined in previous and upcoming chapters a list of needs and wishes has been formulated. Applying this list as a foundation, design choices have been made.

NEEDS

1. The saddle should introduce a pressure distribution similar to a properly fitted saddle by conforming to the pelvic's shape and tilt.

2. The rear part should be adjustable within a 0-to-15-degree range with a minimum of 6 steps

3. The nose part should be adjustable within a 0-to-15-degree range with a minimum of 4 steps

4. The stiffness throughout the saddle should be similar to comparable saddles.

5. The saddle should hold a person of 100 kg.
Safety factor of 3 = 3000N (SafetyCulture, 2024)

6. Both the rear and nose angle should be changeable within 3 minutes (off the bike)

7. The saddle fitting and adjustment process should be doable using only standard tools

8. The saddle should fit on a standard saddle clamp

9. The saddle should not weight more than 350 grams

WISHES

1. The rear and nose angle should be adjustable without steps

2. The saddle should not weight more than 250 grams

6. PELVIC TILT AND SADDLE PROFILE

As highlighted in Chapter 3, the most common saddle sores often occur at the perineum and sit bones due to incorrect pressure distribution on the saddle. This issue commonly arises from using a saddle profile that doesn't match the cyclist's pelvic tilt. This chapter delves into the causes of perineum and sit bone sores, examines the factors affecting pelvic tilt, explains the idea behind the saddle profile, and explores how these are all related.

6.1 SORES BY UNBALANCED PRESSURE DISTRIBUTION

Both recreational and elite cyclists commonly encounter saddle pain and sores while cycling. These are most often caused by an unbalanced pressure distribution (Bury, Leavy, Lan, O'Connor, & Jancey, 2021; Miller & Berry, 2007). Most of the pressure should be carried by the sit bones, while the rest should be distributed over the softer tissue. When this is not achieved, discomfort around the ischial tuberosity (sit bones) and pain due to excessive pressure on the perineum are the most common results (Christiaans, 1998).

ISCHIAL TUBEROSITY

A common medical complaint related to saddles is discomfort around the ischial tuberosity (Keytel, 2002). According to Dettori & Norvell (2012), this issue affects approximately half of all cyclists. Such pains often stem from incorrect saddle shape or a saddle that is excessively soft (SQLab, n.d.). These sores are particularly noticeable at the start of the cycling season, as riders acclimate after a few rides, but may persist for some individuals (Mellion, 1991).

PERINEAL COMPRESSION

Excessive pressure on the perineal region can result in various complications. Compression of the pudendal nerve within Alcock's canal can lead to genital numbness and sexual dysfunction, including erectile dysfunction (Baran, 2014). Estimates vary, but up to 90 percent of cyclists may experience at least one of these symptoms occasionally (Leibovitch & Mor, 2005; Dettori & Norvell, 2012; Baran, 2014). For some individuals, more severe conditions like Perineal Nodular Induration can develop, resulting in firmness in the perineal area, potentially requiring surgical intervention (Napier & Heron, 2022).

To prevent these sores, it is essential to achieve proper pressure distribution between the ischial tuberosity and perineum. To do so two criteria must be met; (1) having the right bike fit and (2) selecting the appropriate saddle (Mellion, 1991; Baran, 2014). To achieve the latter, it is especially important to consider the pelvic tilt as explained in the next chapter.

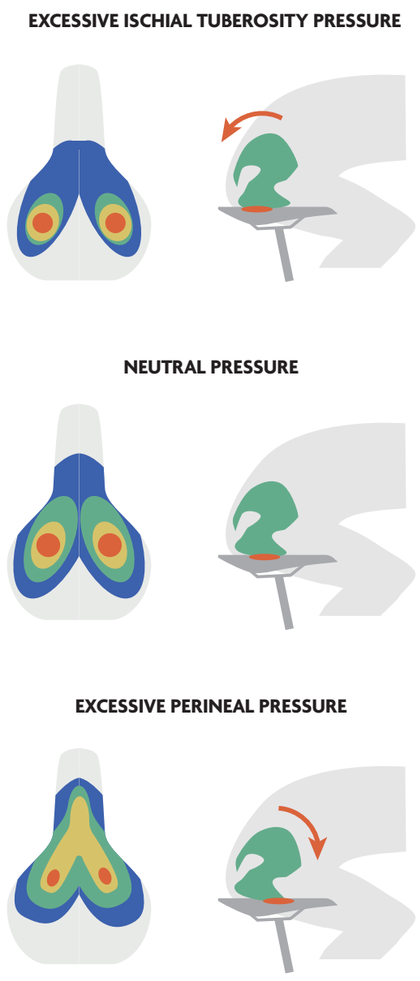


Figure 22: Pressure distribution on the saddle for different pelvic tilts.

6.2 PELVIC TILT

Pelvic tilt is often referred to as the movement or position of the pelvis in the sagittal plane (looking from the side) (Suits, 2021). Tilting the pelvis forwards has a similar effect as rotating the saddle upwards. The more the pelvis is rotated forwards, the more pressure is put onto the perineum, while moving the pelvis backwards puts more pressure on the sit bones. Pelvic tilt is the sum of many factors of which the natural pelvic tilt, lumbar flexibility and driving position are most important.

NATURAL PELVIC TILT

In natural standing position, there is difference between humans when looking at pelvic tilt. In literature three types of pelvic postures are described; Posterior (rotated forwards), Neutral, Anterior (rotated backwards) (see Figure 23). Between 75% and 85% of the population has a natural anterior pelvic tilt while 6% to 7% of the population has a posterior pelvic tilt. The rest is neutral (Herrington, 2011). Since the spine is connected to the pelvis, this natural tilt also has an influence on the rest of the upper body.

There is no significant difference in average pelvic tilt between cyclists and non-cyclists in a standing position. However, the range of pelvic tilt is something that could be trained (Antequera-Vique, 2022). On average people have a 21.9 degrees pelvic tilt range (Takaki, 2016), but for cyclists this is significantly higher compared to non-cyclists (McEvoy, 2007). Next to that, older cyclists tend to have lower pelvic tilt compared to younger cyclists (Antequera-Vique, 2022).

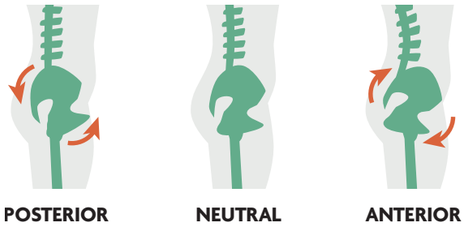


Figure 23: Posterior, neutral, and anterior pelvic tilt.

LUMBAR FLEXIBILITY

Lower back flexibility also known as lumbar flexibility, is an important factor when considering pelvic tilt. According to Sauer (2007), there is a negative correlation between lumbar flexibility and pelvic tilt. This is because when the lower back is not flexible, the pelvis compensates for this (seeFigure 25). The difference between people in the same position can be as high as 10 degrees. Interesting to note is that this phenomenon is only true for males not females. Generally, older cyclists have a lower lumbar flexibility compared to younger cyclists (Antequera-Vique, 2022).

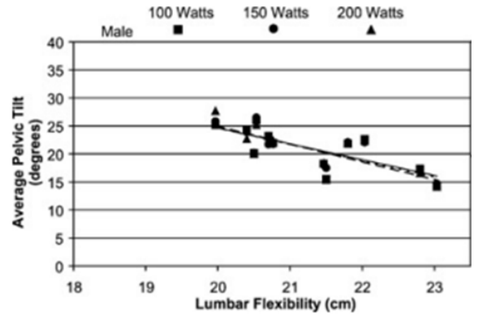


Figure 25: Correlation between lumbar flexibility and pelvic tilt.

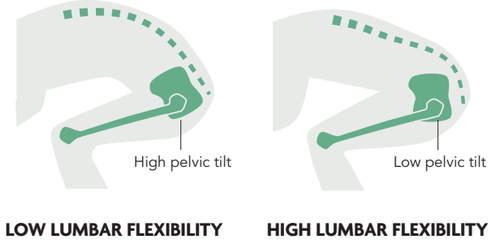


Figure 27: The effect of low and high lumbar flexibility on pelvic tilt.

DRIVING POSITION

During cycling, the pelvic rotation is not static. As shown in Figure 27, during one cycle the pelvic tilts in all three directions (Sauer, 2007). More apparent is that the sagittal tilt changes drastically in a tops (inclined) position compared to a drops (upright) position. Especially handlebar type and position are closely related to pelvic tilt (see Figure 26). The lower and further the handlebar, the greater the pelvic tilt (Antequera-Vique, 2022).

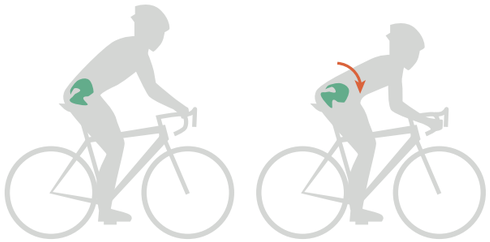


Figure 29: Effect of driving position to pelvic tilt on the saddle.

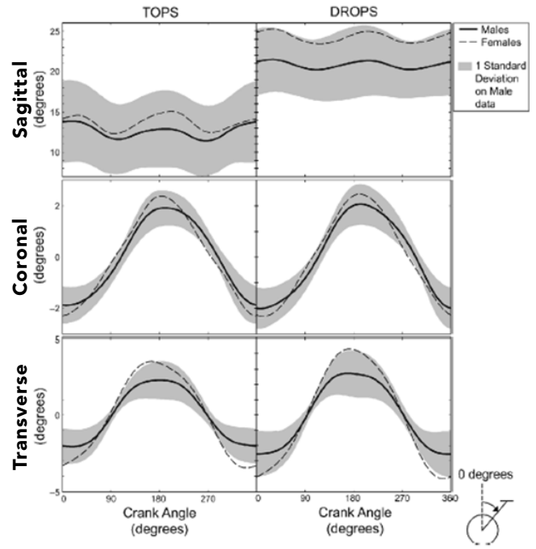


Figure 30: Pelvic movement in different direction on the saddle for a full paddle stroke for both tops and drops position.

6.3 SADDLE PROFILE

To change the pressure distribution, various adjustments can be made to the saddle, such as incorporating a cutout, shortening its length, or angling it downwards (Bury, Leavy, Lan, O'Connor, & Jancey, 2021). However, one of the most effective strategies is to modify the saddle's profile.

Saddles range from completely flat, to extremely waved, and everything in between (see Figure 28).



Figure 31: Saddle ranging from extremely flat (left) to exptremely waved (right).

Compared to flat saddles, waved saddles are shaped more like the pelvis when rolled forwards (anterior tilt). Therefore, waved saddles support more of the weight at the sitbones relieving pressure on the perineum as shown in Figure 29 (Stanbury, 2020). This is especially aparent for less flexible drivers or drivers who sit in a very inclined position, since than the pelvis is rotated more forward. However, because of the concave shape, the cyclists is somewhat stuck in one position. Therefore, a waved saddle is less versatile compared to a flat saddle.

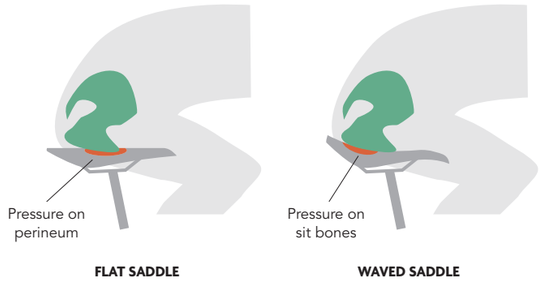


Figure 32: Pressure support for a flat vs waved saddle.

6.4 CONCLUSIONS

MAIN TAKE-AWAYS

- To prevent saddle sores, especially around the ischial tuberosity and perineal, it is essential to have the right pressure distribution on the saddle.
- A common cause of having the wrong pressure distribution on the saddle is by not having the right saddle profile for the particular pelvic tilt of the cyclist.
- Pelvic tilt is a function of many parameters of which the most important are natural pelvic tilt, lumbar flexibility, and driving position.

Therefore, to choose the right saddle profile, it is especially important to consider the cyclist's pelvic tilt (Need 1).

7. FINAL DESIGN: SCULP

A proposal has been made for a new saddle design featuring a variable profile. Additionally, a Fit Kit for home use is has been created to guide the users fitting journey. The name of the product is Sculp, which refers to the fact that the saddle can be sculped to conform to the needs and wishes of the user. This will also be the name used for future referencing. This chapter provides a brief overview of the key design decisions that have been made, including links to other chapters and appendices for a more detailed descriptions of these decisions.

7.1 PRODUCT IN USE

Using Sculp should be an ongoing process. Upon receiving the package containing the saddle and Fit-Kit, the user does a bicycle and saddle fit. While some may find the ideal fit immediately, others may need to make adjustments to optimize comfort. When the saddle is installed on a different bicycle, or if the rider decides to switch to a different riding style, such as from touring to racing, the fitting process should be repeated. Also, throughout the season, a rider's flexibility may change, and a different saddle profile might become more suitable (Bakker, Interview, 2023).

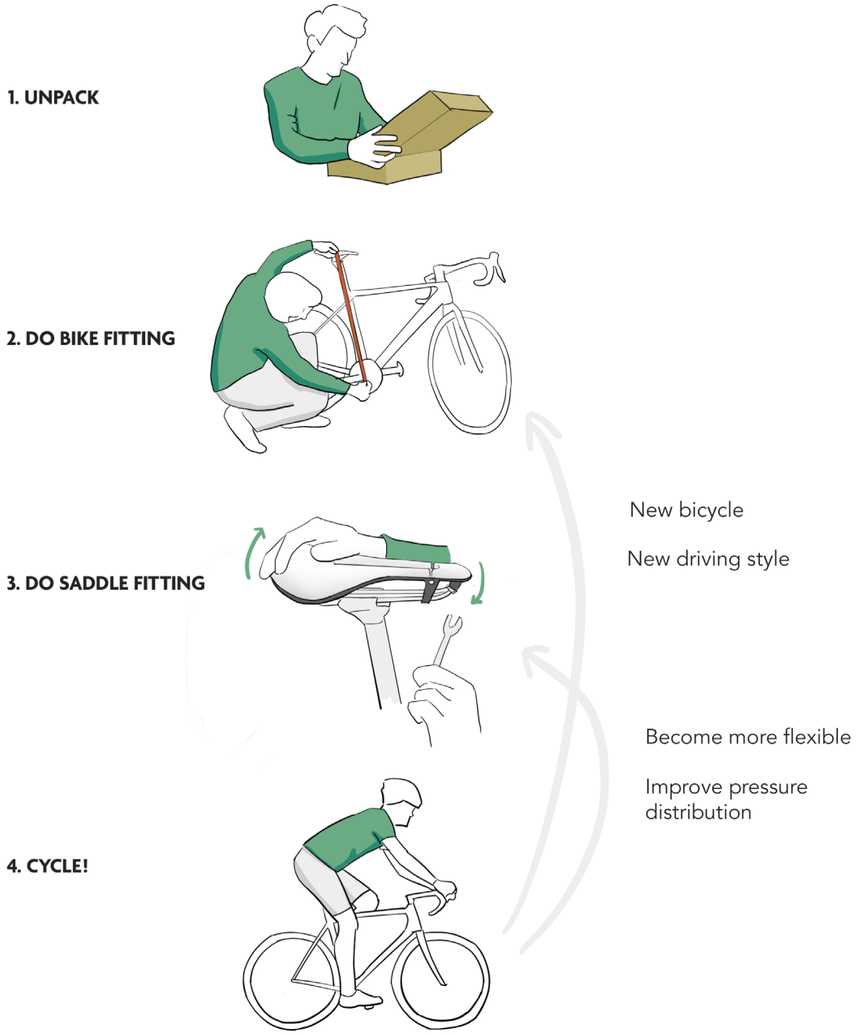


Figure 33: The itterative process of using Sculp.

