CHALMERS
UNIVERSITY OF TECHNOLOGY

Autonomous Vehicle Seats

A User Oriented Concept Design

OLA BENGTSSON

Bachelor Thesis within Industrial Design Engineering

In co-operation with NEVS

Department of Product Development

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2017

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Title page:

Visualization of concept design

PREFACE

This project was initiated by NEVS and is subject for a Bachelor Thesis in Industrial Design Engineering. It covers 15 university credits and is carried out by Ola Bengtsson, student at Chalmers university of Technology. Olof Wranne has been supervising the project from an academic perspective at the department of Product and production development at Chalmers. The seat engineering team at NEVS, organized by Göran Ström, has been supportive giving feedback and relevant technical information throughout the project. I would like to thank all these people for excellent support.

A special credit goes out to Lisa Rydqvist, who has given expert feedback on aesthetic and graphic design throughout the project.

ABSTRACT

User needs of autonomous vehicle seats are identified and analysed in a pre-study, and the results have then been used as arguments creating a digital concept design.

User needs are researched both with primary and secondary sources – combining both research on a wide target group as well as observations and interviews with a delimited defined market segment.

Results from the pre-study show that the market entry of autonomous vehicles will widen the expectations of the product, with a greater variation of presumed user activities as the traditional focus on the driving activities and the driver seat will fade. Results from the secondary research show that many are still afraid of the new technology and if they would step in the car, looking out the window would be the most probable activity. Results from interviews and observations among the defined target group, however, show that the majority would spend their time working.

The defined user needs are of great variety and would be challenging to stimulate individually. Therefore, it is suggested that the following four needs should be prioritized, as they would stimulate a wider group of different needs; *stability, customization, spaciousness/outside view* and *green status*.

As green status was defined as an important need, a sustainability analysis of material alternatives for the seat frame was performed. Of six materials compared, the use of aluminium was measured to require the lowest amount of energy and emit the lowest amount of CO_2.

Results from conceptualization suggest that the seat arrangement should consist of two back seats that are prioritized in comfort, while a backwards facing two-piece sofa is placed in the front. Located at opposite walls of the vehicle, interior space is maximized and adjustments in x or y direction will therefore not be needed. The sofa has a foldable seat back creating extra spaciousness on demand. The seat frame is visible, eliminating redundant plastic cover material for a sustainable cause.

The report gives a holistic user perspective of autonomous vehicle seats, and should be seen as an introduction to further analysis.

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1. INTRODUCTION

This chapter defines the framework of the project, including its purpose and delimitations.

1.1. BACKGROUND

NEVS was founded in 2012 with the goal to create new sustainable solutions for a world whose future are facing big environmental challenges. Their key product is electric cars which they are primarily producing towards the Chinese market (NEVS.com, 2017). Like many other car manufacturers, e g Volvo, Ford, Tesla and Nissan, they are also investigating the market of autonomous vehicles.

Autonomous driving is no longer a futuristic vision, it is already here. According to Business insider (2016) fully autonomous cars will debut on the road in 2019 and by 2020 there will be 10 million road-registered cars with self-driving features. The technology exists, but no one knows for sure how the users are going to occupy themselves once they have let go of the steering wheel. This knowledge is of most importance, as it will affect interior design and functions.

Focusing on user needs has become more and more relevant in the automotive industry. Even though the products are extremely complex the user takes technical performance for granted. Because of that, softer values like shape, colour, surface and ergonomics will only rise in importance for a car producer to be able to be able to compete with rivalling companies (Johannesson et al, 2013).

NEVS wants to investigate the needs of their customers in the future, and limited for this project, how that will be reflected in a seat design in an autonomous vehicle of the future.

1.2. PURPOSE

The purpose is to identify and analyse user needs of seats in an autonomous vehicle. Furthermore, relevant features of an autonomous vehicle seat are to be identified, investigated and visualized.

1.3. AIM

The aim for this thesis is to create a seat concept for an autonomous vehicle relevant for the identified user needs. The seat concept should be placed into a relevant context, thus, an autonomous vehicle.

1.4. DELIMITATIONS

This project will be limited to a user oriented conceptual design, which means that neither manufacturing, administrative regulations, construction nor cost will be taken in consideration, if it is not directly linked to the project's main goal. Other important delimitations are:

- Potential use of new materials will be investigated, mainly from a sustainability perspective.
- CAD models and renderings will function as the main visualizing platform. They are not limited to any specific software.
- CAD models will not be made in such detail that it will function as blueprints for manufacturing.
- The project will be set to SAE autonomy level 5 - the highest level which defines a vehicle only navigating by itself.
- The project is limited to examine traveling in a private car.
- Implementation of the product is defined to occur in a time where autonomous vehicles have been widely established on the market. This is assumed to be in 2030-2050.
- Identified results that are specifically important for seats in an autonomous vehicle, compared with a non-autonomous vehicle, will be prioritized.

1.5. RESEARCH QUESTIONS

- What are the user needs of an autonomous vehicle?
- How can defined user needs be reflected in functions in a vehicle seat?
- How many people should be carried inside the vehicle?
- What would be a relevant seat arrangement?
- What materials could be used as more sustainable alternatives compared to the seats produced today?
- How does other car manufacturers design their concepts for autonomous vehicles?

1.6. PROJECT STRUCTURE

The design project structure is, in its most basic form, an extension based on the process defined by Johannesson (image 1, 2013*)* which consists of the following phases:

- Problem analysis, results in a specification of requirements
- Synthesis, results in product concepts and evaluation
- Analysis, results in predicted behavior related to product

If the developed concept does not fulfil the requirements in a satisfying manner, the process can be iterated back to relevant stage. Using this process as a cornerstone, a more customized process is developed for this project. This process is defined in the stages below. The *pre-study* equals the *problem analysis* from above, the *iterative creative process* and *concept development* equals the *synthesis* while *visualization* and *evaluation* equals the *analysis* phase.

- Planning and organizing
- Pre-study
- Iterative creative process
- Presentation 1
- Concept development
- Visualization
- Evaluation
- Presentation 2 (final)

2. THEORETICAL FRAMEWORK

This chapter describes theoretical content that is relevant for the concept development process.

2.1. GLOSSARY

A short summary of niche words used in the report that may be useful to the reader.

2.1.1. Crumple (deformation) zones

Crumple or deformation zones are areas in the vehicle designed to absorb kinetic energy in the event of a collision. These areas may be located in the front, back and side of the body shell, mitigating collision impact on driver and passengers (Volkswagen, 2017). Materials used for this are weaker than the tougher shell that surrounds the passengers. Examples of materials used in these zones are high tensile steel, composites, carbon fibre and aluminium (Autoportal, 2015).

2.1.2. Power seat

A power seat can be adjusted in different positions by electric powered mechanics directed by the user's click on matching buttons.

2.1.3. X-, y- and z-axes in dimensioning

X-, y- and z-axis are frequently used as references in the report. These are used as they normally are in three dimensional construction where x stands for the length of the object, y for width and z for height.

2.2. AUTONOMOUS VEHICLES

The official stages of autonomous navigated vehicles are defined by SAE (former society of automotive engineers). Autonomy is graded between 0-5 and are described as followed:

Level 0-2: Human driver monitors the environment:

- Level 0, *no automation*: The driver manages all driving tasks by him/herself, even when possible dangers are alarmed by the vehicle.

- Level 1, *driver assistance*: The driver may be assisted with steering *or* acceleration/deceleration by a (1) assistance system.
- Level 2, *partial automation*: The driver is assisted by one or more systems that assists steering *and* acceleration/deceleration.

Level 3-5: Automated driving system monitors the environment:

- Level 3, *conditional automation*: The system manages has the potential to perform all driving tasks with the expectation that the driver will interact when needed.
- Level 4, *high automation*: The system manages has the potential to perform all driving tasks and can handle all situations even without human interaction.
- Level 5, *full automation*: A full-time automated system that handles all environmental and roadway conditions that can be managed by a human.

(SAE, 2017)

2.3. A MODERN CAR DRIVER SEAT

If nothing else is noted, the following specification is based on the Volvo XC90 D5 Inscription 2015 (A2mac1.com, 2017). This vehicle is referred to because of its many comfort features.

A modern car driver seat is a complex multifunctional product with many components (Figure 1). The foundation is usually a steel frame mounted with a seat cushion, seatback and a headrest. The padding between the frame and the cover is made of polyurethane foam and the cover is made of leather and fabric. Seat cushions can be adjusted in Z direction both in the front and the rear, and may therefore also be tilted around the Y-axis. It has a four-way lumbar support which means it can be adjusted in Z and X-direction. The seatback may be reclined, also around the y-axis. In some cars, the headrest can be adjusted in z and x direction, like in a BMW 730 from 2005 (a2mac1.com, 2017). These adjustments can either be made manually with levers or knobs, or they can be electrically powered demanding only a push on a button. Some car manufacturers offer their customers the function of pre-setting the seat. This means that the seat position adjusted by the user can be saved and returned to by the click of a button.

Figure 1: Exploded view of a Volvo XC90 driver seat (A2mac1.com, 2017)

Heated and ventilated seat cushions and seatbacks are common. The Volvo has two thin heating pads in beneath the seat cover; one for the seat back and one for the seat cushion. Two cooling fans are also placed beneath the seat covers, one for the seat back and one for the seat cushion (a2mac1.com, 2017).

The Volvo also uses a seat extension in the front of the seat cushion. This means that the seat cushion length can be adjusted in the x direction (a2mac1.com, 2017).

The Volvo weigh 2141 kg, whereof 163 kg is taken up by the seats. The driver seat alone weighs approximately 29 kg. The main parts of the driver seat are power adjusters (9 kg), seat back (8 kg), seat cushion (7kg) and heat/cooling systems (0,75 kg) (a2mac1.com, 2017).

There are 14 main material groups in the Volvo driver seat (Figure 2), of which steel is the single most weighing material, mostly located at the frame (49,8 %). Other materials with high impact on weight are ABS plastic (9,20 %, which is mostly placed in the seat back cover) and

PUR foam (7,5 %, which is used as padding) and leather (6,7 %, used as seat cover) (a2mac1.com, 2017). Power adjusters is single most dense component group in the driver seat as it equals approximately a third of the total weight (a2mac1.com, 2017, Figure 3).