7.2 **PRODUCT EXPLAINED**

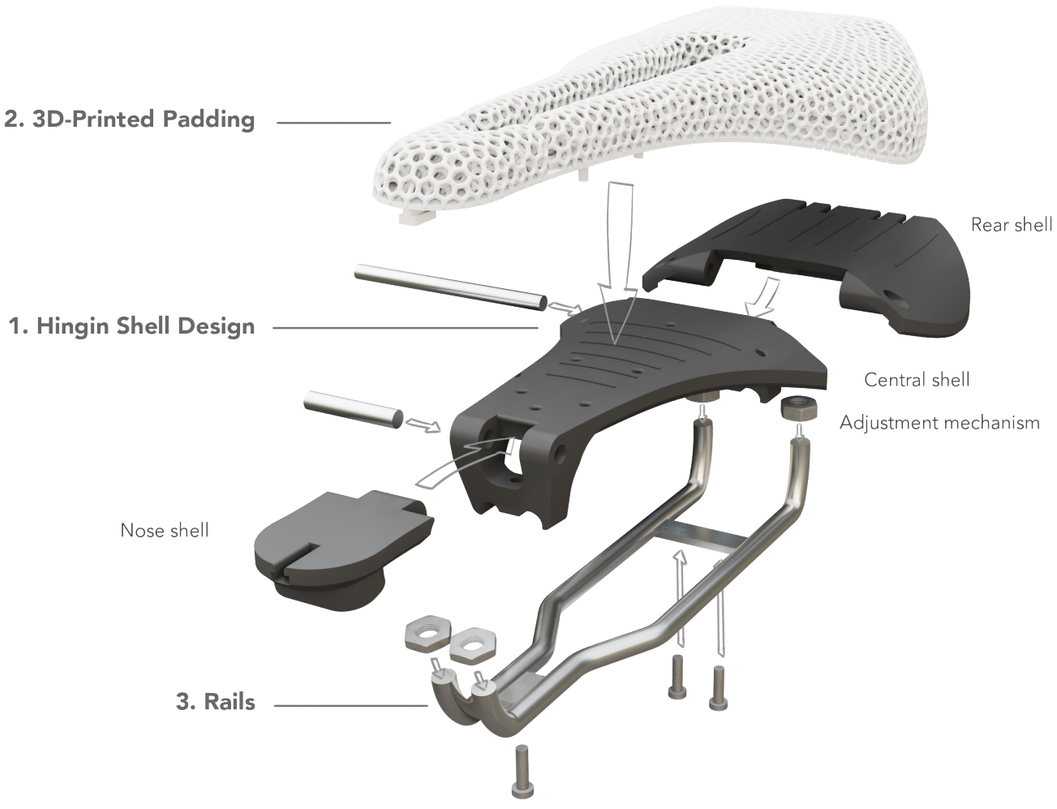


Figure 34: Exploded view of the proposed saddle design.

A bicycle saddle was designed that features a variable profile. This is done by a shell with hinging nose and rear parts. The padding ensures seamless transitions between these components. The shell is connected to the rails that simultaneously act as a way of adjusting the shell parts. Down below the most important design decisions have been laid out.

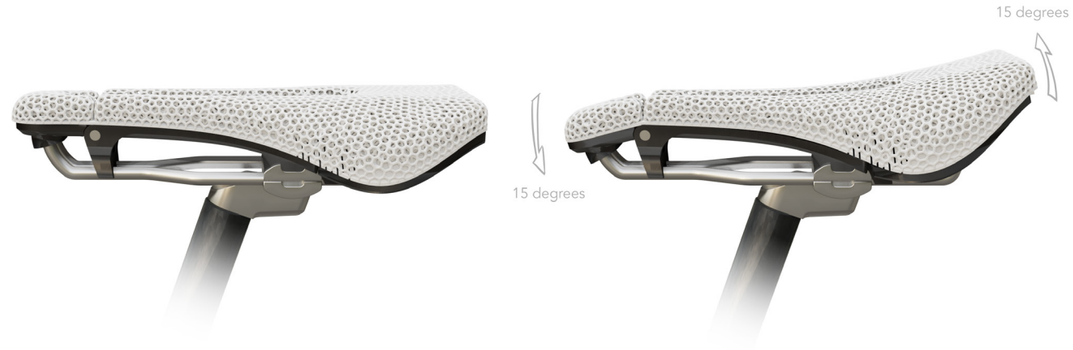


Figure 35: Side view of saddle in flat vs waved position.

1. HINGING SHELL DESIGN

The shell is comprised of three components: the nose, central, and rear parts. The central section is linked to the nose and rear through a hinge mechanism, facilitating a 15-degree rotation for both segments. These can rotate independently to allow for more adjustability. Further elaboration on this choice is provided in Chapter 8.1.

For optimal performance, the shell will be made from injection-molded carbon-filled Nylon. This material is selected for its great strength-to-weight ratio and its already widespread use in bicycle saddle designs. Additional details regarding this decision can be found in Chapter 8.2.



Figure 36: Hinging shell parts; nose (top) and rear (bottom).

2. 3D PRINTED PADDING

On top of the shell, a 3D printed padding is placed, which offers two key advantages to this design.

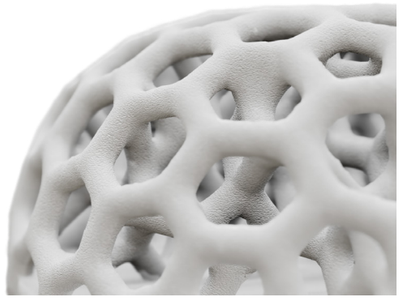
Firstly, a 3D printed lattice structure allows for a seamless transition between the shell's components, particularly important given the sharp fold created by the hinge mechanism. This lattice structure possesses foam-like properties while enabling heterogeneous (different per direction) stiffness properties. Consequently, it can be precisely designed to create a smoother curve over the shell parts, while maintaining the right properties for a comfortable padding. More on this is explained in Chapter 8.3.

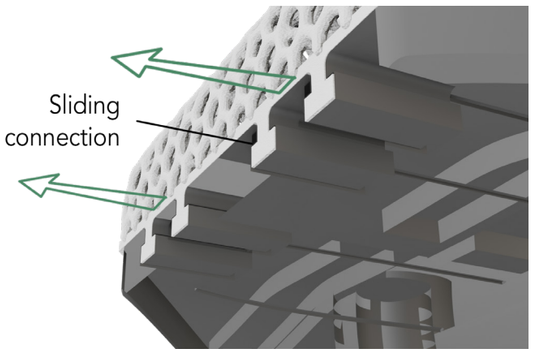
Additionally, 3D printing allows for the integration of additional features into the design, such as grip, fixed connections, and sliding connections to the shell. Especially the latter is essential as the rotational movement between the parts requires relative movement between them.

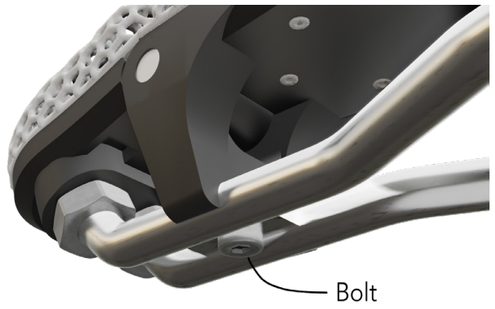
3. RAILS

The rails are a standard 7mm size (Need 8). The left and right parts are connected through welded-on plates, forming a robust foundation onto which the central shell piece can be bolted. This configuration creates a relatively stiff construction between the two.

To facilitate adjustment and secure positioning of both the rear and nose mechanisms, an adjustment mechanism is designed. This involves creating threads at the ends of the rails, allowing a nut to drive the nose and rear parts up and down as needed. This can be done without steps (Wish 1) and it allows for quick adjustabilty (Need 6) with only standard tools (Need 7). Further elaboration on this decision can be found in detail in Appendix 7.







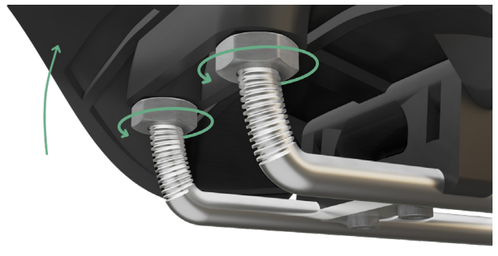


Figure 37: Details of final design: (1) close up of padding, (2) sliding mechanism, (3) rails to shell connection, and (4) adjustment mechansim.

BASED ON EXISTING SADDLES

There are many saddles out there, and they all fall on the spectrum from flat to waved. To find the range in which the adjustable saddle should fall, six wavy saddles of well-known brands have been compared, based on the measurement explained in Figure 35. Results are shown in Table 1.

As shown in the Table, waved saddles typically fall within a rear angle of around 15 degrees and a nose angle of approximately 13 degrees. However, outliers such as the Selle SMP Dynamic feature an extremely waved design. In the context of this project, it has been determined that both the rear and nose adjustability should range between 0 and 15 degrees. Which means that the dynamically adjustable saddle encompasses the range of all but the outlying saddles.

Since saddle design is all in the details, a reference saddle is chosen. The Turnix Performance saddle by Pro (see Figure 36) serves as an ideal starting point, offering average specifications and a reputation as a versatile, general-purpose saddle that appeals to a broad range of cyclists.

The final saddle design incorporates a cutout. This has been chosen because it reliefs pressure on the perineum especially during inclined positions and is therefore found in many waved saddles.

Both the rear and nose angle should be adjustble within a 0° to 15° angle (see Need 2 & 3)

Padding should incorperate a cutout

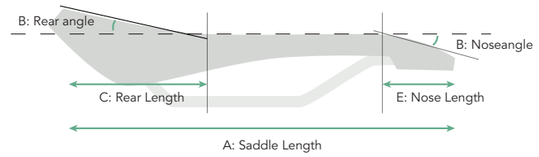


Figure 38: Waved saddle parameters.

Table 1: Waved saddle parameters for six popular waved saddles.

	A	B	C	D	E
Pro Turnix Performance	275mm	13°	125mm	10°	48mm
Fizik Tempo Aliente R3	277mm	15°	130mm	12°	75mm
BBB Echelon	280mm	10°	128mm	-	-
Selle Italia Novus	248mm	11°	110mm	13°	52mm
Specialized S-Works Romin Evo	260mm	13°	133mm	10°	74mm
Selle SMP Dynamic	274mm	22°	137mm	34°	72 mm



Figure 39: Pro Turnix Performance saddle.

7.3 FIT-KIT EXPLAINED

Experts emphasize a general lack of consumer education on saddle and bicycle comfort. To ensure a comfortable riding experience, it's crucial for customers to properly adjust both the bicycle and saddle. Especially when introducing additional settings for the saddle, this is only beneficial when it is properly done.

> *It is associated with educating the cyclist as well. The end consumer may not have much knowledge on how different parameters influence the experience.*
>
> - Jip van Montfort, 2023

Despite numerous online resources available to guide individuals in setting up their bicycles at home, many remain unaware of them, find the process cumbersome, or have other reasons for not doing so. Encouraging and simplifying the process can help more people engage in doing a proper bicycle fit at home.

Proven accurate guidelines can steer cyclists towards achieving a proper saddle and bike fit. Drawing from various sources, including research by Christiaans (1998), Mellion (1991), Baker (2009), Hershkovich (2022), and Posedia (2024), an easy to follow, one-page, step-by-step guide has been developed to aid individuals in this process. This guide is included alongside the saddle and supplementary items, aiding the fitting procedure. Each step has been chosen to ensure that no specialized tools or setups are necessary (Need 7). The guide is shown on the following page.

The kit contains a measuring tape with two sides: one side (green) measures in 1 cm increments, and the other side (orange) in 1.07 cm increments. To adhere to the 107% rule, which Christiaans (1991) suggests for setting the saddle height accurately, the inner leg is measured using the green side, and then the saddle height is adjusted using the orange side. Additionally, a plumb line with a weight is included to help estimate the for-aft positioning of the saddle. Lastly, a carpenter's level is provided to precisely adjust the saddle angle, as even small angle changes can significantly impact comfort and performance. While some users may already possess similar tools, including them in the kit could still reduce the barrier to performing these adjustments.

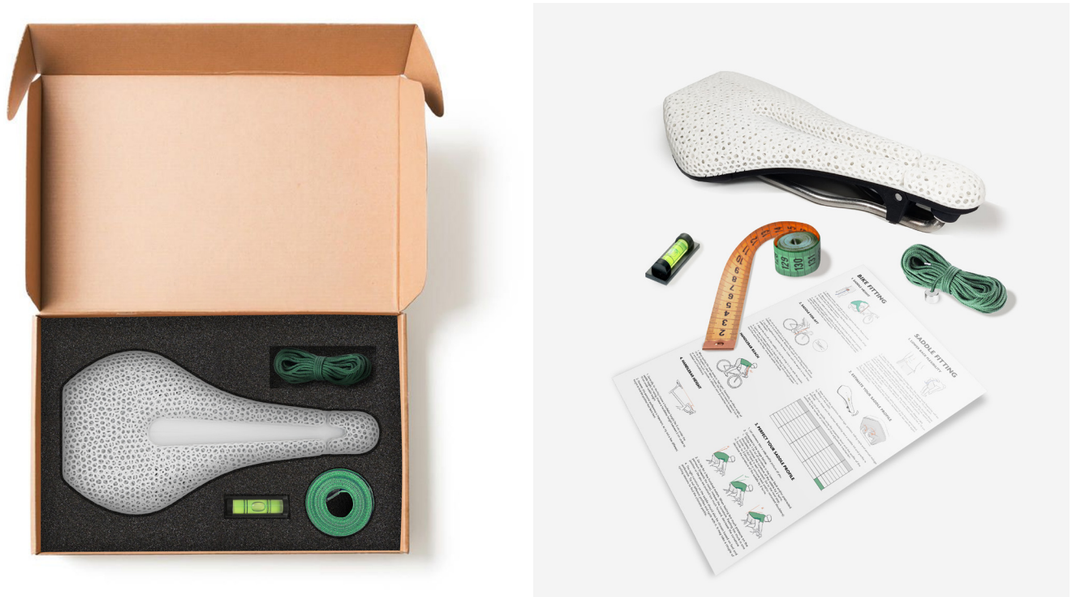


Figure 40: Full package including the saddle, a guide, and fitting accessoires.