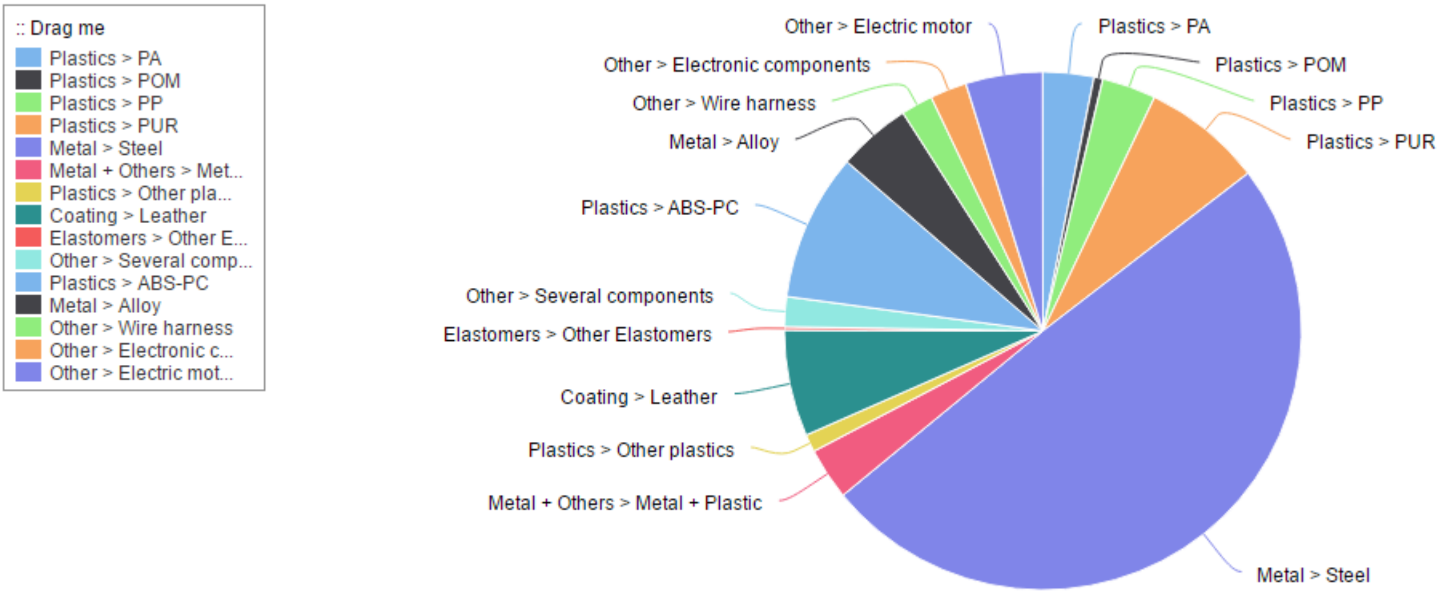

Figure 2: Pie chart of materials used in a Volvo XC90 driver seat (A2mac1.com, 2017)

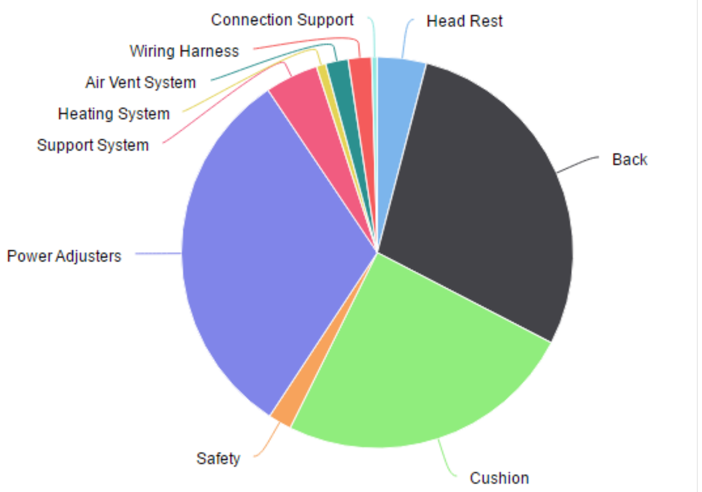

Figure 3: Pie chart of materials used in a Volvo XC90 driver seat, divided in components (A2mac1.com, 2017)

2.4. SEAT ERGONOMICS

Providing a comfortable support for ischial tuberosity, or the sitting bones, is of most importance in seat ergonomics. Each of these bones supports 18% of the body weight while seated (Kolich, M & Taboun, SM, 2007). The pressure supporting the ischial tuberosity should reflect that proportion of body weight, but it should then decrease symmetrically and evenly towards the sides and front of the seat cushion (Kolich, M & Taboun, SM, 2007). Lowering the back of the seat cushion in combination with lumbar support may reduce pressure on the ischial tuberosities and vibrations transmitted through the body (M. Makhsous, R. Hendrix, Z. Crowther, E. Nam, and F. Lin, 2005).

Supporting the distal half of the thigh is important but the pressure should be minimized. There is a risk, especially for small women, that high pressure in this area can have negative effect on circulation and deformation under the thigh (Kolich, M & Taboun, SM, 2007).

Pressure from seatback on lumbar areas is said by the user to be comfortable. However, high pressure may give discomfort in longer travelling periods. Aside from the ischial tuberosity and lumbar support, no isolated high-pressure points should be applied, this because it can obstruct circulation and lead to discomfort. Padding in the seatback should however not be too soft, because that will limit the change of distributed pressure when the user changes posture (Kolich, M & Taboun, SM, 2007).

Horizontal or 5° forward slope is to prefer to decrease pressure on the seat cushion. Reclining backrest 5° backward will increase pressure on seat cushion, reclining more than 5° will decrease pressure with 4% every 10° (P.K. Nag, S. Pal, S.M. Kotadiya, A. Nag, K. Gosai, 2007).

Use of armrest reduces pressure from the seat, increasing it at the feet instead. This might decrease the stress on the user´s spine and surrounding structures (P.K. Nag, S. Pal, S.M. Kotadiya, A. Nag, K. Gosai, 2007)

Active seats for pressure distribution are not as effective as passive ones with polyutherane foam or air floatation cushions (R. Aissaoui ; M. Lacoste ; J. Dansereau, 2002).

2.5. BED ERGONOMICS

According to an ergonomic study on 64 people in the ages of 25-50, the W-position is the most preferred one when lying in supine and side positions (Park, Se Jin; Kim, Jin Sun; Kim, Chae-Bogk, 2009). The W-position describes elevated leg-, lumbar- and neck support. The U-position, which is the same as W except low lumbar support, is preferred in prone position. Results showed that heightening of legs and feet increased comfort and blood circulation (Park et al, 2009).

Hip and thigh area highest pressure among all postures, especially high in supine positions. 40% of the total pressure was located at the hip. 30% is evenly divided from lower to upper back, 4% on neck, 5% on head, 13 % on thighs and approximately 10% on feet. The area between feet and thighs are the least pressured area taking up approximately 2% of the total pressure These numbers are accurate for supine positions both on a flat and on a W-adjusted bed (Park et al, 2009).

2.6. CENTRIPETAL FORCE

An object that makes a turn is affected by the centripetal force. This force is directed towards the centre of the curve radius giving the object a change in direction (Khan Academy, 2017). An example of this a car making right turn in a city crossing; as the car turns due to its centripetal force, the passengers may feel the sensation of moving towards their left as their movement is of a tangent direction of the curve (Figure 4 and 4).

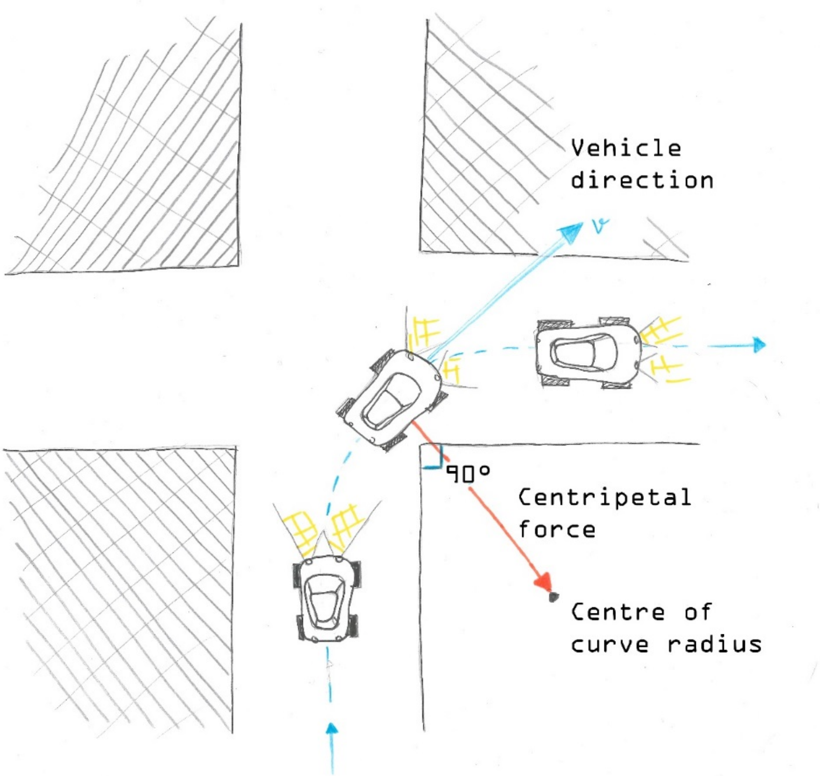

Figure 4: Illustration of centripetal force

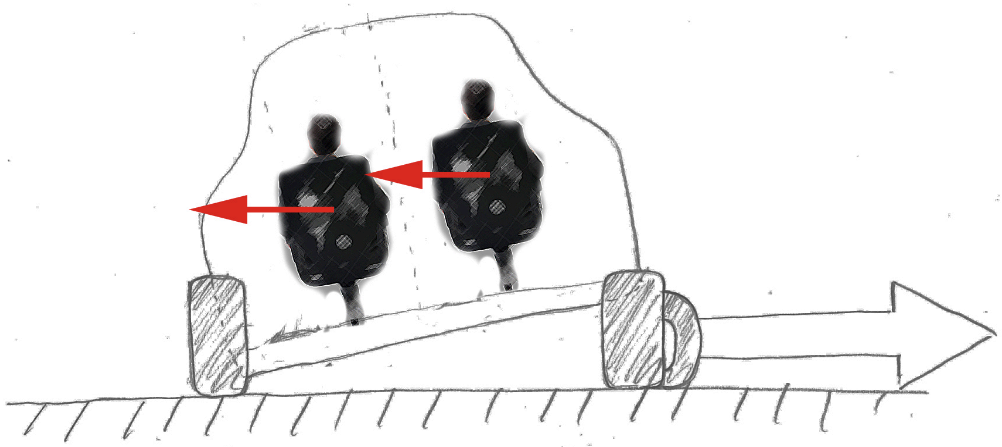

Figure 5: The sensation of moving outwards in a car turn. Red arrows indicate direction of passengers movement relative to the vehicle, while the arrow to the right indicates direction of centripetal force.