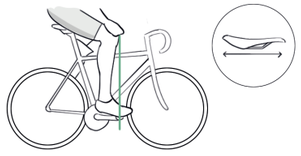
BIKE FITTING

1. SADDLE HEIGHT



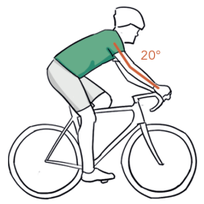
1. Without shoes, stand with your back against the wall. Place a book between your crotch as high as possible.
2. Measure the distance between the floor and the top of the book, using the green side of the tape measure.
3. Set your crank arm perpendicular to your seat tube in the lower position.
4. Adjust the height of your saddle so that the distance between the padel and the rail of the saddle is equal to the leg length measurement, but now use the orange side of the tape measure.

2. SADDLE FOR-AFT



1. Go sit on the bicycle in a position equal to your driving position while holding on to a solid structure. Rotate the crank arms so they are horizontal.
2. Lay the weighted string over the knee. Lower until the weight is lower than padel height.
3. Adjust the fore-aft of the saddle so that the sting is in line with the padel.
4. Cycle a few hundred meters. If it feels like there is too much pressure on your arms, move the saddle backwards. If it feels like not enough power could be applied by the legs, move the saddle forward.

3. HANDLEBAR REACH



1. When cycling the reach needs to 'feel right'. Generally, an elbow angle of 15 to 20 degrees is ideal. When it feels like the arms need to stretch too far, or are bent too much, consider a different stem (connection between headset and handlebars).

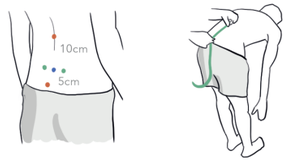
4. HANDLEBAR HEIGHT



1. Generally, for touring choose a handlebar height 0to 5 cm under the saddle height, for racing choose a handlebar height between 5 cm under to 10 cm under saddle height.
2. However, this personal prefference is important, so try out a few different height to find the position that feels best.

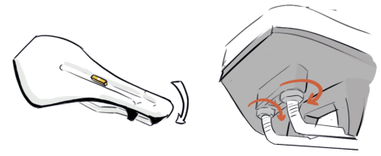
SADDLE FITTING

1. LOWER BACK FLEXIBILITY



1. Using the Wolfson Modified Schober Test, the lower back flexibility will be measured. For this, stand straight up, feet facing forward, 10 cm apart.
2. Let someone locate the PSIS's on the lower back. Using the thumbs these can be clearly noticed as parts of the pelvis that are around 10 cm apart just above the waist. Draw a dot exactly in the middle of these points.
3. Using the green side of the tape measure, the other person draws a dot 5 cm under the other dot and 10 cm above it. So now there should be a 15 cm distance between the two.
4. Try to touch the toes with your hands while keeping the knees extended. The other person now measures the distance between the two points again and notes it down.

2. ESTIMATE YOUR SADDLE PROFILE



1. Now answer the questions about age, gender, riding style and annual milage by filling in the table.
2. Based on these and the lumbar flexibility test a saddle tilt and profile is defined.
3. Set the tilt of the saddle using the carpenter level and the profile of the saddle by the number of rotations of the adjustment mechanism.

3. PERFECT YOUR SADDLE PROFILE

1. Let someone take a side profile picture of you.
2. Compared to the image below:
   i. Similar to 1 (A lot of curvature in the lower back and/or protracted shoulders): increase the curvature of the saddle by 2 turns.
   ii. Similar to 2 (full back is well rounded): Go to the next step.
   iii. Similar to 3 (almost flat or concave back and/or retracted shoulders): decrease the curvature of the saddle by 2 turns.



3. Go ride for a few hundred meters. When feeling too much pressure on the perineum (towards the nose), increase the curvature. Feeling too stuck in one position or like you are pushed too much forward, decrease the curvature
4. The right curvature on the saddle should also be chosen based on feel and preference. Try out different profiles and cycle with it. It may take a couple of cycling sessions to find the ultimate profile.

Figure 41: The bicycle and saddle fit guide.

8. IN DETAIL

In this chapter, two important parts of the design are explained in more detail, namely the shell and the padding. It explains why certain decisions were made based on the technical details, calcula-tions, and test.

8.1 SHELL: COMPLIANT VS MECHANICAL

While most designed mechanisms are rigid, compliant mechanisms, which use the material's flexibility, are becoming increasingly more popular due to potential benefits such as weight reduction, lower production costs, and decreased part count, among others. However, there are also notable challenges associated with employing compliance (Howell, 2013). Further details on compliant mechanisms can be found in Appendix 8. For the shell's bending mechanism, three concepts have been explored, two of which are compliant, while one is mechanical. These concepts mostly focus on the rear mechanism of the shell, but the same principles apply to the nose. For more details on the nose mechanism prototypes, see Appendix 9.

CONCEPT 1: 3D FOLDING

This concept uses compliance, or flexibility, of the shell's material. By folding the side panels up or down, a flat or waved side profile can be created. This is achieved by the specific curvature of a hinging structure, also known as a LET-joint, connecting the top and sides. This specific joint was chosen based on tensile tests as explained in Appendix 10. Additionally, the bellows on top enable for a big curvature without excessive internal stresses. The structure's deformation is actuated by a rod with left- and right-handed threads, which draw the side panels together. This 3D folding structure gives it overall stiffness in some configuration. However, the hinges create a sharp fold line and there is little design freedom for the shape of the shell, which is crucial since small variations in saddle shape can make a big difference in comfort.



Figure 42: Model itterations for 3D folding concept

CONCEPT 2: 2D FOLDING

In this concept, a compliant LET-joint is positioned at the bending point, allowing for flexibility in the structure. The rear section is guided upwards by the rail ends, providing stability. This approach offers complete design freedom for the shell's shape and eliminates sharp bending lines. Nonetheless, the LET-joint has low stiffness, which is problematic since most weight will be located here. Next to that, this joint allows for three Degrees of Freedom in the rear part, making it hard to constrain.

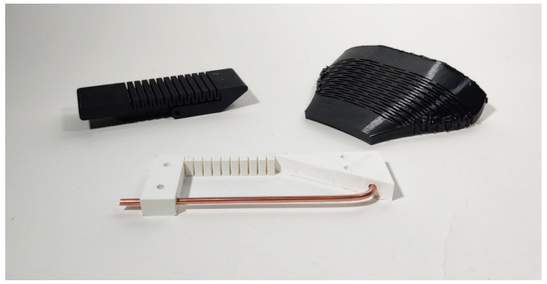


Figure 43: Model itterations for 2D folding concept

CONCEPT 3: MECHANICAL

This concept uses a mechanical hinge to rotation the rear part, thereby enhancing the saddle's stiffness and simplifying fastening. Furthermore, it maintains complete design freedom for the saddle's shape. However, it does introduce a sharp folding line between the central and the hinging parts of the saddle.



Figure 44: Model itterations for mechanical concept

CONCEPT CHOICE

In the Table down below, the main advantage and disadvantage for each concept is shown.

After weighing the pros and cons of the three concepts, the mechanical principle has been selected. The potential issue of the sharp folding line between the central and rear part (Need 1), can be addressed by effective padding design, as detailed in the Chapter 8.3.

Use a mechanical axle princliple for both rear and nose rotation

Table 2: Advantages and disadvantages of the three concepts compared.

3D Fold	2D Fold	Mechanical
Gets stiffness from structure but only in some configurations	Overall stiffness is low	Stiff in all configurations
Hard to actuate	Hard to actuate	Easy to actuate
Sharp folding lines (sides)	No sharp folding lines	Sharp folding line
Complex to design	Relatively easy to design	Easy to design
Less design freedom in saddle-shape	Complete design freedom in shape	Complete design freedom in shape



Figure 45: Saddle shell with mechanically hinging rear and nose parts

8.2 SHELL: MATERIAL PROPERTIES

The choice of material for a bicycle saddle's shell relies on two main properties: strength and stiffness.

STRENGTH

Given the substantial forces applied on a bicycle saddle, choosing for a material with high strength is important. Additionally, a high strength-to-weight ratio is desirable as cyclists want to minimize weight for enhanced performance.

STIFFNESS

The aspect of stiffness of a saddle is often more nuanced. Generally, higher stiffness correlates with greater efficiency, as energy transfers to the pedals rather than being dissipated through saddle deformation. However, excessive stiffness can lead to discomfort, as the shell's flexibility serves as a shock absorber.

MATERIAL CHOICE

Cheaper bicycle saddle shells are often made from non-reinforced nylon offering high flexibility and good strength. To enhance strength and stiffness without adding excessive weight, manufacturers often incorporate 20- to 30-percent carbon into it, allowing for a thinner construction. Some saddle are predominantly made from carbon fibre, being even more light and stiff, but more expensive (Benedict, 2019).

Carbon-infused nylon offers a great balance between comfort, efficiency, and durability for most recreational cyclists. An additional advantage of this material is that it can be injection moulding resulting in cost-effectiveness in mass production. Therefore, this material has been chosen.

The shell will be made from injection moulded carbon-infused nylon

STRENGTH ANALYSIS

As per the requirements outlined by Need 5, the saddle must be capable of withstanding a force of 3000N. To ensure compliance with this specification, a Finite Element Method (FEM) analysis was conducted, aiming to refine the design for optimal weight without surpassing the material's structural limits. The forces simulated in the FEM analysis mirror the typical force distribution experienced by the saddle, as depicted in Figure 43.

For this particular FEM analysis, PA6 with a 30% carbon composition was selected (Granta, 2024) due to its favorable mechanical properties.

Following an iterative design process, a shell design with a thickness of 3.5mm, complemented by reinforcement ribs, was created. The resulting weight of the shell is 116 grams. The FEM results of this part can be seen in Figure 44.

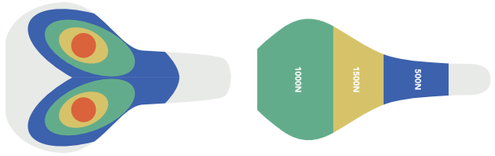


Figure 46: Regular pressure distribution on a bicycle saddle (left) and the pressure distribution used for FEM analyses.

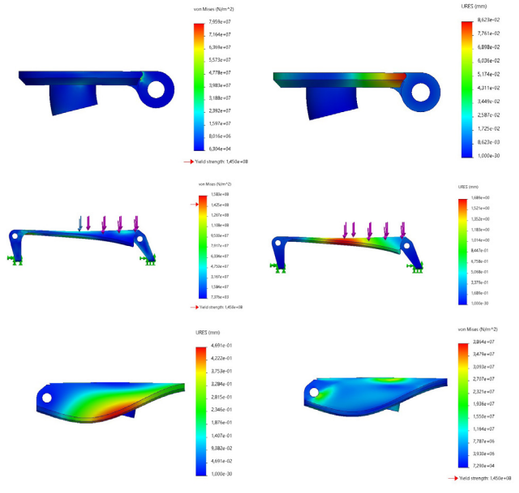


Figure 47: FEM analysis for each part of the optimized shell design (nose, central and rear) showing both the displacement (left) and internal stresses (right). Note: the nose part has been loaded with 1000N to simulate an extremely inclined position.

STIFFNESS ANALYSIS

Traditionally, the saddle shell is fixated to the rails at both ends, creating a hammock-like structure that offers flexibility around the sit bone region see Figure 45. However, the saddle design proposed in this project diverges from this by introducing a connection between the shell and the rails just underneath the sit bone area to support the cental shell piece. This introduces more stiffness, thus compromises on comfort. To bring back the desired flexibility (Need 4), adjustments can be made to the geometry and constraints of the connection (Howell, 2013). FEM-analyses have been done to validate this hypothesis, revealing that a 60-degree connection with hinge constraints has eight times more flexibility compared to a 15-degree connection with fixed constraints (see Figure 46). Moreover, exploring alterations to the geometry of the connection or the shell itself are viable options to accomplish the same thing.

The rear shell-to-rails connection should be angled to allow for more flexibility
(more research needed for exact geometry)

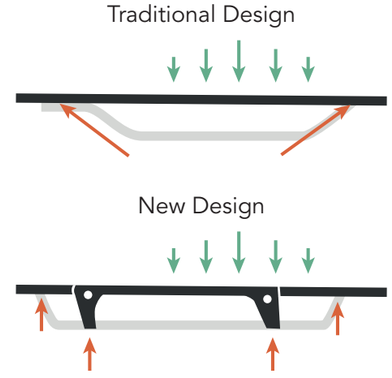


Figure 48: Loading for both a traditional saddle design and the new proposed design. Green arrows are forces applied by cyclist, red arrows are counterforces of the rails to the shell.

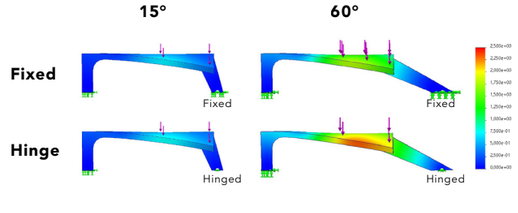


Figure 49: Displacement for the central shell structure with fixed or hinge rear connection to the rails that is either 15 or 60 degrees.

8.3 **3D PRINTED PADDING**

As highlighted in the Chapter 8.1, the shell creates a sharp crease which should be smoothed out by clever padding design (see Figure 47). To accomplish this, experiments have been conducted using both foam and a 3D printed lattice structure.