2.7. ROAD SAFETY

The risk of road accidents will probably be reduced by establishing automotive vehicles in a city. 93% of road crashes are due to human error (NHTSA, 2008) which gives the new vehicles the potential to be a lot safer. However, it is still a long way to go if they are to be as safe as trains or airplanes; cars are today approximately 100 times as deadly as airplanes, and 50 times as deadly as riding on a train (The Guardian, 2014).

2.8. CLAUSTROPHOBIA AND THE SENSATION OF LOSING CONTROL

Losing control means that the fear centre of the brain (amygdala) gets control at the expense of the ability to rationalize received information (Folk, Jim & Folk, Marian; 2017). Traveling in a confined space as in an automobile could theoretically cause stress from being enclosed or claustrophobia, which makes the passenger feel like being in danger, causing an irrational stressed body reaction (medicalnewstoday.com, 2015).

3. METHODS

This chapter describes methods that has been applied throughout the project including project planning, pre-study, conceptualization, evaluation and visualization. Results from the described methods are presented in the next chapters.

3.1. Market segmentation

To get a more detailed view of the user, characteristics of the market segment can be sorted into four main factors; *geographic, demographic, psychographic* and *behavioral* (businessdictionary.com, 2017).

Since this project is a concept development of a future product, the market is yet to be defined. Therefore, literature studies functioned as a method to identify the characteristics of a potential customer, and the characteristics were then sorted in the four categories above.

3.2. Focus groups

This method is about picking a group of relevant people to discuss a new product. The group should include 5-15 people that performs an open discussion about the product led by a neutral moderator. With this method, it is possible to get a wider view of the concept and new ideas to help further development (Johannesson, 2013).

3.3. Interviews and surveys

Interviews and surveys with structured questions are categorized as quantitative market analysis. These are made to collect results that can be analysed in a statistical manner (Johannesson, 2013). The interviews can also be made in a deeper manner, with questions that can lead to a variety of answers. This leads to qualitative results, where softer product values can be identified (Johannesson, 2013).

3.4. Observations

According to the Lindstedt & Burenius (2006) the best way to study the customer is to observe him/her while using the product in a natural habitat. Being *"the fly on the wall"* gives the opportunity to identify unspoken user needs (KANO model, see chapter 3.5). This gives a more honest picture of the user needs compared to conscious answers in an interview, this because the develops *"blind spots"* and forgets important user needs when discussing it (Lindstedt & Burenius 2006).

3.5. The KANO Model

The KANO model categorizes user needs in three different groups; *unspoken basics*, *spoken performances* and *unspoken excitement*. Unspoken basics is the kind of needs that the user takes for granted, hence, it renders low customer value. Spoken performances are needs that has been explicit demanded but have not been available to the user before. The last category is unspoken excitement which is a need that the user does not know he or she has, but becomes a positive surprise when fulfiled (Lindstedt & Burenius, 2006).

This method was used after the user needs was defined, it is integrated in the specification of requirements.

3.6. PNI-analysis

The PNI-analysis is a straight forward evaluation method where an idea or a concept is listed with positive (P), negative (N) and interesting (I) feedback (Österlin, 2011). It may be summarized in a table or noted directly at a picture or a sketch. This results in eliminated, chosen or further investigated ideas.

3.7. Brainstorming

This creative method is of a quantitative kind. The main goal is to come up with as many ideas as possible without restrictions or realistic thinking (Johannesson et al, 2013). The method should be performed in a group between 5-15 people with a moderator that motivates the participants to create more ideas and contribute to others' (Johannesson et al, 2013). An important goal is to find new and innovative ideas.

3.8. The Ecodesign Strategy Wheel

The *eco-design strategy wheel* is a creative or analytic method that lists different aspects of sustainable design over the product life cycle. It starts at *1: Innovation* which is an abstract level suggesting how to reshape the main idea about the product. 7 levels follow through the life cycle suggesting sustainable solutions in the following stages; *2. Reduce material impact, 3. Manufacturing innovation, 4. Reduced distribution impacts, Reduced behavior and Use impacts, 6 system longevity, 7. Transitional systems* and finally*, Optimized end-of-life* (White, Pierre & Belletire, 2013).

3.9. Morphologic analysis

This concept generating method is based on combining different solutions to different needs. It is listed with needs on the y-axis and solutions on the x-axis. Having created this chart, it is now possible to draw lines between the different solutions creating new concepts (Johannesson et al. 2013). This is exemplified by the main solution for *maintaining low temperature in food*, which in the y-axis could state different partial functions like *contain food, maintain temperature* and *give access.* Solutions to these partial functions are then stated on the x-axis. Having done this, a mix of partial solutions can then be generated into a full concept (Johannesson et al. 2013).

3.10. Pugh evaluation matrix

Concepts developed need to be evaluated in a wide perspective. This may cause problems as the requirements may be plenty and complex. With the Pugh evaluation matrix, new concepts are compared with the present product. These concepts are listed on the x-axis while relevant requirements and needs are listed on the y-axis (Johannesson et al, 2013). The comparison can be made in different ways, but it is exemplified by Johannesson et al (2013) that the reference solution has 0 points in all the different aspects, and the compared concepts get either a (+) or a (–) depending whether it is better or worse in that aspect. The number of pluses and minuses are then summarized at the end, rendering a *net worth* (Johannesson et al, 2013).

4. PRE-STUDY

The pre-study consists of five main parts; market segment, user needs, other concept solutions, dimensioning and material sustainability. They are all concluded and then summarized at the end of this chapter with a specification of requirements.

4.1. Market segment

There is a reason to believe that the first people buying an autonomous vehicle will be the so called *early adopters.* These people are trendsetters that are willing to pay a little extra to get their hands on new technology. Typical properties of these people are that they are educated, wealthy, trendsetting, opinion forming and risk-taking (Shaw, 2015). This character is even more represented in the growth economies. According to a study by IBM on 16000 people, the people of the growth economies have a summed expression of *"When can I have it-mentality"* which means that they are very eager to try it out (Stanley, 2016).

One of these growth economies is China, which has the most rapidly increasing megacities in the world (Forbes, 2013). Sales of private cars has exploded recent years, with almost 24 million new registered cars only in 2015 and in bringing the ownership total up to 172 million cars in the country (Xinhua new agency, 2016). According to a study of 3255 people the Chinese also seem to be more open minded towards autonomous vehicles than the western countries. Westerners were about 7 times as likely to answer that they do not want to use an autonomous vehicle compared with the Chinese (Schoettle & Sivak, 2014). One reason for this may be China's problems with congestion and air pollution in the big cities that has led to tough restrictions. In Beijing, there is a license plate lottery system that has been installed with the purpose of reducing these effects (New York Times, 2016). Citizens need to apply for a license plate, and the odds are bad. In June of 2016, only 1 in 725 applicants were granted a new license plate (New York Times, 2016).

Inhabitants of Chinese mega cities also spend big parts of their day commuting. An average of 52 minutes one way trip to work is reality here (South China Morning Post, 2015) which may also be a reason why autonomous vehicles seem to be more welcomed compared to the western countries.

A common behavioral feature of Chinese businesspeople, is having a personal chauffeur. When used, the backseat is the most important position in the car (Autonews.com, 2013).

As this project handles a futuristic scenario around 2030-2050, it may be relevant to look at the characteristics of Chinese undergraduates. They are a social group of people. 80% live together with friends, and expresses that the use of a car should be of a social kind (Stanley, 2016). However, a general Chinese household is relatively small with 3,1 people (Statista, 2017).

The most important factor for Shanghai undergraduates buying a new car in the future is the independency. According to a study (Belgiawan, et al, 2014) including respondents worldwide "*convenience", "easy to make a trip"* and *"easy to pick up/drop off others"* were the most frequent keywords. The second most unison opinion was that the car should be symbolic affective, including the keywords:

- distinguish oneself from others
- trendy
- bring prestige
- cool
- self-expressive
- fun

Other important factors for buying a new car defined in this research was environmental friendliness and safety (Belgiawan, et al, 2014). Environmental friendliness, or green consumption, is a global trend that is rapidly increasing. 65% of worldwide consumers say that they try to have positive impact on the environment on an everyday basis (Euromonitor, 2015).

The identified segment is divided in the following four categories: *geographic, demographic, psychographic* and *behavioral*.

Geographic

- China
- Megacity

Demographic

- Educated
- Wealthy

Behavioral

- Risk taking
- Innovative
- Sustainable consumers
- Personal chauffeur
- Back seat is the position of choice.

Psychographic

- Social
- Independent
- Trendsetting
- Opinion forming
- Need for self-expression
- Prestigious

4.2. Identifying the user needs

In this chapter, results from analysing primary and secondary research related to user needs are presented.

4.2.1. Outspoken activities according to secondary research

The most common activity that would be performed by Chinese passengers in an autonomous vehicle according to the article was "*Watching the road even though I am not driving" (36,1%)* (Schoettle & Sivak, 2014). This indicates importance of keeping a clear outside view and creating a comfortable atmosphere.

There is a demand for entertainment and leisure while traveling in an autonomous car. According to Schoettle & Sivak (2014) the three most likely leisure activities the Chinese would do in an autonomous car are *texting/talking to friends/family*, *watch films* and/or *play games.*

In a participant study by Pettersson, I (2015), an autonomous vehicle was by a participant visualized as an "*extension of the living room"* which seemed to be a common interest for most of the participants.