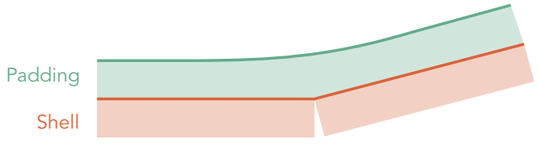
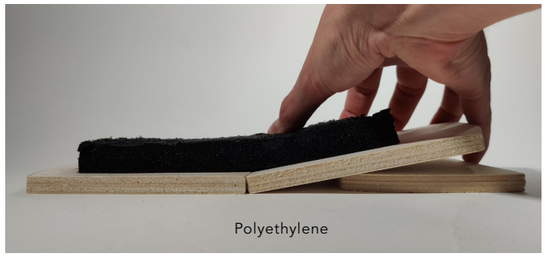


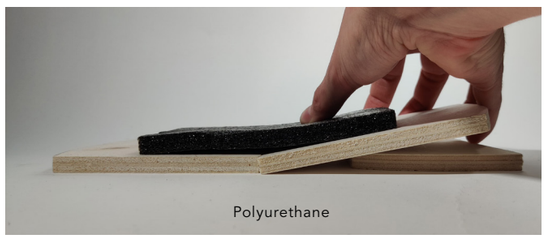
Figure 50: Shell has a sharp fold, padding should smoothly form over it.

TESTING WITH FOAM

Three distinct foam types were compared to evaluate their response to bending inside a sharp 15-degree angle.

As expected, stiffer materials yielded a more pronounced roundness. However, there is little freedom in selecting the padding's stiffness due to the positioning of the crease around the sit bones, where the right padding stiffness should also be selected based on comfort. Another noteworthy observation from these tests is that the rotation of the rear and nose sections prompts the foam to shift over the shell, creating a relative distance of approximately 5 mm. This suggests that the foam should either be able to expand and contract along the length of the saddle or incorporate guides to allow for back-and-forth sliding.





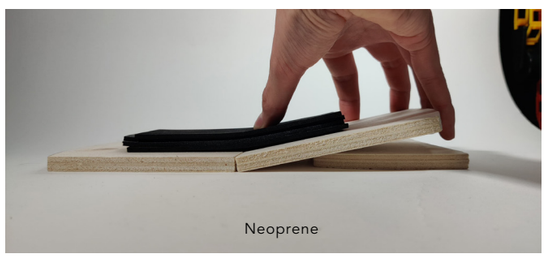


Figure 51: Testing crease smoothness with different types of foam material.

3D PRINTED LATTICE STRUCTURE

A 3D printed lattice structure can be a viable alternative to foam. Lattices, defined as "micro-structures consisting of a network of nodes, struts, or thin walls" (Agwu, 2021), are frequently seen in nature, such as in honeycombs and the inside of bones, due to their exceptional strength-to-weight ratio (Xu, 2016). Increasingly, they are being used in man-made designs, including bicycle saddles. They are typically produced through 3D printing, as producing them using conventional methods is nearly impossible (Xu, 2016).

Lattice structures generally fall into one of three categories: strut-based-, shell-, or triply periodic minimum surface-lattice structures (see Figure 49). For a saddle, a strut-based structure is a logical choice due to its relatively high flexibility compared to the others (Sokollu, 2022). Nonetheless, within strut-based lattice structures, various types exist, some of which are illustrated in Figure 50. Research conducted by Dong (2019) revealed that the Vintile structure is well-suited for use in shoe soles, owing to its optimal flexibility properties and low buckle rate. Additionally, it shows low internal stress concentration compared to other structures (Mekonen, 2020). Hence, this structure has been selected for testing, as outlined later in this chapter.

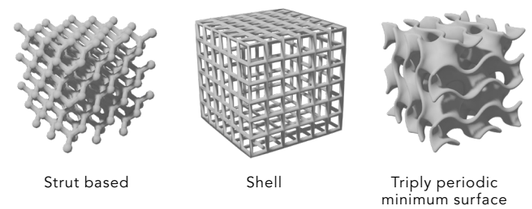


Figure 52: Types of lattice structures

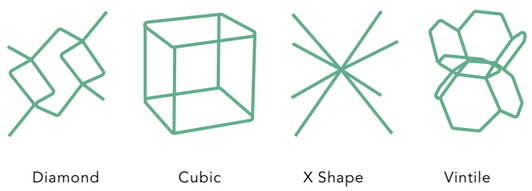


Figure 53: Types of strut-based lattice structures

HETEROGENEOUS STIFFNESS PROPERTIES

An advantage of selecting a lattice structure over foam lies in its capability to have specially designed heterogeneous properties. This means that the padding's stiffness can be varied based on the location or the direction of the applied force.

First of all, this offers the advantage of enabling the saddle to feature varying degrees of stiffness at different points. This is beneficial since the sit bones needs firmer padding, while softer tissue requires a lower firmness.

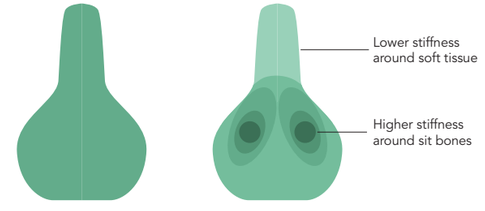


Figure 54: Saddle with even stiffness throughout the padding (left) vs saddle with variable stiffness throughout the padding (right).

And most importantly, the vertical stiffness of the saddle can be independently adjusted from its bending stiffness. This means that a smooth bending radius can be established without compromising on a soft-feeling saddle.

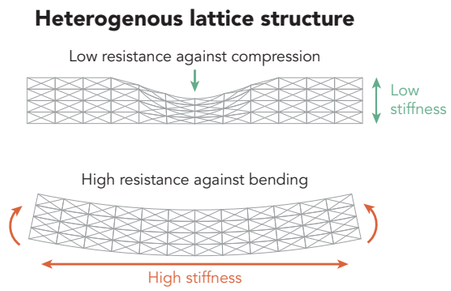


Figure 55: Heterogeneous lattice structure that is resistant against bending, but not resistant against compression.

Various methods can achieve heterogeneous stiffness, including heterogeneous strut design, altering strut thickness, adjusting cell size, changing lattice type, utilizing multi-materials, topology optimization, among others (Xu, 2016) (Liu, 2021) (Leonardi, 2019). Determining the most suitable method for a saddle necessitates further testing. Given its high adaptability and ease of implementation, a heterogeneous strut design has been explored through testing, as outlined in the next chapter sections.

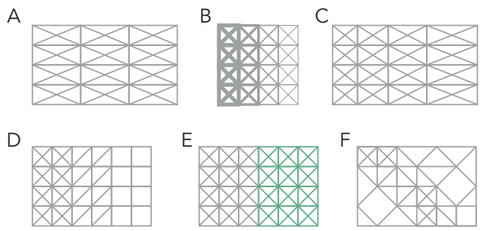


Figure 56: Different ways to create a heterogeneous stiffness through lattice structure design. (A) Heterogeneous strut design, (B) altering strut thickness, (C) variable cell size, (D) variable lattice type, (E) multi-material, and (F) topology optimization.

DESIGNING A LATTICE STRUCTURE

An algorithm was developed using Rhino Grasshopper to convert a solid structure into a Vintile lattice structure with a honeycomb shell, as depicted in Appendix 12. To evaluate the stiffness characteristics of this structure, initial tests were conducted using FDM printing, followed by an SLS-printed padding, as explained in Chapter 9.





Figure 57: Testing lattice structure stiffness using FDM printing (left) and SLS printing (right).

HETEROGENEOUS LATTICE STRUCTURE TEST

To check if a heterogeneous strut design would behave differently depending on the force direction, a test block was made to use in a compression test (see Figure 56). This block, made through SLS-printing with TPU, features a Vintile lattice structure where cells are scaled differently depending on the direction. Specifically, scale factors of 1, 1.5, and 2 for the X, Y, and Z directions respectively.

The outcomes are shown in Figure 55. It's evident that as the scale factor increases, so does the stiffness. This aligns with expectations because higher scale factors mean the struts align more with the applied force direction, making them more resistant to compression. To confirm that this behaviour extends to bending and compression, a FEM analysis was conducted, detailed in Appendix 11. The results indeed support the assumption.

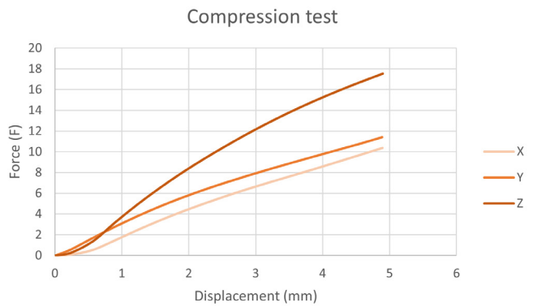


Figure 58: Results of the compression test using a heterogeneous lattice structure.





Figure 59: Compression test setup (left) and the hetereoegeneous lattice structure test block (right)

EXISTING 3D PRINTED SADDLE PADDINGS

Currently, there are already several saddles featuring 3D printed padding available on the market, like the Fizik Tempo Aliante R3 (see Figure 57). These typically also have similar strut-based lattice structures to achieve material flexibility. The predominant method for printing these saddles is Digital Light Synthesis (DLS), wherein a flexible resin is cured by light projection, yielding high-strength parts (Carbon, n.d.). However, these 3D printed saddles tend to be relatively expensive due to their association with premium models and the comparatively costly printing process compared to traditional methods. Nevertheless, it is anticipated that the production method becomes more economical and will be used in more affordable models. Therefore, these saddles will gradually decrease in price (Evans, 2023).



Figure 60: Fizik Tempo Aliante R3, 3D printed saddle

PADDING CHOICE

While using foam for paddings is cheaper than 3D printed alternatives, there are significant benefits to the latter. Firstly, having varying stiffness across the saddle can offer additional comfort for sensitive areas. Additionally, the heterogeneous properties of 3D printed materials enable smoother transitions between different parts of the shell. Lastly, 3D printing enables the integration of features like sliding connections, as detailed in Chapter 7.

Thus, a lattice structure produced via 3D printing has been selected as the primary material for the padding.

The padding will be made using a 3D printed Vintile lattice structure

9. EVALUATION

To test whether the assumptions align with reality, a working prototype was built. This prototype has been used to conduct a user test, evaluating the overall comfort, and testing whether the sad-dle profile results in the expected behaviour to the user. Also expected weight and cost price have been calculated.

9.1 **FINAL PROTOTYPE**





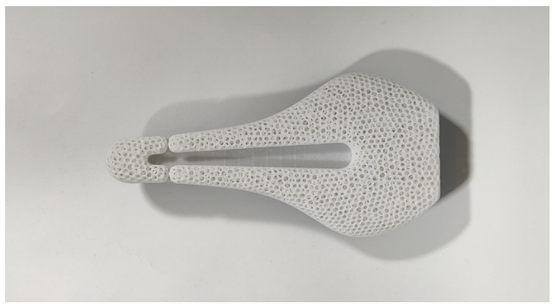






Figure 61: Photos of the functional prototype.

All the design choices outlined in Chapter 7 and 8 have been combined to produce a functional prototype (as shown in Figure 58). This prototype differs slightly from the theoretical design to simplify fabrication.

Firstly, the shell is constructed from SLS-printed glass-filled PA12, which is not as strong as injection-moulded carbon-filled nylon. Consequently, the thickness of the shell is increased significantly, with additional reinforcement ribs. It also does not incorperate an angled shell-to-rail connection, creating a relative stiff construction.

Additionally, the padding is crafted from SLS-printed TPU instead of DLS-printed resin. This results in less flexibility, which is noticeable. The padding feels firmer than initially anticipated. Moreover, the prototype lacks a heterogeneous lattice structure in the padding, as further testing is required to determine the optimal cell ratios.

Lastly, the rails are composed of 8mm solid steel rods instead of 7mm hollow rods. This alteration was made because they are significantly cheaper and easier to find.

PROTOTYPE EVALUATION

Considering at the description above, the prototype performs in many ways like expected. It is stiffer compared to most other saddles due to the thicker material, the lack of angled shell-to-rails connection and firm padding. The overall strength of the saddle seems sufficient. The adjustment mechanism works as expected, however, currently it does not constrain upwards movement of the shell parts. Despite the padding lacking a heterogeneous lattice structure, it still moulds into a well-rounded shape over the shell. This is most likely due to the prototype padding' s high stiffness and thickness. It is anticipated that this roundness will diminish as it becomes more similar to regular saddles. The sliding connections work well; however, further testing is necessary to ascertain their long-term performance, as traditional saddles typically fixate the padding firmly to the shell through gluing or stapling.



Figure 62: Photos of the prototyping process.



9.2 USER TESTING

To evaluate the functional prototype, a user test was conducted with three recreational cyclists. During the test, participants cycled on a stationary bicycle for approximately 15 minutes while wearing appropriate cycling clothing. They experienced both the top (tops) and bottom (drops) handlebar positions. Questions were asked regarding the overall comfort of the saddle, and participants were asked about pressure distribution while the saddle was altered in shape. Also, the participants were asked whether they felt a seamline due to the folding of the shell, since this was a particular concern.

OVERALL COMFORT

Participants expressed satisfaction with the overall shape of the saddle, although they noted it felt rather firm. This was expected as explained in the previous chapter. Additionally, the overly grippy texture of the padding prevented sliding on the saddle and it resulted in slight chafing against the nose.

FLAT VS WAVED

Participants accurately perceived the shape of the saddle, distinguishing between flat, waved and position in between. They reported feeling more inclined towards the drops position with the waved profile and experienced less pressure on the perineum in this position. Conversely, the flat profile felt more comfortable in the tops position, as expected.

> *I feel like the saddle is more waved. Where first I felt more pressure on the front, this is now reduced. [...] I feel like I am more pushed forwards. [...] Therefore, preferably I would like to sit in a more inclined position.*
>
> - Participant 1

ADJUSTABLE NOSE

The adjustable nose feature was not prominently noticed during the test, possibly because it received minimal pressure. Further research is needed to determine its effectiveness over longer testing durations.

CREASE

Participants did not report any noticeable creases in the shell, finding the saddle to have an overall smooth shape. However, testing with longer cycling durations is required to confirm this observation.

> *I feel like the saddle has a gradual roundness, like there is a big fillet on it.*
>
> - Participant 2

9.3 **OPTIMIZING WEIGHT**

The weight of cycling gear holds significant importance for most road cyclists, with saddles often considered an area to reduce weight. More comfortable gel saddles can weigh up to 350 grams, this has been set as the limit (Need 9). Lightweight models can be under 150 grams. But typically are under 250 grams (Wish 2) The prototype created weighs 557 grams due to the high thickness of the shell and padding, along with solid steel 8mm rails.

As outlined in Chapter 8.2, an optimized shell design was developed, bringing its weight down to 116 grams. Significant weight reduction can be achieved by using hollow Tirox chromoly rails, like those found in other saddles. Additionally, considering the relatively thick design of the prototype compared to existing 3D printed padding designs, further weight reduction in this component is also expected. On the right is a comparison between the prototype and the optimized design.

A comparison between the weight of the prorotype and the oprimized design can be seen in Table 3.

Table 3: Weight comparison between prototype and optimized design.