Defined in 4.1, inhabitants of Beijing and Shanghai have an average total commuting time of 104 minutes per day. This is precious time that could be used together with family or hobbies. Therefore, it is relevant to discuss whether the commuting time could be integrated into your working day. On this subject, primary and secondary research give different results. Looking at the questionnaire performed by Schoettle & Sivak (2014) 5% of inhabitants of China, UK, US and Australia say that they would work in an autonomous vehicle

4.2.2. Outcome of interviews with target group

To get information about the user need of a more specified target group interviews (see chapter 3.3) were made with participants with similar properties as of those defined in the market segment. Interviews were conducted at two occasions; the first one at Stena Centre and the second at Creative Loops, both hubs for creative entrepreneurs located in Gothenburg, Sweden. Interviewees either worked at small startup businesses or freelanced, mostly in creative or innovate branches. The locations were chosen to match the identified market segment, matching the criteria of being independent, innovative and risk taking. An open question was asked: *"How would you spend your time in an autonomous car if you spent 2 hours every day commuting to your job"?*

18 persons were interviewed and asked only on one question; *"How would you spend your time in an autonomous car if you spent 2 hours every day commuting to your job?".* The most frequent answers were work related being an answer from 15 respondents. This was followed by music (6), watching a movie/TV (4) sleep/relax (3), read (3), playing videogames (1) and surf the internet (1) (Figure 6).

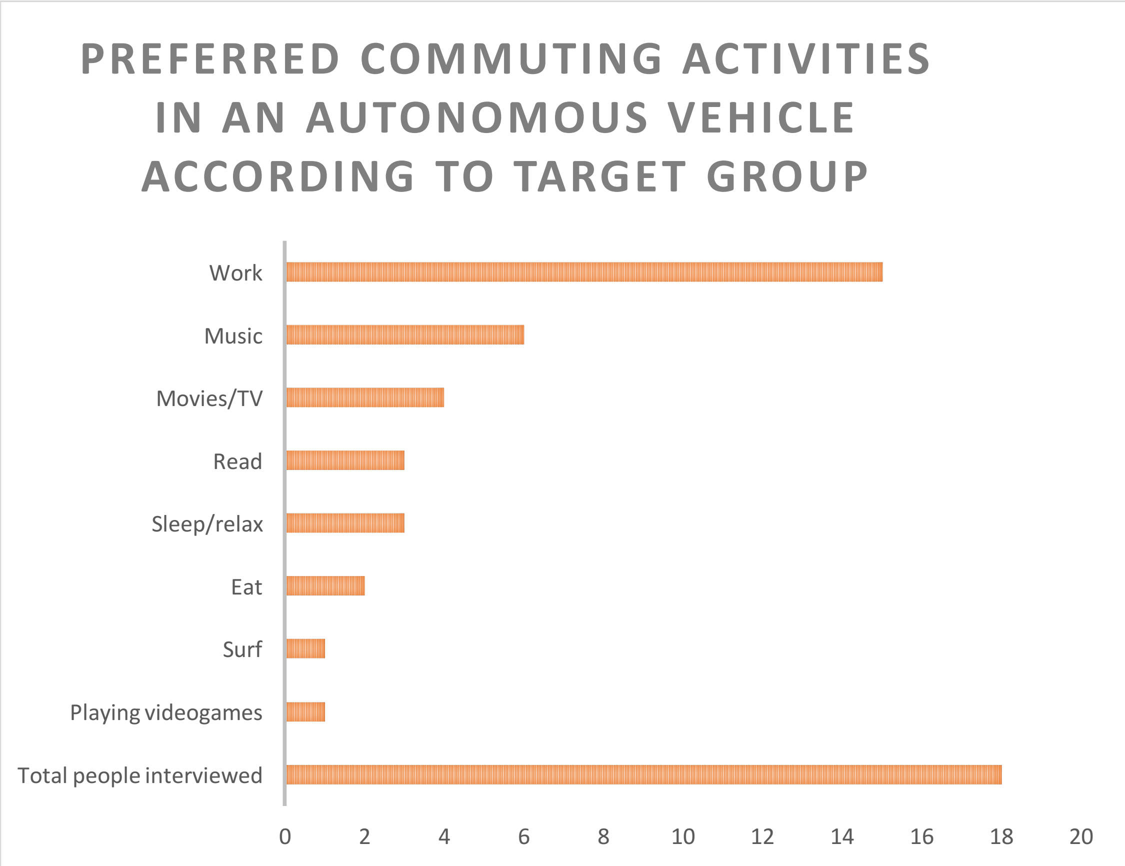

Figure 6: Chart describing results from interviews with people from specified target group.

Categorizing these results into work, entertainment, sleep/relax and eat we get the following results: Entertainment (17), work (15) sleep (3) and eat (2).

4.2.3. Outcome of online questionnaire with target group

To get a wider understanding of the customers' needs, a survey (see chapter 3.3) addressing demanded activities inside an autonomous vehicle was performed digitally in a Facebook group. The actual group was the forum of the design engineers at Chalmers University of Technology, and it was chosen because of its relevance to the market segment (innovative, educated, green and need-for-self-expression). The question asked was *"How would you spend your time in an autonomous car if you spent 2 hours every day commuting to your job"?*

8 people contributed to the question and there was a great width of answers. The two most common ones were *work/study* (5) together with *surfing the web* (5). The top five most frequent

answers are related *to being productive* and *integrating everyday activities*, e.g. eating, sleeping and preparing lunch (Figure 7).

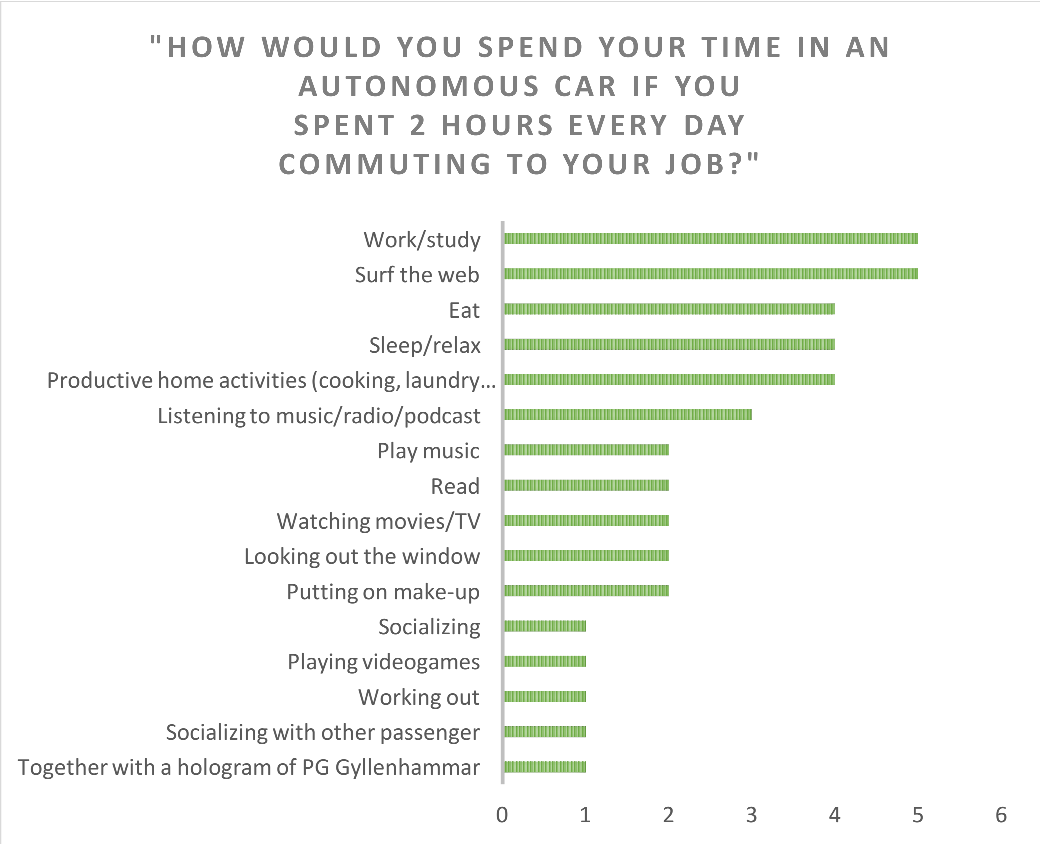

Figure 7: Online questionnaire with 8 people from target group

Categorizing these needs in work/study, entertainment, eat, sleep/relax, everyday activities, socializing and other we get the following results:

- Entertainment (5+3+2+2+2+1=15)
- Everyday activities (6)
- Work/study (5)
- Sleep/relax (4)
- Eat (4)
- Socializing (3)
- Working out (1)

4.2.4. Outcome of observations of bus commuters

As outspoken needs may differ from what the user really do while seated, observations (see chapter 3.43.3) of potential users were made. Two different bus commuter observations were performed between Lindholmen Science Park and Vasaplatsen, Gothenburg. The trips were initiated 15.25 the 26/1-2017 and 8/2-2017 and they were split in two parts; Lindholmen – Nordstan and Nordstan – Vasaplatsen. This because Nordstan is an important stop in Gothenburg where a lot of people get off which refreshes the passenger demographics. A total of 99 passengers were observed at a specified time and the most common activity was looking out the window (59) followed by phone interaction (21), headphone use (18), talking to each other (12) and reading (3) (Figure 8). An interesting finding was that 30 of the 99 observed passengers were standing on the bus even though there were enough spare seats (8).

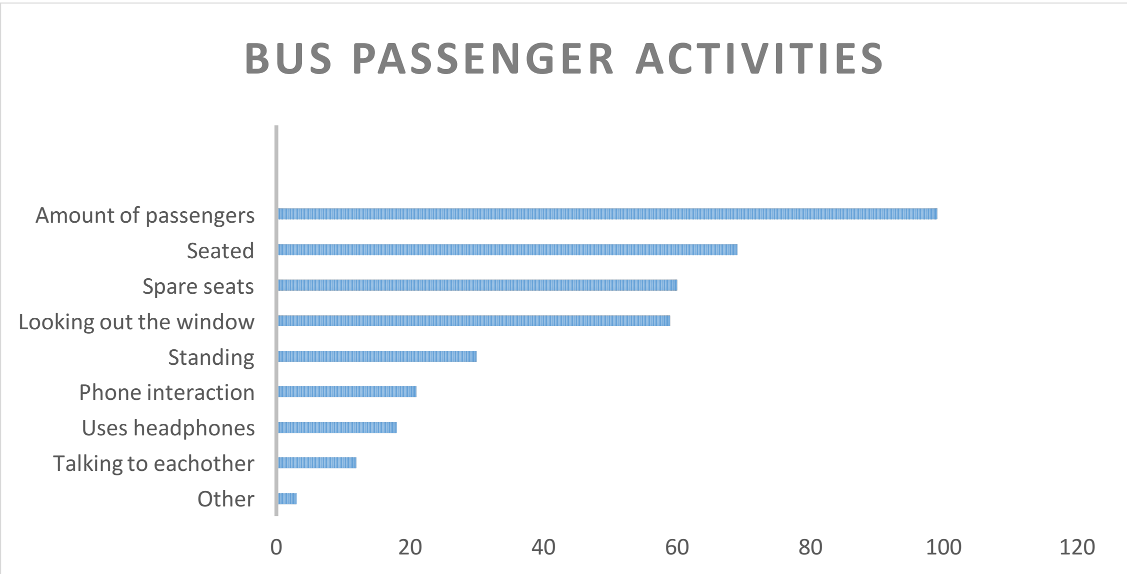

Figure 8: Bus passenger activities chart

4.2.5. Outcome of train passenger observations

Two different train observations were made on the high-speed train line between Gothenburg C and Stockholm C. Passengers of two train cars were observed at a specified time both ways and the most common activity was interacting with phone (51) followed by drink on table (30), headphone use (19), talking to each other (14) and interacting with computer (12), snacks on table (11) and knitting (1) (Figure 9). Both trips went after sundown which made the activity *looking out the window* irrelevant in this scenario. At the time of observation, no one was standing up (Figure 10).

A common activity is to take of jacket and putting it on a shelf above the seats. If the passenger brought a bigger suitcase, he or she put it at a special compartment inside the train. Smaller pieces of luggage are brought to the seat and can be placed on the floor beneath the seat. Magazines can be put in a net pocket attached on the lower back of the seat, drinks and food can either be put in the area located in y-direction between the seats or on a foldable table mounted on the back of the seat in front of the passenger. A handle is attached on the seat close to the isle, this is used by passengers walking to the bathroom or the bistro.

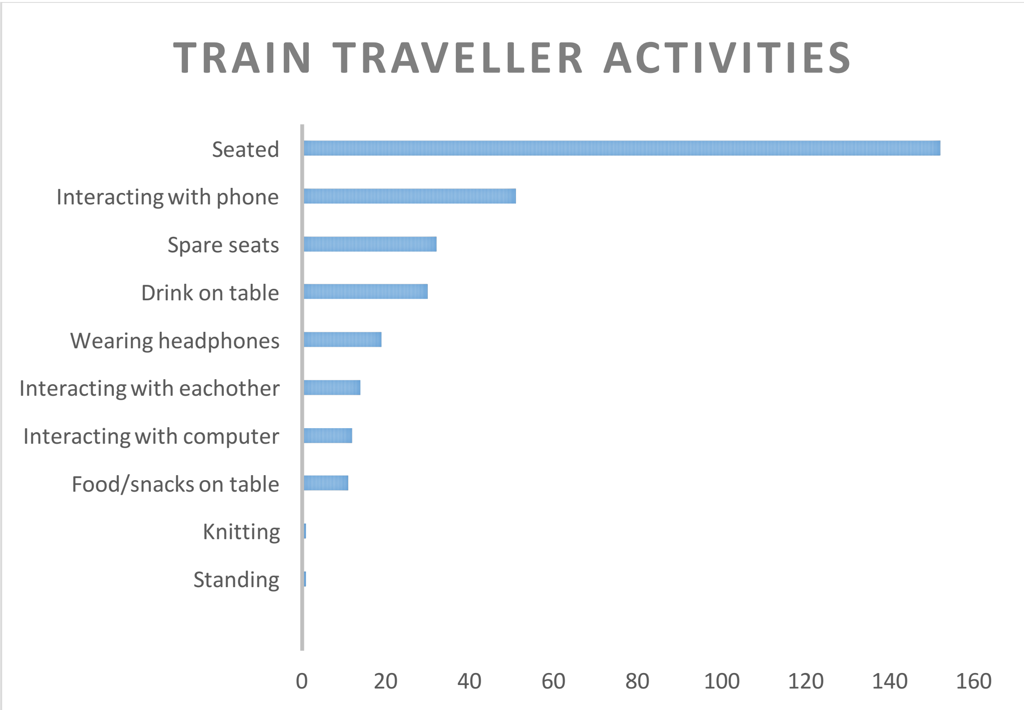

Figure 9: Chart of train passenger activities.

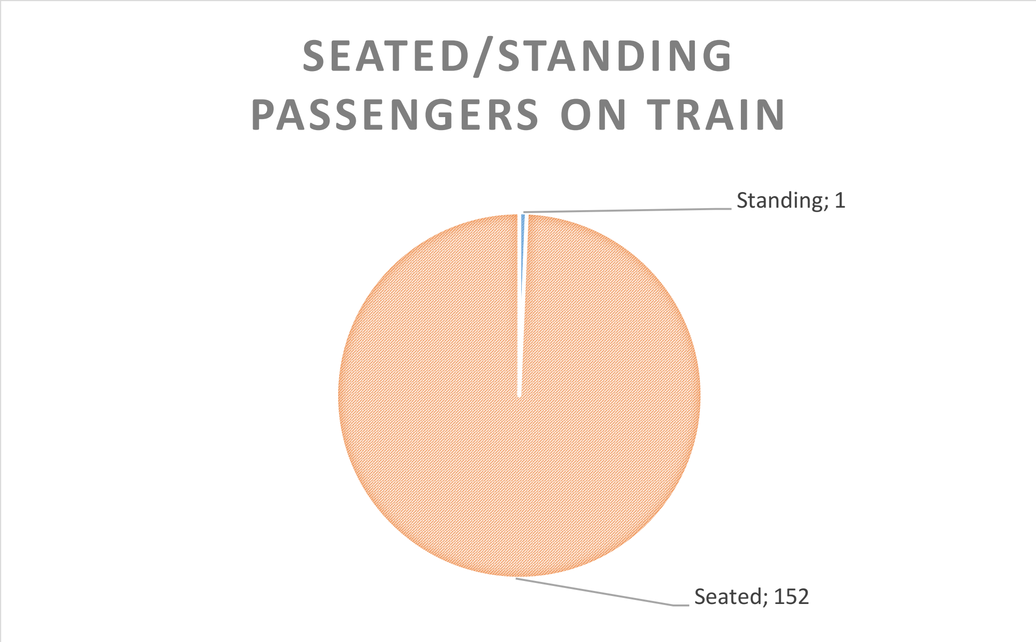

Figure 10: Chart of standing/seated passengers on train

4.2.6. Attitude towards the expressions of an autonomous vehicle

According to Pettersson (2015) autonomous vehicle users need a softer and cozier design language to create a *calm mood*. There were differences in opinion between the participants regarding futuristic versus traditional design. Women wanted to show off their novelty while the men wanted the traditional design because they do not want to scare anyone off.

> *"It shouldn't be like a normal car at*
>
> *all! This is new, and exciting. The inside of the car should have a*
>
> *more futuristic design. This is different and it should show".*

Female participant in the research of Pettersson, I (2015).

4.2.7. Motion sickness

Futuristic scenarios with autonomous vehicles often include passengers doing a lot of things, like having business meetings or a dinner. A big difference though between a car and say, a train, is that a car, especially in the city, starts, stops and turns a lot more. Therefore, it is important to discuss the causes of motion sickness. The main cause to motion sickness is that it arises *"when the vestibular systems of the inner ear send messages about body position or movement that are contradicted by the information sent by the eyes"* (Encyclopædia Britannica, 2017). In a car, this can be exemplified by a situation where the car makes a sharp steer, but the passenger is busy reading and therefore only feels the curve, without seeing it. With this at hand, travelling backwards could also enhance risk for motion sickness, as the upcoming curves and stops are not visible.

This problem with motion sickness in autonomous vehicles is discussed by Michael Sivak and Brandon Schoettle, research professors of Transport Research Institute of University of Michigan. Having predicted that users of an autonomous car will be more active compared to travelling in a conventional car, the professors claim that users will increase their risk of being motion sick (The Observer, 2015). Chinese inhabitants were analysed among 5 other nationalities. 40,3% of the Chinese are expected to have more frequent and severe attacks of motion sickness, 6-10% would often, usually or always experience some level of motion sickness (The Observer, 2015).

According to Encyclopædia Britannica (2017) the best prevention method is to *"...fix the body, especially the head, with reference to the vehicle"*. Other recommended actions according to University of Maryland Medical Centre (2017) to prevent motion sickness are:

- Sit in the front seat in a car.
- Keep your eyes on the horizon.
- Do not read
- Rest your head against the seat back, to keep it still.
- Turn the air vents toward your face.
- Do not smoke

According to Schmäl, F (2013) the traveler should also keep her or his eyes forward avoiding glancing backward or sideways in order to prevent conflicts between visual and gravitational information. However, the human body adapt herself to this conflict by simply being exposed to it. Other findings in Schmäl´s research was that music, sleep, controlled breathing and the absence of alcohol had positive preventing effects.