	Prototype (g)	Optimized Design (g)
Padding	106	80
Shell	211	116
Rails	210	90
Axles	30	20
Total	**557**	**306**



Figure 63: Design of the prototype (left) vs weight optimized design (right).

9.4 **PRICE**

To accurately estimate the price of a saddle, it's best to look at the prices of similar saddles currently available on the market. Generally, saddles with 3D printed padding tend to be expensive. This is because the process of 3D printing is more costly on a large scale compared to injection moulding. Additionally, these saddles are often found in higher-end models (Evans, 2023). However, their prices have been gradually decreasing. While the initial models cost between €350 and €450, now you can find cheaper options priced around €250 (Bracey, 2020). Nonetheless, this is still quite expensive compared to traditional saddles. It's important to note that prices may still be inflated, as more lesser-known companies are entering the market and offering similar saddles with 3D printed padding for under €100.

Using a standard cost price calculation template (Kals, 2018), it was estimated that the cost price of such a saddle is around €285 (see Appendix 13). A summary of this calculation is shown in Table 4.Considering that the proposed saddle design is more complex than regular saddles but doesn't use the highest quality materials, a price range between €275 and €300 seems reasonable. It's expected that as technology advances and 3D printing becomes cheaper, these prices will continue to decrease in the future.

Table 4: Estimated price breakdown of the final product based on Kals (2018).

Part	Price (Euros)
Production + Material cost	25.27
Purchase of parts	33.40
Assembly cost	1.41
Overhead and selling cost	224.23
Total	**285.31**

10. CONCLUSION

10.1 **CONCLUSION**

In conclusion, this research underscores the importance of selecting a suitable bicycle saddle and achieving proper bike fit for cyclists. The findings demonstrate that many cyclists overlook these factors, often leading to discomfort and suboptimal riding experiences. Then, in search for comfort buying multiple saddles or opting for a professional bike fit. The introduction of a saddle with adjustable geometry presents a promising middleground.

The concept of a saddle with an adjustable nose and rear offers cyclists a wide range of saddle profiles to accommodate diverse anatomies, riding styles, and preferences. Through research and user testing, it was observed that this adjustable profile allows for a more natural pelvis support and better pressure distribution, ultimately enhancing comfort during cycling.

The saddle allows for this adjustability by a hinging shell design with a specially designed padding made from a 3D printed lattice structure. This ensures a seamless and comfortable feel.

Furthermore, the development of the Fit Kit complements the adjustable saddle by guiding users towards achieving the perfect bike and saddle fit.

By prioritizing individual rider needs and preferences, Sculp improves the cycling experience, enhancing comfort and enjoyment on the road.

10.2 **RECOMMENDATIONS**

Due to the limited time of the project, there are areas that require further research and improvements.

TESTING

• The final test involved only three participants, each spending no more than 30 minutes on the saddle. However, saddle sores often develop over extended periods of cycling. Therefore, conducting user tests with more participants cycling for longer durations would provide more accurate insights, especially among individuals prone to ischial tuberosity or perineal pain.

• Incorporating pressure mapping data would be beneficial for further testing, as it could offer objective insights into pressure distribution on the saddle.

• The final test did not reveal significant perceived differences between different settings of the hinging nose. However, this may not necessarily mean that this feature does not contribute to comfort over extended periods. Further testing is needed to understand its potential impact.

SADDLE DESIGN

The final design is only the first iteration and requires many alterations to become a final product.

• Real-world durability tests are necessary to validate the design, as only Finite Element Method (FEM) analysis and prototype testing in a controlled environment have been conducted thus far.

• The seamless transition between the shell parts should be established by the padding design. Additional research is needed to identify an optimal design that provides enough curvature while being comfortable.

• Currently, the visual design of the saddle is mostly derived from functionality, thus form follows function. Especially the nose of the saddle appears rather bulky. Therefore, more research could be done to optimize the design for looks keeping the consumers needs and wishes in mind.

• More research into getting similar heterogeneous properties for traditional foams (perhaps with additional parts) could be done, since this might significantly bring the saddle cost down.

FIT-KIT

• Further research is needed to identify the simplest and most accurate methods for informing cyclers about their fit, particularly concerning pelvic tilt, which can be challenging to measure.

• Exploring alternative systems, such as an online database linking problems and sores to potential solutions, or a forum providing personalized tips, could be explored.

10.3 **REFLECTION**

Before starting my graduation project, I felt quite nervous. Wondering what it will look like, whether I would enjoy it, and what my supervisors would be like. However, I quickly realized that everything was fine. Throughout this project, I feel like I've grown, both as a designer and as a person.

I employed various design methods, sometimes taking them stricter than others. I discovered that I learn best through hands-on experience. Conducting interviews and tests with cyclists was particularly educating and I definetly improved my skills in this area. In the end I think there was a balanced mix of physical prototyping, testing, and theoretical research throughout the project.

PERSONAL LEARNING GOALS

My first personal learning goal was to maintain and adhere to a well-defined planning. Because the project was rather fuzzy and the research-oriented nature of the project, the final deliverable was not predetermined. This was challenging for me since there was no clear focus point. Therefore, I quickly realized the importance of flexibility in the project. This is something that I think was going well, especially when the project started to take form. Using milestones and to dos to guide myself through. Certain project phases took longer than expected, such as user tests and reporting. A recommendation for the future is to allocate extra time for potential setbacks.

Another goal was to ensure my mental well-being by maintaining a healthy work-life balance and working on personal growth. For this I implemented a 4-day work week, only working during standard working hours and taking rest when I needed to. I immediately noticed a positive impact, felt more rested and energetic. While I sometimes still have to listen to my body a bit more, I generally feel a lot better and more confident.

The third goal was to improve my understanding of technical aspects of design. Particularly my skills in CAD, FEM analysis, and decision-making based on technical testing have improved during the project's later stages.

The last goal was to develop my prototyping skills. This is one of the main things I improved in. Making a huge number of prototypes in many different fidelity.

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APPENDICES

APPENDIX 1: INDIVIDUAL BRAINSTORM SESSION

Possible design direction were explored by an individual brainstorm session where the following questions were asked:

- What are contrasting scenarios during a cycling trip?
- When do you want to change properties on a saddle?
- How to change properties on a saddle?
- How to shape shift

By combining the answers to these questions, ideas were generated, as shown in Figure 61.



Figure 64: Results of individual brainstorm session.

APPENDIX 2: QUESTIONS ASKED TO EXPERTS

- Wat maakt voor jou zadels ontwerpen zo interessant?
- Hoe ziet een zadelontwerp proces er ongeveer uit?
- Wat maakt een zadel ontwerpen en ontwikkelen moeilijk?
- Hoe ga je van een gevoel van de fietser naar een product?
- Ken je nog andere voorbeelden van dynamisch aanpasbare zadels?
- Waarom zijn dynamisch aanpasbare zadels (nog) niet populair?
- Zijn er andere scenario's waar dynamisch aanpasbare zadels een voordeel kunnen bieden?
- Wat zijn trends in de wereld van fietszadels die jij interessant vindt?
- Hoe ziet de toekomst van fietszadels er volgens jou uit?
- Kun je door de vorm van het zadel te wijzigen de drukpunten verplaatsen zonder dat het voor meer problemen zorgt?
- Als iemand een zadel heeft met de 'perfecte' vorm en fit, zou het verplaatsen van drukpunten dan nog nodig zijn?
- Hoe zou je een zadel moeten veranderen om zo drukpunten te verplaatsen? Vorm, hardheid, etc.
- Hoe zou je de vorm van het zadel aanpassen om de drukpunten te verplaatsen? Bolheid? Kicktail
- Is het goed om de druk op het zadel van de binnenkant naar de buitenkant van je zitbot te verplaatsen?
- Is het beter om een zadel te hebben die in twee uiterste standen kan worden gezet of liever meer?

APPENDIX 3: PROPOSED IDEAS

1 | BISTABLE COMPLIANT SADDLE

OPPORTUNITY

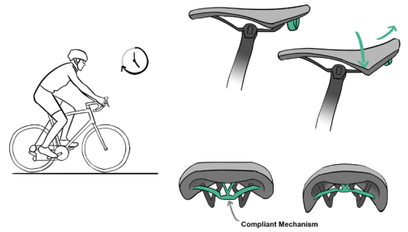
Many people experience saddle pain and sores during cycling. This is true for both recreational as well as elite cyclists (Bury, Leavy, Lan, O'Connor, & Jancey, 2021), especially when spending an extensive time on the saddle (Miller & Berry, 2007). These complications can negatively affect the cyclist's involvement in the sport (Bury, Leavy, Lan, O'Connor, & Jancey, 2021).

Leibovitch & Mor (2005) reported that 50-91% of cyclists experienced genital numbness and other forms of discomfort during riding (Leibovitch & Mor, 2005). Dettori & Norvell (2012) stated that perineum numbness and erectile dysfunction are common under bicycle riders when driving distances greater than 64 km. The same report also states that buttock pain occurs at around half the cyclists. Especially ischial tuberosity pain (pain around sit bones). Other often mentioned complaints are about pain in the back, wrists and hands, shoulders and neck and knees (Dettori & Norvell, 2012).

There are several ways in which these saddle pains can be prevented including saddle position, shape, and cutouts. (Bury, Leavy, Lan, O'Connor, & Jancey, 2021).

A lot of research is done to comfort on regular and vehicle seats. After an extensive time of sitting the discomfort increases. Then people tend to introduce macro movements to reduce discomfort (Fujimaki & Noro, 2005). Although no literature on this was found, anecdotal proof can be found anywhere that this is similar on bicycle saddles as well. Van Veen, et al. (2015), found that a continuously moving car seat results in more comfort (Veen, Orlinskly, Franz, & Vink, 2015). Besides, there are multiple products on the market that change pressure points on the seat of a wheelchair which help against decubitus (pressure spots).

A bicycle saddle that can be changed in shape can change the pressure distribution on the buttock to relief pain on longer rides. For instance, changing pressure from the inner to the outer part of the sit bone (because the sit bone should always be the point that carries the most load). Or by releasing some of the pressure present at the perineum.



SOLUTION

Design a road-bicycle saddle for people that drive for an extended time that could change its shape during cycling which moves and reliefs pressure points to reduce discomfort. Can be automated or manual with warnings during cycling.

CHALLENGE

- Should be lightweight while stiff.
- Changing pressure points should not introduce an even worst distribution of pressure on new spots.

TECHNOLOGIES

Bistable Compliant Mechanism.

- A compliant mechanism is a mechanism that is made from a material that flexes. Therefore, it could consist of a single piece making it reliable and potentially lightweight.
- A bistable mechanism is a mechanism that naturally shapes in one of two positions. Therefore, it could change the shape the shell of a saddle in two ways while both being stiff.

Metamaterials.

- A metamaterial is a syntactic material with unique properties. This could be a material that has a variable stiffness. For instance, by changing the amount of sideways compression.

Traditional mechanisme

2 | EMBROIDERED PRESSURE SENSORS

OPPORTUNITY

In the sport world, more and more data is gathered to track and analyse the sporters performance. An example of a new technology that is used in running socks are embroidered pressure sensors (see Figure 62). These could track how someone is landing on their feet. But they also collect other data like cadence and distance. This gives direct feedback to the user to inform him or her how to improve (Sensoria, 2023).

GebioMized as well as many other brands have created saddle covers with integrated sensors to gather saddle pressure mapping data (gebioMized, 2023). This tool is currently often used during bike fits or for research purposes. However, the price of the system (multiple thousands of euros) together with its formfactor do not make it practical for daily use.

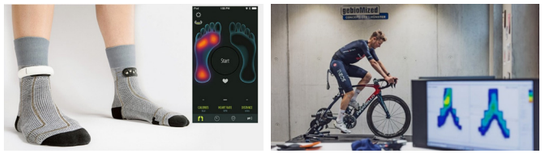
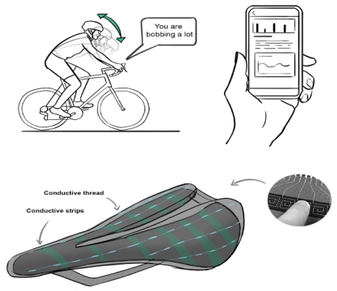


Figure 65: (left) Sensoria smart socks, (right) GebioMized system

Carpes, Mota & Faria (2010) showed that the bilateral asymmetry index range between 5% and 20%. Asymmetric pressure when riding a bicycle could increase the risk of injuries (Carpes, Mota, & Faria, 2010). For instance, unilateral vulval enlargement, lower back pain (Carpes, Dagnese, & Kleinpaul, 2009), sores and other pains. According to Rannama, et al. (2014), asymmetry and performance showed a significant negative correlation during sprint cycling (RANNAMA, PORT, BAZANOV, & PEDAK, 2014).

Other factors for cycling efficiency are bobbing and swaying or in other words, the up & down and left & right movement of the shoulders respectively. Nowadays professional cyclists perform more core exercises to provide more stability to the torso. This results in a more efficient ride.

A bicycle saddle with integrated pressure sensors could measure different metrics to make the driving experience more comfortable and efficient. This could be done by measuring bilateral asymmetry and bobbing and swaying. Another interesting use case could be to get an overview of the type of driving style during the trip. When was the cycling racing, touring or out of



the saddle. Next to that pressure mapping data could generate more generic data like; cadence, driving position and perhaps even an estimation of power output. Just like a power- or cadence meter is now connected to your cycling computer and sport app, this additional data can also be added to it.

SOLUTION

Design a road-bicycle saddle with integrated sensors that could gather data about the cycling trip such as bilateral symmetry, bobbing and swaying motions, cadence and more. This can be used to give feedback to the user on how to improve.

CHALLENGE

- Should be lightweight.
- Should be durable.
- Should be precise enough to distinguish different movements and road conditions.

TECHNOLOGIES

Embroidered pressure sensors.

- More and more research is done to soft sensors, including soft pressure sensors. These could be made by embedding conductive threads inside a fabric or foam that measure resistance or conductivity. Compared to the professional equipment, this could be done in a way more affordable way.

Force sensitive resistors

- A simple way to measure pressure is by FSRs. These are thin films that could be glued on top of the saddle shell.

Torque sensors

- Asymmetry or swaying could potentially be measured by a torque sensor on the saddle post.

3 | RENTAL BICYCLE SADDLE

OPPORTUNITY

Rental bikes are often a one-size-fits-all solution. These saddles are used by many people with different anatomies and wishes. Looking at the NS OV-fiets, only the saddle height can be adjusted. Handlebar position, saddle fore aft, and saddle type are all fixed.

In general, city bike saddles tend to fit most people, since width is less of an important factor at an upright position (Miller & Berry, 2007). Next to that, short trips often do not often lead to a lot of discomfort even when the saddle is not ideal for the driver (Bakker, Interview, 2023). However, on longer sits this can drastically change. Then, good support of the buttock is more important.