4.2.8. Feeling safe

A big challenge for the designers of autonomous vehicles is to make the user to feel safe in the car. According to a study, 75% of the American drivers are afraid of traveling with an autonomous vehicle (American Automobile Association, 2016). This fear does not seem to be as intense in China though. Another study quizzing 3255 people in six countries from east to west reveals that only 3% of the Chinese respondents would *not* travel with an autonomous car, while the same number for UK or US citizens are approximately seven times higher (Schoettle & Sivak, 2014). Some people may just need to try it for a while before getting comfortable, an opinion shared by all participants of a pilot study by Petterson, I & Karlsson, M (2015):

> *"For some, it would take months of close surveillance until they could finally relax and trust the car. In spite of the worries about the initial phases of usage, all were convinced they would sooner or later adopt autonomous driving in everyday use, indicating that trust takes time to develop".*

Nonetheless, creating a space that feels safe is important. 90% of American new-vehicle buyers claimed that safety is very important or extremely important (Forbes, 2015). Technofobia cannot be underestimated. About 50% of the population in different categories in several studies feel anxious about using a computer (Osiceanu, 2015) which also can be related to the fear of using an autonomous vehicle.

Because autonomous vehicles are not yet established for private consumption, a relevant method of studying the reasons for this fear could be to compare it with the fear of flying. Excluding the fear of heights of course. Two reasons for flight fear that in fact could be relevant even for autonomous cars are the states of *losing control* and *claustrophobia*[1] *(BBC, 2016).*

4.2.9. Wanted features in car seats today

According to a study with over 66 000 new-vehicle buyers, 5/10 of the most requested features was seat related (Forbes, 2015). First off was *power driver seat* (79%), followed by *heated front*

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[1] Defined in chapter 2.4

seats (70%), *easy-to-clean floor & seat materials* (64%), *power front passenger seat* (60%) and *leather seats* (58%).

4.2.10. Demand for car sharing, and its consequences

The car sharing market in China is increasing. Tech trend strategists of Accenture says that car sharing in China will three-fold until 2020 (Accenture, 2016). This system may become even more relevant in a mega city like Beijing, where a buyer of a new car need to enter a lottery like system (with small chances of winning) just to get a license plate (as defined in 4.1).

Car sharing will probably effect the interior vehicle design as the usage per day will increase. The demands of the aftermarket in cars might give a hint of what will become important while choosing features in a shared vehicle. Examples of these features can be found in a poll from SIFO, showing that only 16% of aftermarket of Swedish car buyers requests light coloured seat fabric (mynewsdesk.com, 2017). Another interesting fact from that study is that 60% of the customers specifically requests heated seats.

4.2.11. Conclusions of identified user needs

Several findings, both from external and empiric research, has been in conflict when responses from a wider group of respondents have been compared with more niche groups. An example of this is that people from western countries seems to be afraid of the new technology, while the Chinese seems to be welcoming it. As defined in 2.4 safety will probably be considerably enhanced due to removal of the human factor. But even though it will not be as safe as on an airplane (see chapter 2.7) and because of that, seat belts may still be needed in special situations like during heavy snow or high-speed travelling.

Another example of conflicts in results is that work is not a prioritized spoken activity among a general group of respondents, while interviews with the specified demographic and psychographic market segment give that work is the most probable activity. An important factor to this result may be that two-hour commuting time was part of a user scenario in the primary research but not in the secondary research. Aiming at a more niche group of respondents defined in this project, creating a place of work is of most importance.

Needed activities identified with high frequency in both primary and secondary research are looking out the window, entertainment and relaxing/sleeping. In the category entertainment, music, movies/TV and playing video games, are included. Using a laptop or a cell phone was a frequent answer, but these activities are not noted as individual activities as these platforms may not be common in the future. Features presented in the BMW in 2.7.4. indicate this.

Standing up was a very common activity on shorter bus rides even though there were plenty of spare seats. This activity was hardly seen on the high-speed train between Stockholm and Gothenburg. This gives us that people want to sit down when they are travelling for a longer time, but there is also a demand for a more active position.

There is also a demand for the right expressions in an autonomous vehicle. The most obvious one is related to green consumption, a demand that surely will increase as material shortages intensifies. Among the near future Chinese car buyers there is a demand for social interaction and convenience, preferred expressions are *trendy* and *personal*.

Observations from the train ride between Gothenburg and Stockholm showed that eating and drinking are frequent activities among train passengers. This was also confirmed by several respondents in interviews and questionnaires The behaviour was not as frequent with the observed bus passengers, a fact that can be derived to travel time. The bus rides were only about 10 minutes long while the train rides were more than 3 hours.

The autonomous vehicle will, unlike the train, still drive through curves and it will perform lots of acceleration and deceleration. If the autonomous vehicle is going to be an extension of the living room, the office or the dining room the demand for stability will increase. And as passengers will increase their time doing other things than watching the road, the risk of motion sickness will increase as defined in chapter 4.2.7. As this need is not outspoken by the user, it is defined as an *unspoken delight*.

Looking at the needs of car buyers today, seat related features were among the most important factors which indicates the weight of comfort. The high demand of power seats (79% of respondents) indicates that customization is essential. The demand of leather seats (58%) or heated seats (70%) can neither be neglected.

A demand that buyers of both new and used cars express are *minimize servicing*. The fact that only 16% of the Swedish buyers of new cars requests light coloured seat fabric also indicates that this should be avoided as cars may be shared with multiple users in the future.

The need of integrated storage was found on trains as pockets, shelves above and on the floor beneath the seats. These are frequently used functions which indicates an important need, but it may also be functions that should be provided by other components in the car. However, leaving the space beneath the seats free give both a spacious feel and a place for storage.

4.3. Outcome of analysing existing solutions

The products analysed in this paragraph are further described in attachment 2.

Several new private car concepts, like Olli, Mercedes F015 and Nio Eve use innovative ways of seat arrangements, but all at the expense of larger dimensions.

One interesting pattern that can be seen in most concepts, is that the seats are covered with light fabric. These colours give a light, elegant and spacious feel, but they are also a big risk to wear and tear and unattractive in the aftermarket as defined in 4.3.16. In a sharing context, this may be a problem, as the wear and tear of the product will increase.

Lexus Kinetic Seat (attachment 2.6) uses a dark appearance, it has a lightweight feel to it because of its thin and transparent materials.

Several concepts use chairs facing a backward direction. This give a more dynamic, social and flexible cabin, but it can also enhance the risk of motion sickness, as defined in 2.1. Olli offered standing positions as well as seats angled 90° along the z-axis away from the direction. These designs show that there is a need to experiment with new seat arrangements.

Olli and the Nio Eve both have seat cushions that do not give side support. This may work fine at slower speeds and at shorter trips, but travelling for 2 hours/a day, as defined in this project, this may become uncomfortable when stability is important. The Lexus kinetic seat, with its adjusting seat and back support, may have potential for a more stable position in curves.

The BMW had a lot of interesting technical features. Analysing the heartbeat of the passenger and giving haptic feedback are new ways of communicating with the user. The use of a holographic touchscreen also gives a hint that laptops, LCD screens, smartphones – digital communication and interface in general – may fundamentally change in a nearby future.

Together with Tesla, BMW also used some interesting new attachments. Tesla with its thin floor attachment on the seats in the middle row contributes to a more spacious feel. BMW uses headrests attached in the roof, which can be a problem if the seat reclines.

4.4. Defining interior and exterior dimensions

To start the concept development of the seats, a presumed interior dimension must be set. Important factors to interior size are removal of driving equipment, material delimitations, infrastructure and development of safer vehicles. As defined in chapter 2.7, autonomous vehicles have a potential to become 93% safer, which is a fact that could lead to new ways of integrating safety functions like airbags and deformation zones. Combined with removal of combustion engine, transmission, steering, fuel tank and deformation zones the interior could become much more space efficient. Taking driving experience of the user needs, wheels could also be thinner and moved away from the interior towards the sides of the vehicle.

Problems with congestion and lack of parking space in the Chinese mega cities (defined in 4.1) might also become factors of limiting the size of the car. And if the vehicles are to be energy efficient, material weight and aerodynamics are also going to be important factors (the effect of minimizing weigh is further explained in 4.8). As defined earlier, the commute is the main travel purpose of the vehicle, and therefore, it will mainly be used by 1-2 people. It was also defined (chapter 2: Market segment) that a regular Chinese household includes 3 persons, so that should be the minimum capacity. Adding that the vehicle could be shared or used as a taxi, the capacity should include at least four people.

With these factors at hand, it is hard to draw any conclusions of how the interior dimensions are going to change in the future. However, if the exterior will be limited and the interior freer, a relevant assumption would be to use current exterior dimensions and an empty spacious interior without obstructive objects. Interior dimensions are therefore roughly set after a popular vehicle today, the Volkswagen Tiguan 2017. The Tiguan is a SUV and it was chosen because it is spacious and very popular in China. The dimensions are: exterior length 4486 mm, wheel base: 2681 mm, interior width 1503 mm, exterior width 1839 mm and exterior height 1632 mm (Volkswagen, 2017). These dimensions should not be read as a scientific result; it is more a reference for further concept development.

4.5. Engineering contradictions

Looking at the four focus needs *provide stability, provide customization, provide spaciousness and a clear outside view* and *provide green status* some of them are contradictory. Customization features for example needs extra mechanical and electric components which may lead to a greater weight and a greater variation of materials used – as defined in chapter

2.3. This would interfere with the demand of more sustainable products and maybe spaciousness as it requires greater material volume.

Seat stability is given by side support of the seat cushion, seatback and headrest. This will affect spaciousness and green status as increased material volume will be needed.

4.6. Specification of requirements

The requirements are divided in the three categories user needs, relevant ergonomics and dimensioning. They are summarized in a list according to the importance defined in 4.3, important outtakes from the theoretical framework and the dimensioning chapter. The criteria are weighted according to the system below. KANO need categorization is described in 3.5.

Importance

- Maximum: 4
- High: 3
- Medium: 2
- Low: 1

KANO need categories

- Unspoken delights 3
- Spoken performances 2
- Unspoken basics 1

These points are then added and summarized into the weight column which indicates the priority of the defined need.

No.	Description	Importance	KANO need category	Weight
1.	User needs	N/A	N/A	N/A
1.1.	Express safety	High	Spoken performances	5
1.2.	Provide fixed seat (when needed)	High	Unspoken basics	4
1.3.	Provide working position	Maximum	Spoken performances	6
1.4.	Provide outside view	Maximum	Spoken performances	6
1.5.	Provide entertainment position	Maximum	Spoken performances	6
1.6.	Support relaxing/sleeping position	High	Spoken performances	5
1.7.	Support active position	High	Unspoken delights	6
1.8.	Provide a social environment	High	Spoken performances	5
1.9.	Provide convenience	Medium	Spoken performances	4
1.10.	Provide personal expression	Medium	Spoken performances	4
1.11.	Provide eating position	Medium	Unspoken delights	5

1.12.	Provide drinking position	Medium	Unspoken basics	3
1.13.	Provide customization	Maximum	Spoken performances	6
1.14.	Provide leather seats	Medium	Spoken performances	4
1.15.	Minimize servicing	High	Spoken performances	5
1.16.	Provide heat	High	Spoken performances	5
1.17.	Avoid light coloured seat material	High	Spoken performances	5
1.18.	Provide green status	Maximum	Spoken performances	6
1.19.	Express trendiness	Medium	Spoken performances	4
1.20.	Provide storage	Medium	Unspoken delights	5
2.	Dimensional constraints	N/A	N/A	
2.1.	Provide seats for a minimum of 3 people	Maximum	Unspoken basics	5
2.2.	Fit inside defined width	High	Unspoken basics	4
2.3.	Fit inside defined height	High	Unspoken basics	4
2.4.	Fit inside defined length	High	Unspoken basics	4
3.	Ergonomics	N/A	N/A	
3.1.	Provide stability	Maximum	Unspoken delights	7
3.2.	Provide spaciousness	High	Unspoken delights	6
3.3.	Support head	Maximum	Unspoken basics	5
3.4.	Minimize glancing backwards	High	Unspoken basics	4
3.5.	Minimize pressure on distal half of thigh	Maximum	Unspoken basics	5
3.6.	Support ischial tuberosity	Maximum	Unspoken basics	5
3.7.	Support back	Maxiumum	Unspoken basics	5
3.8.	Provide lumbar support	Maximum	Unspoken basics	5
3.9.	Provide change of pressure by user movement (not too soft padding)	Maximum	Unspoken delights	5

4.7. Prioritized requirements

Having the requirements sorted after weight, it is defined that *providing stability* is the most important requirement as it is both defined as an *unspoken delight (4.6.)* and a key function for a lot of other requirements. Looking at the requirements with the highest priority (weight 6-7), some of them are related to each other. As defined before, stability is related to a lot of different needs of the autonomous vehicle seat. Providing different positions for *active use, entertainment* and *work* are all related to providing *customization*. Providing spaciousness and a clear outside view are both solved by minimizing or hiding components. Instead of trying to find solutions for all identified needs individually, it would be more relevant to focus on these four needs that may affect all the needs and functions in the car. These four needs are summarized below:

- Provide stability
- Provide customization (active, entertainment, working position)
- Provide spaciousness and a clear outside view
- Provide green status

3.1.	Provide stability	Maximum	Unspoken delights	7
1.3.	Provide working position	Maximum	Spoken performances	6
1.4.	Provide outside view	Maximum	Spoken performances	6
3.2.	Provide spaciousness	High	Unspoken delights	6
1.5.	Provide entertainment position	Maximum	Spoken performances	6
1.7.	Support active position	High	Unspoken delights	6
1.13.	Provide customization	Maximum	Spoken performances	6
1.18.	Provide green status	Maximum	Spoken performances	6
1.1.	Express safety	High	Spoken performances	5
2.1.	Provide seats for a minimum of 3 people	Maximum	Unspoken basics	5
3.3.	Support head	Maximum	Unspoken basics	5
1.6.	Support relaxing/sleeping position	High	Spoken performances	5
3.5.	Minimize pressure on distal half of thigh	Maximum	Unspoken basics	5

1.8.	Provide a social environment	High	Spoken performances	5
3.6.	Support ischial tuberosity	Maximum	Unspoken basics	5
3.7.	Provide lumbar support	Maximum	Unspoken basics	5
3.7.	Support back	Maximum	Unspoken basics	5
3.8.	Provide change of pressure by user movement (not too soft padding)	Maximum	Unspoken delights	5
1.11.	Provide eating position	Medium	Unspoken delights	5
1.15.	Minimize servicing	High	Spoken performances	5
1.16.	Provide heat	High	Spoken performances	5
1.17.	Avoid light coloured seat material	High	Spoken performances	5
1.20.	Provide storage	Medium	Unspoken delights	5
1.2.	Provide fixed seat (when needed)	High	Unspoken basics	4
2.2.	Fit inside defined width	High	Unspoken basics	4
2.3.	Fit inside defined height	High	Unspoken basics	4
2.4.	Fit inside defined length	High	Unspoken basics	4
3.4.	Minimize glancing backwards	High	Unspoken basics	4
1.9.	Provide convenience	Medium	Spoken performances	4
1.10.	Provide personal expression	Medium	Spoken performances	4
1.14.	Provide leather seats	Medium	Spoken performances	4
1.19.	Express trendiness	Medium	Spoken performances	4
1.12.	Provide drinking position	Medium	Unspoken basics	3

Figure 11: Specification of requirements, sorted after weight.

4.8. Sustainable materials

Reducing the weight of the vehicle is most importance for energy efficiency, which is important in a bigger environmental perspective as transportation stands for a relevant part of the energy consumed worldwide. Every weight reduction of 10% improves energy efficiency with 6-8% (Joost, William, 2012) making weight reduction the focus area of this material analysis.

As defined in chapter 2.3, steel is the major material in the driver seat, taking up almost 50% of the total material weight (equivalent to approximately 14,5 kg). Because of that, alternatives to the steel frame will be in focus in the following chapter.

4.8.1. Material shortenings

If the world keeps consuming and mining natural resources at the same rate, some of our most common materials will soon be gone. Copper, led and zink are materials whose known resources will be depleted in 28, 21 and 25 years respectively. Known sources of oil will be depleted in 41 years. Iron and aluminium are, in relief to those materials, more stable. Their known resources are anticipated in 132 and 202 years respectively (Gröndahl & Svanström, 2010).

4.8.2. Alternative materials to a steel seat frame

The chapter includes analysis of materials that are being used as car seats today, the most common one is steel, while CFRP, GFRP and aluminium are more used in extreme situations like racing. Magnesium and EPP are also included in this analysis as they are said to have a big potential in future vehicle seats, mainly because of its lighter density compared to steel. The weight reduction analysed will be compared to the reference seat in chapter 2.3 which is estimated to weigh 14,5 kg.

4.8.2.1. CFRP (Carbon fibre reinforced plastic)

A seat frame concept built on CFRP (carbon fibre reinforced plastic) was tested according to Federal Motor Vehicle Safety Standards (FMVSS) 202, 207 and 208 (Kwang Ju Lee, Joon Hyeok Choi, Seok Woon Seon, 2014). It needed extra thickness around the recliner to avoid stress concentration. Stress level at the CFRP frame was measured 51.1 to 95.5 % of a corresponding steel frame. The CFRP frame weighed 56,2% of the steel frame.

Applying this potential weight reduction on the reference seat (2.3) a CFRP seat frame would weigh 8,1 kg.

4.8.2.2. Magnesium

Switching material from alloy steel to magnesium would reduce the weight of the seat back frame by 41,3% without failing in regulations regarding stiffness or toughness (Yun Kai Gao, Da Wei Gao, Yu Hang Gao, 2010). Applying this potential weight reduction on the reference seat (2.3) a magnesium seat frame would weigh 8,5 kg.

4.8.2.3. GFRP (glass fibre reinforced plastic)

Audi created a lightweight concept car named *TT ultra quattro concept* that uses glass fibre reinforced car bucket seats (Sunday Mercury, 2013). Seat weight was not given, but is estimated to 60% (8,5 kg, slightly higher than the CFRP frame) of the reference seat weight; this because the material is slightly denser and weaker than CFRP (Granta CES, 2017).

4.8.2.4. Expanded polypropylene (EPP)

The Woodbridge Group(R) has developed car seat frames made of closed cell expanded polypropylene (EPP) called StructureLite(R) (Technology and business journal, 2010). The products are supposed to reduce standard seat weight by 35% and are already established on the market as *"virtually every OEM is currently utilizing the benefits of this technology"* (Technology and business journal, 2010).

Estimating 35% weight loss on the reference seat (2.3) would give a weight reduction from 14,5 to 9,4 kg.

4.8.2.5. Aluminium

Aluminium seat frames are commonly used on metro and trains, as it is robust, fireproof and resistant to vandalism (Kiel-Sitze.de, 2017). The material has also been used in lightweight car seat buckets, the Kirkey Lightweight Sprint Deluxe seat bucket weigh only 4,8 kg (sportseats4you.co.uk, 2017).

4.8.3. ECO Audit

Using the material database of Granta CES, the identified materials above are compared in an *ECO audit,* reference material is 14,5 kg medium carbon steel based on the seat in chapter

2.3. The audit compares the energy used in material extraction and refinement and manufacturing as well as the CO2 footprint between the materials (figure 33 and 34).

Recyclability is important in a sustainability perspective. In the ECO audit below the materials with recycling possibility has been estimated to be produced with a typical recycling rate. These rates are defined by Granta CES and are based on the recycle fraction of current supply, giving a generalized global rate. The recycling rate varies between markets, from over 95% in Sweden (Naturvårdsverket, 2015) to 4% in China (rewardingrecylcing.com, 2015), which should be taken in account when analysing the numbers below.

Looking at this ECO audit (figure 33 and 34), it is clear that CFRP and GFRP are not yet suitable for sustainable production as it is extremely energy and CO2 demanding without established recycling possibilities.

A steel frame would consume, estimated on a *typical* recycling rate, a net energy worth of 284 MJ and emit a CO2 equivalent weight of 21,9 kg. A magnesium frame would consume, estimated on a *typical* recycling rate, a net energy worth of 500 MJ and emit a CO2 equivalent weight of 38 kg. The expanded polypropylene frame would consume, included a 100% recyclability rate, a net energy worth of 673 MJ and emit a CO2 equivalent weight of 52 kg. An aluminium bucket frame would consume, estimated on a *typical* recycling rate, a net energy worth of 179 MJ and emit a CO2 equivalent weight of 14,2 kg.

From this analysis, we see that aluminium is the best material in a sustainable perspective. An important feature in aluminium is that is very energy efficient in the recycling phase. Only 5% of the energy is needed compared to producing new material (Gjuterihandboken, 2017).