People tend to prefer soft saddles, because this gives a more comfortable feeling the moment you sit on it. However, harder saddles are preferable for longer trips, since this allows your sit bones to carry more of the weight instead of the softer tissue.

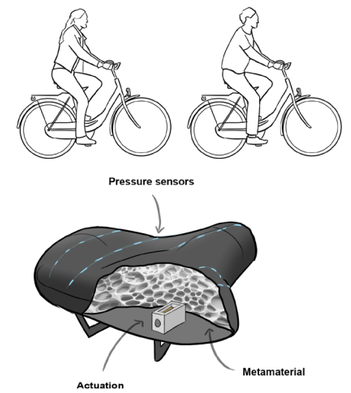
Nowadays many companies that design bicycle saddles try to find ways to create padding with variable stiffness throughout the saddle to ‘perfectly’ support the bodyweight on the right spots. Often with more pressure on the sit bones and less pressure on the softer tissue. This is done by using multiple types of padding or other materials in different regions. Another upcoming technique is using a 3D printed lattice structure with variable stiffness (Specialized, 2023). Other companies are making saddles specially tailored to the person sitting on it (gebioMized, 2023).

These techniques however are still static and do not allow multiple users to use the same saddle effectively.

Research by Roozendaal et al. (2022), found that for car seats pressure mapping data alone is not enough to create a comfortable sitting experience (Roozendaal, et al., 2022). This is because comfort is a highly subjective topic that cannot only be achieved by pressure mapping data.

SOLUTION

Design a rental-bicycle saddle that can create a more ideal pressure point distribution by altering hardness made for to longer trips.



CHALLENGE

- Rental bikes should be durable and cheap.
- How reliable is a pressure map for comfort?

TECHNOLOGIES

Pressure mapping: see concept 2

Metamaterials

- A metamaterial is a syntactic material with unique properties. This could be a material that has a variable stiffness. For instance, by changing the amount of sideways compression.

Soft robotics

- In soft robotics pneumatic systems, are often used. By inflation or deflation, the stiffness of a material can be changed.

Traditional mechanism

- A traditional mechanism can be used to change the shape of the saddle or move the padding to change the stiffness of the material per location.

APPENDIX 4: DESIRABILITY, FEASIBILITY AND VIABILITY FOR THE THREE IDEAS

The three concepts are vastly different in what type of problem it solves and what kind of solution is proposed. Therefore, it is hard to compare them directly. To find out where the real opportunities lay, many experts were consulted. Ranging from metamaterials-, compliant mechanisms-, and pressure mapping experts to cyclists, bike fitters and ergonomics experts. Next to that, multiple bicycle saddle designer companies have been consulted.

The three main criteria for evaluating the different ideas are desirability (do customers want it) feasibility (can it be achieved) and viability (will the idea be profitable).

IDEA 1: BISTABLE COMPLIANT SADDLE

Desirability: Many cyclists encounter saddle sores on extended rides. Despite their efforts to find solutions, addressing this issue proves challenging.
Feasibility: Physical tests showed that a bicycle saddle can be altered to make it shape-shifting. While compliance is not the only solution, according to Broeren (2023), a compliant mechanism expert, such a structure should be feasible. However, the introduction of a mechanism beneath the saddle is likely to result in increased weight, reduced strength, enhanced flexibility, higher cost, or a combination of these factors (Broeren, 2023).
Viability: The proposed solution is unique and could potentially add value to the user. The cyclists and the experts that were interviewed saw most potential in this solution. Moreover, a transformable saddle offers versatility, potentially catering to a broader range of users by accommodating various anatomies on the same saddle or adapting to different riding scenarios.

IDEA 2: EMBROIDERED PRESSURE SENSORS

Desirability: Pressure information could potentially provide professional cyclists with valuable insights to fine-tune their training regimes. However, it is unclear how much added value this brings next to the data from other devices.
Feasibility: Previous research and existing products indicate that a specific system is feasible to develop. A functional prototype was constructed and tested to validate its functionality, as demonstrated in Figure 63. However, it remains uncertain whether the system can achieve the level of accuracy necessary to collect relevant information effectively.
Viability: The target demographic for this product is likely to be relatively niche. However, in the professional cycling world, a lot of money is spent on equipment.



Figure 66: Working prototype made for idea 2 using Velostat.

IDEA 3: RENTAL BICYCLE SADDLE

Desirability: While many trips taken on rented bikes are typically short, where comfort may be less of a concern, there are instances, such as bike rentals at locations like Texel or the Veluwe, where longer journeys are possible. However, it's worth noting that rental bikes often do not provide an optimal overall bike fit, which means that even with an adjustable bicycle saddle, discomfort may not be fully achieved.
Feasibility: Depending on the way the concept is executed, it appears to pose significant execution challenges. Although pressure measurements, as outlined in idea 2, are technically achievable, extracting precise information from them introduces difficulties, given the subjective nature of perceived discomfort. To test if a change in pressure distribution on the sit bones could be recognized, a prototype was made.
Viability: The utilization of metamaterials to modify saddle stiffness is a novel idea that should be feasible according to Broeren (2023) and Buso (2023).The rental- and shared-bicycle industry is rather big. However, according to NS (2023), rental bicycles should be cheap and durable, making it a difficult market for this concept.

CONCLUSION

Idea 1 emerged as the top scorer in terms of desirability, feasibility, and viability. However, there is currently limited research available on whether altering pressure points leads to increased comfort during longer trips. Hence, a user test will be conducted, as detailed in the following chapter. Additionally, as noted by several experts, a similar concept could potentially serve to a broader target audience with varying anatomies or riding styles.

APPENDIX 5: OPPORTUNITY DIRECTIONS

Based on previous findings, including general research, physical tests, problem statements and idea findings, seven distinct opportunity direction clusters have been made. Down below an overview of these clusters with a illustrative examples of ideas within each cluster is shown.

REDUCE DISCOMFORT OVER EXTENDED TIME

One common issue in cycling is the discomfort experienced during extended rides.

Example
Bicycle saddle that shape-shifts and therefore moves pressure points to a different part of the sit bone.

REDUCE DISCOMFORT IN DIFFERENT DRIVING POSITIONS

Adjusting the riding position and style may require an adjustable saddle design to optimize comfort in both situations.

Examples
- A bicycle saddle that accommodates both touring and inclined positions by adjusting the nose length.
- A bicycle saddle that can be tilted forward, supporting a more aerodynamic posture.
- A bicycle saddle with an extendable nose that allow for a more forward position, enhancing muscular power output.

ALLOW FOR DIFFERENT ANATOMIES ON ONE SADDLE

Different anatomies require different saddles with different properties.

Example
Rental bicycle saddle that changes pressure distribution on the saddle per person

ALLOW FOR DIFFERENT DRIVING CONDITIONS

Rain, temperature, road-type, and other external factors may influence the requirements for the bicycle saddle.

Example
A bicycle saddle that gives more control to the user when the road is slippery.

PRACTICAL SOLUTIONS

The bicycle saddle could be changed for practical purposes. An example is the dropper post.

Example
A saddle that morphs into a handlebar when walking with your bicycle for a transition in triathlon.

PROVIDE FEEDBACK TO THE USER

The bicycle saddle could provide feedback to the user based on sensory data from within the saddle.

Example
Saddle that provides feedback about the posture of the cyclists during trainings.

FOR FITTING PURPOSES

A dynamic bicycle saddle could be used for bike fitting purposes or research applications.

Example
A saddle that morphs to the driver's body, which can then be used to create the 'perfect' bicycle saddle for that driver.

APPENDIX 6: TESTING VARIABLE GEOMETRY SADDLES

A shape-morphing bicycle saddle holds the potential for various advantages. These may include the ability to create more comfort by dynamically adjusting pressure points during extended rides, accommodating diverse riding styles during a single trip, or providing a versatile saddle suitable for a broader range of users. However, the small amount of literature research on variable geometry saddles provides not enough information to make hard conclusions. To validate and refine my assumptions, two types of user tests have been conducted.

EVALUATING PERCEIVED SHAPE DIFFERENCES

While there is a vast amount of research done to comfort on different types of saddles, only a limited amount focusses on directly comparing one variable of the shape. Especially not with a single variable geometry bicycle saddle. To understand if users would benefit from a change in the setting of the saddle, it is important to know if they even could perceive this change. Therefore, a test was conducted to find what the minimal perceived differences in settings was.

For this, three different variable geometry saddles were created. These saddles are shown in Figure 64. Each saddle has a single parameter that is adjustable namely, curvature, profile, and nose-width. These parameters have been chosen based on the expected high impact it has on comfort and on conclusions of discussions with bicycle saddle designers.



Figure 67: The variable geometry saddles used during the tests.

METHOD

Ten participants have been asked to cycle on a stationary bicycle. For this test, a method from Van Veen (2016), was adopted (Veen & Vink, Posture variation in a car within the restrictions of the driving task, 2016). Each saddle was tested in a random order. Per saddle, the participants were asked to cycle for 30 seconds in one of four settings. The order of settings has been randomized so that each setting appeared twice per participant. After these 30 seconds they answered a questions on an 11-point Likert-scale, ranging between two extremes depending on the saddle, such as from too round to too flat. The assumption by Van Veen is that if a participant gives a different score on the Likert scale, they feel a difference in setting of the saddle.

Next to that, qualitative research was done by conducting a short interview after each saddle. For this, participants were asked to stay on the saddle and answer questions on comfort, pressure distribution, tops vs drops position and personal preference. During these interviews the setting of the saddle was also altered.

A Kendall's Tau correlation analysis has been evaluated to find if there is any linear relation between given scores and the setting of the saddle. Next to that, a one-way repeated measured ANOVA has been used to find if there is any significant difference between means for the different settings.

QUANTITATIVE RESULTS

In Figure 65, the average scores and standard deviation per setting of each saddle can be seen. There is significant highly negative correlation for both the curvature- and profile-saddle. However, there is no significant correlation found between setting and scores for the width saddle.

From the one-way repeated measured ANOVA, a similar outcome is present. The within-subject effect tests show that significance for both the curvature- and profile-saddle. For the curvature-saddle 61.5% of the scores is accounted for by the setting of the saddle, this is 46.2% for the profile-saddle. For the width-saddle no significant results were found.

More interestingly, paired T-tests between each setting per saddle shows that for both the curvature- and profile-saddle there is a significant difference between all settings that are at least two steps apart. Next to that, there is a significant difference between settings 2 and 3 for the curvature saddle and settings 3 and 4 for the profile-saddle. Again, for the width-saddle no significant results were found.

QUALITATIVE RESULTS

Generally, the interviews backed up the results of the quantitative research. For both the curvature- and profile-saddle, many participants were able to distinguish between a one-step difference, and most between a two-step difference. There was a difference recognizable between settings of the width saddle, however, perceived setting difference did not consistently correspond to the actual setting difference.

For each saddle the preferences between different settings of each saddle was large. While some liked a fairly flat saddle, other disliked it and vice versa.

For the profile-saddle, some participants highlighted that in tops and drops position, a different setting would be preferable.

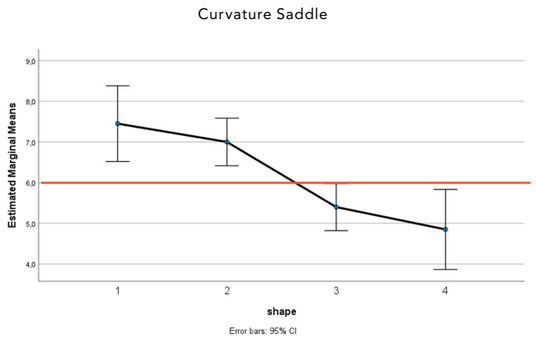


Figure 68: Average scores of all 10 participants for each setting for the three saddles. Vertical axis shows the scores, horizontal axis shows the setting. The vertical bars show the standard deviation.

DISCUSSION

The test was conducted with 10 participants. This is a fairly low sample size for these types of tests. The research from van Veen (2016) was conducted with 20 participants and was done for three rounds instead of two per test. Most likely the significance between two steps could be lowered by increasing the sample size.

There is a clear difference between the scores given during the first test of each saddle compared to the last test as shown in Figure 66. During the first test, participants generally experienced the saddle as less comfortable compared to the last test. This is also something a few participants noted. This might be due to people getting used to the saddle or because the buttock became less sensitive after multiple tests. It might help to test 1 or 2 saddle settings which will not be recorded to make people get used to the particular saddle.

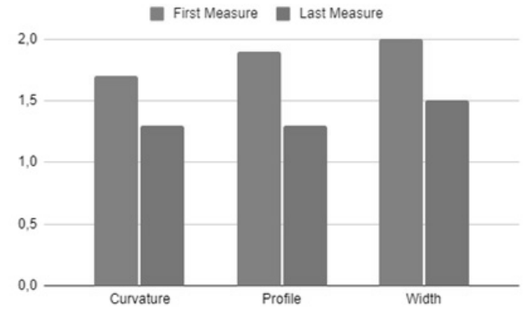


Figure 69: Average first and last test results for all three saddles.

Each saddle was set to a standard position. However, every participant has a different anatomy and preferences. Preferably each participant gets a bikefit up front or brings their own bicycle to do the test. Next to that, it was decided to let people not wear cycling shorts to simulate sitting on the saddle for a longer period of time. Longer cycling tests with shorts may result in different outcomes.

The width saddle showed no significant results. This might be due to how the saddle is build. A cut was made in the bottom of the saddle to make it flex in a certain way. However, for many participants, this was exactly the spot where the sit bones are pushing on. Therefore, the experience was not as expected. Next to that there was a sharp ridges that touched the inner thigh, which was also something people based their scores on.

OUTDOOR CYCLING TESTS

The tests described before only evaluate discomfort in a short time span. Comfort may drastically change on longer trips. Therefore, a 50km and 80km trip were done using the curvature-saddle and profile-saddle respectively. The tops and drops position were also driven to find out if a different setting saddle could positively influence comfort for different driving styles. The conclusion of these tests has been summarised in the list down below.

FINDINGS

- For both saddles there is a clear difference between saddles settings even on longer rides.
- There is a clear optimum in saddle setting for comfort. For both saddles the extreme flat position was uncomfortable.
- After a while the whole buttock area is sensitive. Therefore, a slight change in pressure distribution did not lead to more comfort.
- For tops and drops position, a different setting might be beneficial, this was most clear on the profile-saddle. However, a saddle that accommodates both positions might be enough.

APPENDIX 7: ADJUSTMENT MECHANISMS

To enable adjustment and secure positioning of both the rear and nose mechanisms, leveraging the rails to guide their movement has been chosen. This way the number of components required is minimized and the robustness of the rails create a stiffer and stronger part. Three types of fas-teners have been considered and tested.

1. CLAMPING

The same principle of using clamping force activated by a bolt, as seen in connecting the rails to the saddle clamp, could be applied to fasten the rear and nose parts. This method offers complete adjustability (Wish 1) by setting one part to the desired angle and firmly tightening the clamp. However, it's less effective due to forces being applied in the direction along the clamp (Need 5). Additionally, the curved rails complicate the production of this part.

2. LOCKING

Adding ridges to the rails where a part could slide in enables the locking of the adjustable parts in place. This allows forces to be applied perpendicular to the material, resulting in significantly greater holding strength. This concept is similar to the mechanism often found in car headrests, facilitating quick adjustability. While it can accommodate the requirement for six steps in the rear part (Need 2) and four steps in the nose part (Need 3), complete adjustability is not possible (Wish 1). Additionally, this approach re-quires more parts, adding complexity to the system.

3. THREAD

By incorporating a thread at the end of the rails, a nut can be used to adjust the rotation of the rear and nose parts, providing full adjustability (Wish 1). Moreover, this addition of a thread and nut presents a cost-effective and straightforward solution. A test was conduct-ed to confirm the feasibility of a nut moving over a bent rod, as shown in Figure 67. It was demonstrated that bending the rod first and then cutting the thread allows for this movement.



Figure 70: Test with theading a bended rod.

APPENDIX 8: COMPLIANT MECHANICAL

Most often products use stiff and rigid parts connected to joints to make it move or deform. A compliant mechanism is using the flexibility of the material to create this movement. Compliance is often seen in nature but is more and more used in day-to-day products.

According to Howell (2013), there are many advantages of using compliance over traditional mechanisms. However, there are also challenges. Down below the most relevant advantages and challenges for a shape-morphing bicycle saddle are listed:

ADVANTAGES

- Production costs can be kept lower.
- Fewer parts are needed.
- Less assembly is needed.
- Weight can be reduced.

CHALLENGES

- More difficult to design for and understand motion and force behaviour.
- Consumer perception that flexible components are flimsy or weak.
- It may be difficult to design for both flexibility needed for compliance and stiffness needed for efficiency on the bicycle.

As the last challenge explains, there might be a conflict between the fact that a road-bicycle saddle should stiff, yet flexible enough to be compliant. However, these two principles can go hand in hand. As Howell (2013) explains, there are three ways in which flexibility can be created:

1. Material Properties
2. Geometry
3. Loading and boundary conditions

MATERIAL PROPERTIES

The two most important material properties for a compliant mechanism are Young's Modulus and Yield strength. On the one hand, a compliant mechanism should be flexible enough to bend (low Young's Modulus) but be strong enough not to break when bending (high Yield Strength). A good way to compare different materials is by looking at their modulus of resilience, as shown in the formula down below. This measures the amount of energy per unit volume the material can withstand without a permanent change. This is compared for a few materials in the Table down below.

$$Modulus\ of\ Resilience = \frac{1}{2} \times {S_y}^2 \div E$$

Table 5: Comparison of mechanical properties for compliancy for different materials.

Material	E (GPa)	Sy (MPa)	M. of R. (J/m3)
Polypropylene (PP)	1.4	34	410
Polyethylene (HDPE)	1.4	28	280
Nylon (type 66)	2.8	55	540
Nylon (SLS-printed PA12)	1.65	42	534

As shown in the Table above, both nylon is a material with great properties for compliance, due to its low stiffness and high strength. Next to that many saddles are currently made from nylon. It is resilient and weatherproof. Next to that it can be moulded, but also 3D printed, which is ideal for lower quantities.

MULTI-MATERIAL

An option to give the saddle enough stiffness in some part while keeping it flexible in others is by combining multiple materials. When using 2K injection moulding, parts are very hard to recycle, making it less environmentally friendly. Mechanically attaching multiple materials and parts might work but increases manual labour and costs.

Another option would be to work with materials that have anisotropic properties such as carbon fibre, where flexibility in some directions can be achieved by the direction of the fibres.

GEOMETRY

The geometry of the structure has a large effect on the way it can bend and the amount of flexibility it has in each direction. Thickening a part for compression gives a linear response for deflection. But thickening a part for bending like a cantilever beam gives it to the power of three more resistance against bending (Howell, 2013).



Figure 71: The influence of the height of the structure on bending vs torsion.

LOADING AND BOUNDARY CONDITIONS

How the load is applied and how the structure is connected has a big influence on the flexibility of it. This is most easily explained using the forget-me-nots (vergeet me nietjes), that shows how the direction of load, and the boundary conditions could highly increase the stiffness of a construction (Howell, 2013).



Figure 72: The influence of the width of the structure on bending vs torsion.

APPENDIX 9: NOSE MECHANISM

Based on the insights gained from the rear mechanism, it has been decided that the nose will also use a mechanical bending mechanism. To explore this, two types of prototypes have been developed: one with an axle positioned far from the shell, enabling a larger bending radius, and another with the axle closer to the shell, minimizing padding movement and leveraging the rails as guides.

Given that a sharp bend in the nose exists in other saddles and that the padding forms over the convex bend resulting in a larger radius, the decision has been made to place the axle close to the saddle.

For the padding itself a slid is created that allows for a sharp bend. It is expected that this has no negative influences on comfort since other saddles hace similar features, like the Prologo Scratch M5.



Figure 73: Prototypes made for the hinging nose mechanism (top) and the final design (bottom).

APPENDIX 10: LET-JOINT VS REDUCED MATERIAL JOINT

To find whether a compliant joint would be sufficient for this application, multiple tensile tests have been conducted. For this two types of structures were selected based on research from Howell (2013): a LET-joint and a reduced material joint. Each with three different thicknesses (2, 3, 4 mm). These samples have all gone through a tensile test, compression test at 15 and 30 degrees and bending test.

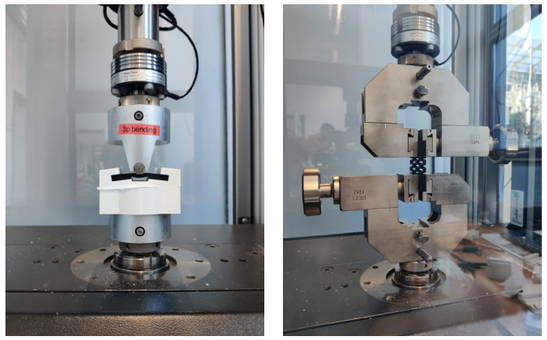


Figure 74: Tensile test setup used to test the differnt types of joints

The geometry of the reduced material joint and LET-joint have been selected so that forces would be equal at the same deflection for the bending test. This is clearly visible in Figure 72 A. No matter what thickness the structure has, both samples show a similar behaviour. This is in line with expected, since bending and torsion have a similar inertia increase, when increasing the height.

For the compression test, two radii were selected, 15 degrees and 30 degrees. It was expected that the 30 degrees samples would be harder to compress since there are more internal stresses present from the start. However, the opposite is true. Both test show similar results, but the force per mm compression at 15 degrees is slightly higher. Another interesting finding is that the LET-joint samples showed multiple linear stress-strain relations with increased steepness. This might be due to different types of torsion or bending that occur during the deformation. The reduced material joint showed a downwards trend. While all of the LET-joint samples returned to their original shape, all of the reduced material joint samples were plastically deformed. Each test was stopped after 2.5 mm of deformation. Only the 3- and 4-mm LET-joint samples reached the maximum load of 500N.

Results from the tensile test showed that the LET-joint requires less force to pull apart and can stretch further without plastic deformation. This is to be explained by the fact that the length of the bending parts is vastly larger for this structure.

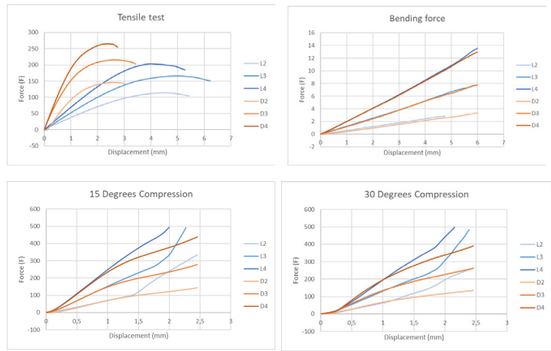


Figure 75: Redults of the different tests for 3 thicknesses per joint type.

CONCLUSION

All of the tests show that the LET-Joint performs best. Therefore, this joint is chosen. The thicker the LET-joint is, the more it resists compression. However, its elastic deformation is nearly identical to the thinner variants. Therefore, a thick LET-joint is chosen.

APPENDIX 11: BENDING VS COMPRESSION

To validate the hypothesis that a lattice structure with wide cells is more resistant against bending but less resistant against compression compared to a structure with high cells, a FEM analysis is performed (see Figure 73).

As can be seen in the FEM, the structure with wide cells deforms 1.3 mm when bending, compared to 5.5 mm for the structure with wide cells. Contrastingly, for the compression test, the deformation of the wide cells is higher compared to the high cells.

This is all expected when considering the direction of the struts compared to the internal stresses. The more a strut is aligned with the force, the higher the internal resistance. For bending the internal forces are mostly compression and tension in the horizontal direction. For the compression test the force is all in the vertical direction.

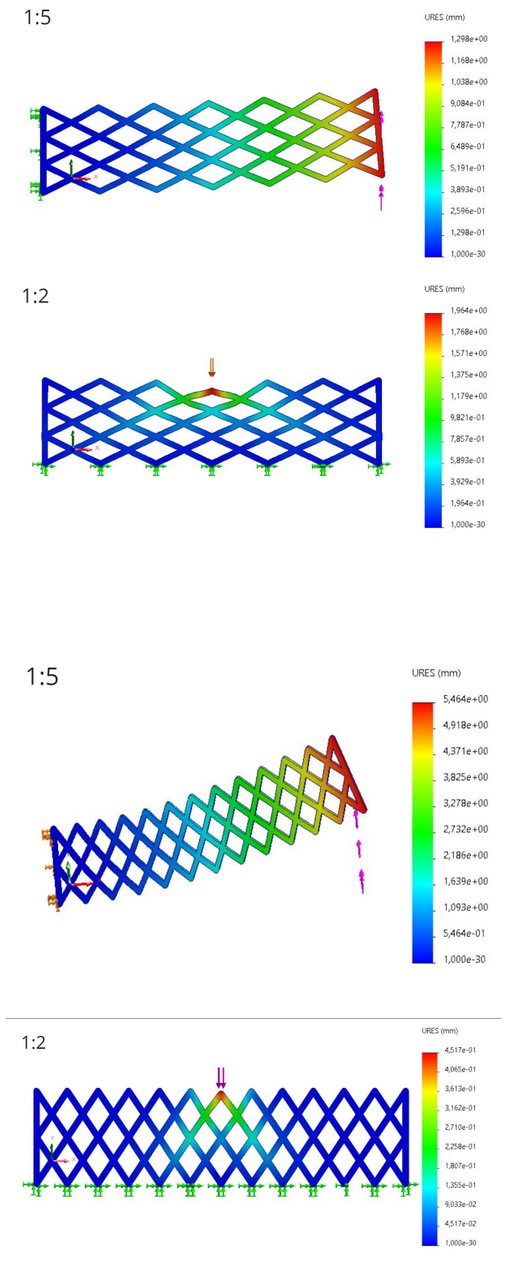


Figure 76: Bedning vs compression FEM analyses for a wide (top) vs high (bottom) cell structure.

APPENDIX 12: SADDLE DESIGN ALGORITHM

Down below the Rhino Grasshopper file can be seen that creates a lattice structure with honeycomb mesh from a solid. The three screenshots should be read like they are connected horizontally starting from the top.

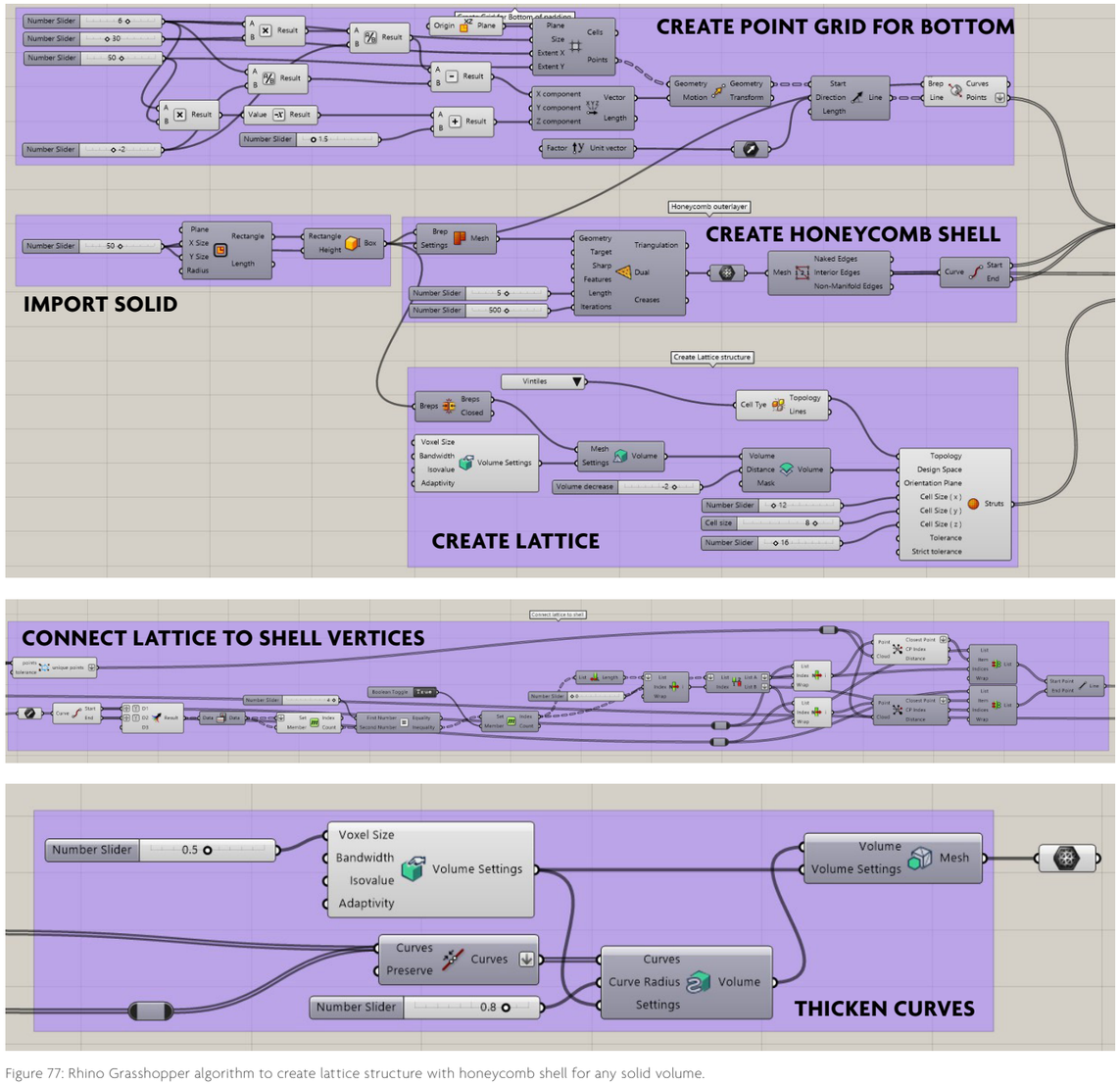


Figure 77: Rhino Grasshopper algorithm to create lattice structure with honeycomb shell for any solid volume.

APPENDIX 13: COST PRICE CALCULATIONS

Down below a cost price overview is made for the concept. Since there are many unknowns and the concept is in its early stages the exact numbers will vary. Especially the cost of the 3D printed padding is unclear. For now this is based on a quote at JLCPCB for a SLA printed padding. Since the material for the padding might be more expensive this is multiplied by two.

MATERIALS AND PRODUCTION

Benaming	Saddle		Productieserie	2.000	stuks	per onderdeel
Materiaalkosten		**bruto hoeveelheid/product**	**eenheid**	**prijs/eenheid**	**bedrag**	
halffabrikaat	PA6 30% Carbon filled	0,16	kg	€ 12,00	€ 1,92	
halffabrikaat	Chromoly tube	0,09	kg	€ 10,00	€ 0,90	
				totaal materiaalkosten	**€ 2,82**	**€ 2,82**
Bewerkingskosten	**capaciteit [stuks/u]**	**machineuren**	**machine-uurtarief**	**machine-kosten**		
Injection moulding	40	50,00	€ 20,00	€ 1.000,00		
Metal bending	60	33,33	€ 5,00	€ 166,67		
Metal welding	30	66,67	€ 20,00	€ 1.333,33		
				totaal machinekosten	**€ 2.500,00**	
machines als bovenstaand	**mens/machine-bezetting**	**arbeidsuren**	**mensuurtarief**	**arbeidskosten**		
Injection moulding	1	50,00	€ 18,00	€ 900,00		
Metal bending	1	33,33	€ 18,00	€ 600,00		
Metal welding	1	66,67	€ 18,00	€ 1.200,00		
				totaal arbeidskosten	**€ 2.700,00**	
				totaal bewerkingskosten	**€ 5.200,00**	**€ 2,60**
Instelkosten serie	**insteltijd [u]**	**uurtarief insteller**	**mach.uurtarief**	**kosten**	**per product**	
Injection moulding	10	€ 24,00	€ 20,00	€ 440,00	**€ 0,22**	
Metal bending	10	€ 24,00	€ 5,00	€ 290,00	**€ 0,15**	**€ 0,37**
Gereedschapskosten	**aanschafprijs**	**standtijd [stuks]**	**restwaarde**	**prijs/eenheid**		
Matrijs 3X €	30.000	2.000	€ 0,00	€ 15,00		
Bend mould €	2.000	2.000	€ 0,00	€ 1,00		
subtotalen €	-		€ 0,00			
gemiddelde waarde €	-					
kapitaalrente	0,0%	rentekosten	€ 0,00	€ 0,00		
				totaal gereedschapskosten	**€ 16,00**	**€ 16,00**
Algemene toeslagen						
uitval-factor*	1,0%				**subtotaal**	**€ 21,79**
overheadfactor**	15,0%					
totaal	**16,0%**					**€ 3,49**
				Productiekostprijs Saddle		**€ 25,27**

PARTS AND ASSEMBLY

Product	Saddle

In-huis te vervaardigen	prijs/stuk	stuks/product	prijs per product		prijs per product
Saddle	€ 25,27	1	€ 25,27		
			€ 25,27	**totaal vervaardiging**	**€ 25,27**

Inkopen		prijs/eenheid	eenheid	eenheid/product	prijs per product		
Moeren	€	0,20	stuk	4	€ 0,80		
Schroeven	€	0,20	stuk	3	€ 0,60		
Carpenter level	€	0,50	stuk	1	€ 0,50		
Plumb line	€	1,00	stuk	1	€ 1,00		
Measuring tape	€	0,50	stuk	1	€ 0,50		
Printed padding	€	30,00	stuk	1	€ 30,00		
					€ 33,40	**totaal inkoop**	**€ 33,40**

Assemblagekosten	capaciteit [stuks/u]	assemblageserie machineuren	2.000 uurtarief			
montagestation	80	25,00	€ 43,33	€ 1.083,25		
instellen montagestation	nvt	10,00	€ 43,33	€ 433,30		
handmontageplek	200	10,00	€ 2,50	€ 25,00		
verpakken	20	0,04	€ 2,00	€ 0,08		
				totaal machinekosten	**€ 1.541,63**	
machines als bovenstaand	**mens/machine-**	**arbeidsuren**	**uurtarief**	**arbeidskosten**		
montagestation	1	25,00	€ 25,00	€ 625,00		
instellen montagestation	1	10,00	€ 30,00	€ 300,00		
handmontageplek	2	20,00	€ 18,00	€ 360,00		
verpakken	1	0,04	€ 18,00	€ 0,72		
				totaal arbeidskosten	**€ 1.285,72**	
				totaal assemblagekosten	**€ 2.827,35**	**€ 1,41**
				Productiekostprijs Saddle		**€ 60,08**

SALES

Productiekostprijs geassembleerd product voor interne calculatie:	**Saddle**	**€ 60,08**
Overheadfactor voor algemene bedrijfskosten*	15%	
Overhead factor voor verkoopkosten	5%	
Winstfactor (onvoorziene kosten worden a.h.w. uit de winst betaald)	25%	
Totaalfactor = product van (elk van deze factoren+1) min 1	50,9%	**€ 30,61**
Verkoopprijs af-fabriek (moet je betalen als je product bij de fabriek zelf ophaalt)		**€ 90,69**
Marge tussenhandel (bijvoorbeeld: importeur, groothandel, leverancier, distributeur)	30,0%	**€ 27,21**
Groothandelsverkoopprijs		**€ 117,90**
Marge detailhandel (winkel) is zeer branche- en aanbiedingsafhankelijk, ligt tussen 25% voor een webshop en 300% voor een servicegerichte detaillist in een mooi pand op een A-locatie. Strategie met oog op concurrentie bepaalt de marge.	100,0%	**€ 117,90**
Netto verkoopprijs (exclusief BTW)		**€ 235,79**
BTW (= Belasting op de toegevoegde waarde, = omzetbelasting)**	21,0%	**€ 49,52**
Verkoopadviesprijs, normale winkelprijs		**€ 285,31**

Figure 78: Cost price calculation for the final design.

10.4 APPENDIX 14: PROJECT BRIEF

Personal Project Brief - IDE Master Graduation

TU Delft

Exploring the potential of a dynamically adjustable bicycle saddle — project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 11 - 09 - 2023 — 18 - 03 - 2024 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Over the years, the bicycle has seen numerous improvements. Components have become lighter, aerodynamics have been optimized, and ergonomics have improved. For instance, this year, Jumbo-Visma and Team DSM began testing a smart wheel-axis that can inflate and deflate a rider's tire on demand, enhancing ergonomics in various situations. This trend extends to bicycle saddles, which now feature optimized shapes and 3D-printed structures.

The bicycle saddle is crucial for a cyclist's comfort. Different factors like driving comfort, anatomy, riding positions, and terrain require varying saddle positions and shapes. Presently, saddle designs aim to find a "perfect middle ground" for various applications. However, this generalizing approach may not always be ideal in every situation.

A dynamically adjustable bicycle saddle could offer advantages in terms of ergonomics or driver efficiency. Additional advantages may emerge as the research progresses.

Below are three examples of potential solutions (see figure 1 for more):
1. The NS OV-bike is used by many people every day, each with unique anatomies and saddle preferences. A saddle could be designed that dynamically adjusts to the users needs to create a comfortable experience for all.
2. When cycling on varying terrains, such as uphill versus flat roads, the body demands different saddle shapes and positions. Uphill cycling reduces the hip angle, thereby narrowing the sit-bone width. Additionally, positioning the saddle angle closer to the horizon can help minimize shear forces. These adjustments can contribute to enhanced efficiency and ergonomic benefits (see Figure 2).
3. With the increasing popularity of 3D printing and saddle customization, explore the concept of a fully adaptable bicycle saddle. This innovative saddle design could dynamically alter its shape based on real-time pressure mat data, ultimately creating an optimal fit for each rider. This data-driven approach can be utilized for purposes like printing the customized saddle design.

Since the specific opportunities are yet to be found, no specific type of cyclist has been specified at this stage. As the project progresses, this will be narrowed down further.
The TU Delft houses research labs that might become involved in the project, such as the Bicycle Lab within the 3ME department.
From the start, no company is involved, although this may change during the project if specific resources are required that TU Delft cannot provide.

There has been limited research conducted on the topic of dynamic bicycle saddles. This opens some doors to possibly undiscovered innovations. On the other hand, this could also indicate that it has been tried before and failed.

Depending on the research outcomes, potential limitations of a dynamically adjustable bicycle saddle could include cost, early-stage technology, or societal norms. Also, according to experts that I have talked to, ergonomics is a difficult topic since it relies on peoples perceived experience. Something that is not always measurable.

This graduation project is a typical example of impact open, manifestation fixed. It has been decided that the project will be around dynamically adjustable bicycle saddles, but what problem it will solve is yet to be found.

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Personal Project Brief - IDE Master Graduation

TU Delft

introduction (continued): space for images

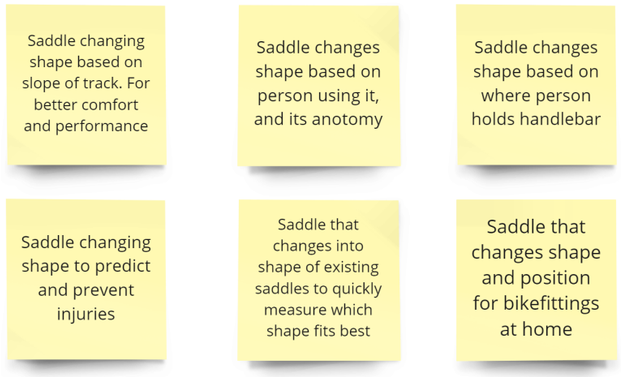


image / figure 1: Possible opportunities for dynamically adjustable bicycle saddles

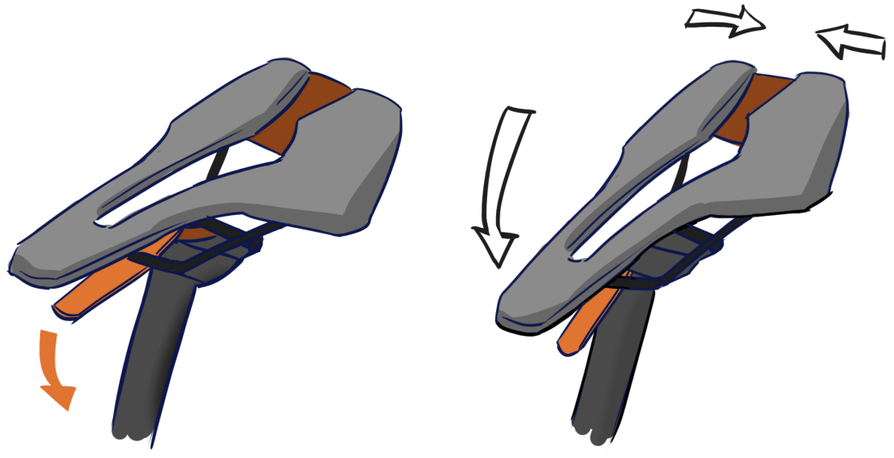


image / figure 2: Possible solution for a dynamically adjustable bicycle saddle for uphill and flat terrain cycling

Personal Project Brief - IDE Master Graduation

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Current bicycle saddles are static while the driver, surrounding, and driving style can change and may therefore require a dynamically adjustable saddle. This research project will explore the added value of a dynamically adjustable bicycle saddle to identify opportunities that may improve the driving experience.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

Design a dynamic bicycle saddle that enhances the cycling experience. This design will be based on an exploration to the potential of a bicycle saddle that can dynamically adjust its properties during cycling.

1. Explore opportunities for dynamically adjustable bicycle saddle properties. Research the way saddle shapes and positions influence ergonomics and efficiency. Who can benefit from it? What solutions are already out there? Etc. This may be done by desktop research, interviews and/or testing.

2. Brainstorm different ideas and work out a single concept in more detail.

3. Based on a chosen concept, design and prototype a bicycle saddle that enhances the cycling experience. This may be done by CAD-modelling, 3D-printing, building and/or more

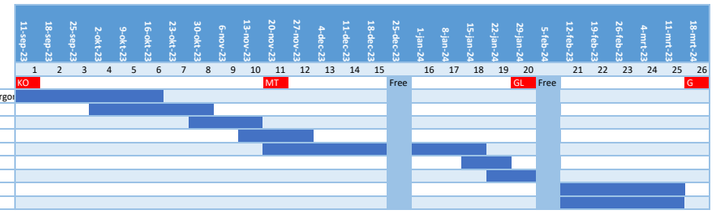
4. Testing the prototype. The type and extend of the test will greatly be dependent on the former steps.

Personal Project Brief - IDE Master Graduation

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 11 - 9 - 2023 18 - 3 - 2024 end date



Notes:
- Throughout the project a 4 day work week will be implemented, resulting in a 25 week graduation project
- All important meetings will be held on the Monday, except for the green light, which will be held on Friday

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

After discussing graduation opportunities with multiple professors and reviewing the repository, I found that the available options didn't fully satisfy me. Consequently, I decided to define my own project. While reading through completed graduation reports, I became enthusiastic about projects related to bicycles. This was partly because I am a road cyclist myself and partly because I identified some intriguing opportunities.

I would describe myself as an analytical thinker capable of devising creative yet practical solutions. I particularly enjoy the technical aspects of design, contemplating mechanisms, and finding practical solutions, especially when I can prototype and experiment in 3D. Recently, I have taken up software projects as a new hobby, and I am eager to explore this further if it aligns with the project's scope.

My ambitions for this project include:
1. Maintaining a structured project by adhering to a well-defined planning.
2. Ensuring my mental well-being by maintaining a healthy work-life balance and working on personal growth.
3. Improving my understanding of technical aspects of design, such as mechanical and software elements.
4. Developing my prototyping skills, depending on the project's direction.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.