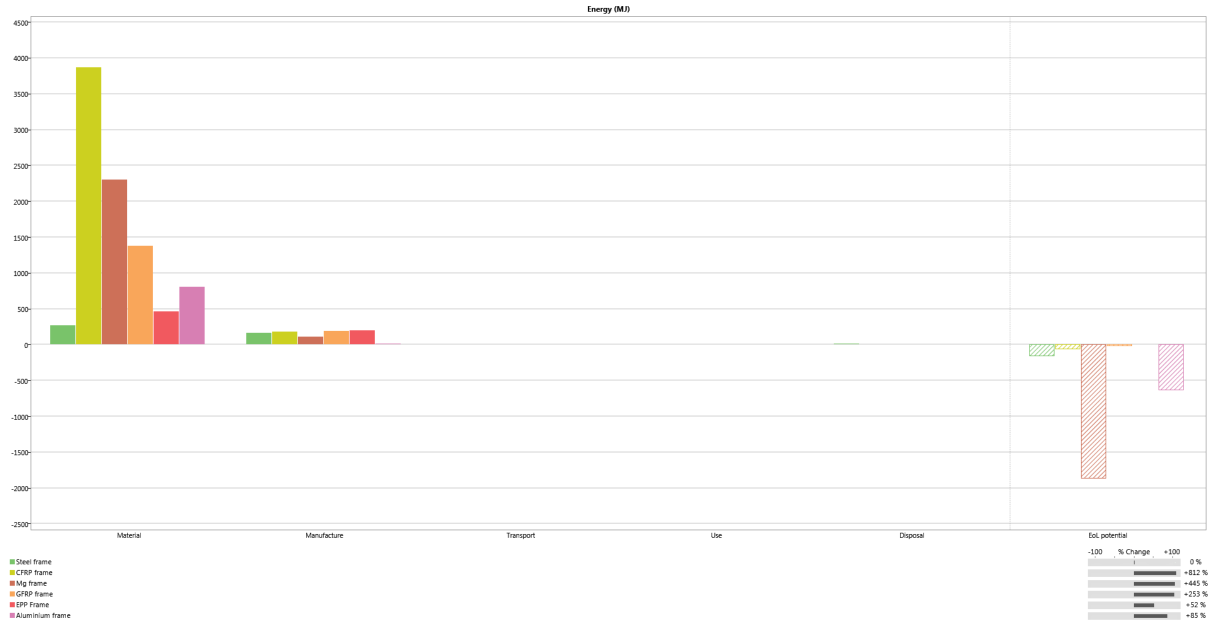


Figure 12: Eco audit: Energy comparison

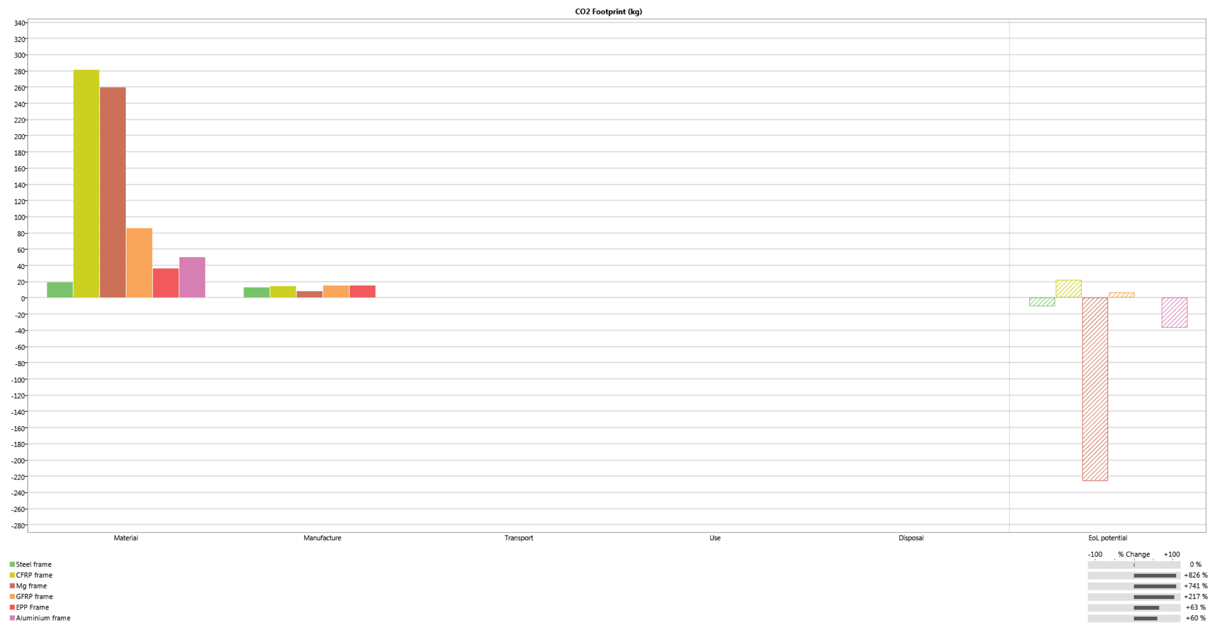


Figure 13: Eco audit: CO2 footprint comparison

4.8.4. Comparing properties of steel and aluminium

As seen in the paragraph above, aluminium is the most sustainable material alternative measuring energy consumption and CO2 emissions. Comparing this material further with the reference product, it is obvious that aluminium alloys are (in general) weaker, softer, less durable and more expensive than steel as seen in the table below (figure 35). Aluminium is about four times more expensive, but the density is only about a third compared to steel (Granta CES, 2017). Steel is about three times as stiff, while the difference in strength differs a lot depending on the specific material. However, strength is in general much higher in steel (Granta CES, 2017).

Property - material	**Medium carbon steel**	**Aluminium alloys**
Price [SEK/kg]	4,98-5,06	19-21,7
Density [kg/m3]	7,8-7,9	2,5-2,9
Young's modulus [GPa] (stiffness)	200-216	68-82
Yield strength (initiated plastic deformation)	305-900	30-500
Tensile strength [Mpa] (max. plastic deformation)	410-1200	58-550
Fracture toughness [Mpa.m^0,5] (initiation of cracks)	12-92	22-35
Fatigue strength at 10^7 cycles [MPa]	229-600	21,6-157

Figure 14: Comparison of medium carbon steel and aluminium alloys. The reference for the data is general statistics from Granta CES (2017).

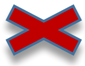
5. EARLY CONCEPTUALIZING

This phase was initiated by defining the surrounding dimensions and the seat layout. Then, functions to the identified needs were generated in a quantitative way. These functions were then evaluated and summarized in a morphologic analysis where 3 seat concepts were created. Based on feedback by a focus group on these 3 concepts, a fourth concept was made. These concepts were then analysed in an evaluation matrix in the end of this chapter.

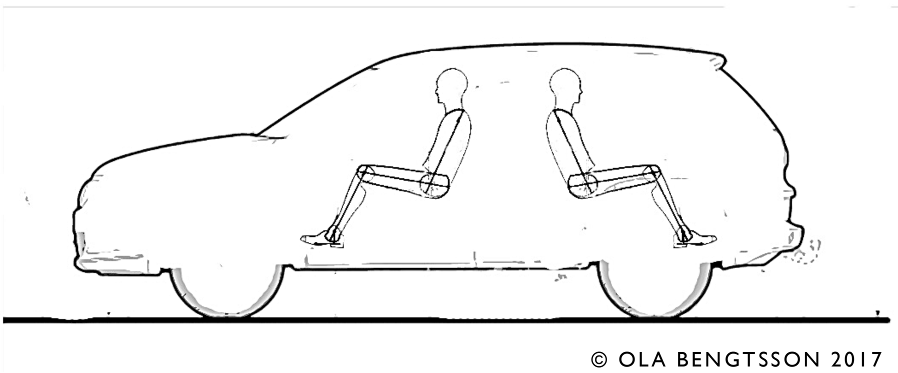
5.1. Conceptualizing seat arrangement

After having defined dimensions and relevant number of passengers, a conceptualizing of passenger formation was initiated. It was made testing different arrangements inside a car.

The following symbols indicate evaluation result of the concept.

 Concept of continued development  Eliminated concept

Concept layout 1 has a big weakness limiting the passengers' ability to recline their seats (Figure 15). Power seats was the most requested feature in new cars, and this concept would not provide that function. Because of that, this concept should not be developed further.



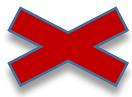


Figure 15: Concept layout 1

Concept 3 is neither a relevant formation to develop further. Travelling backwards should be avoided as the passengers lose sight of action which enhances risk of motion sickness (Figure 16).

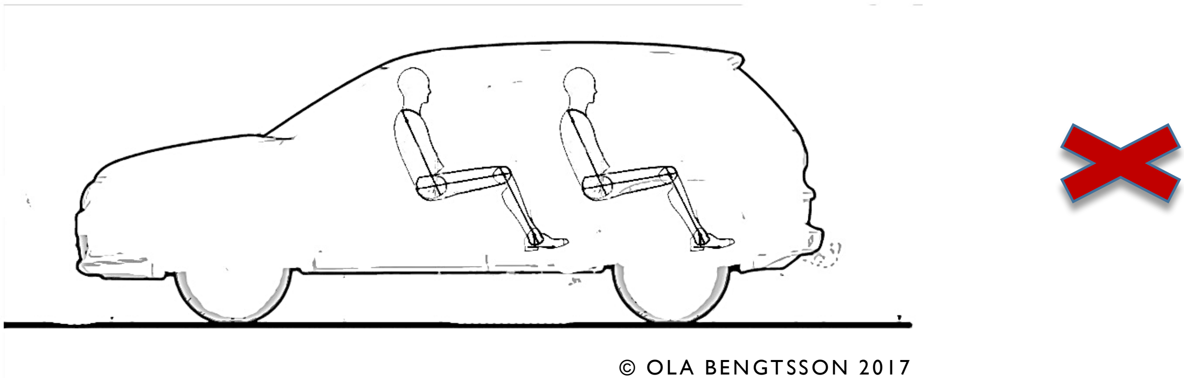


Figure 16: Concept layout 3

The traditional arrangement, concept 2**,** is comfortable as all passengers sees the line of action and reclining seats are possible (Figure 17).

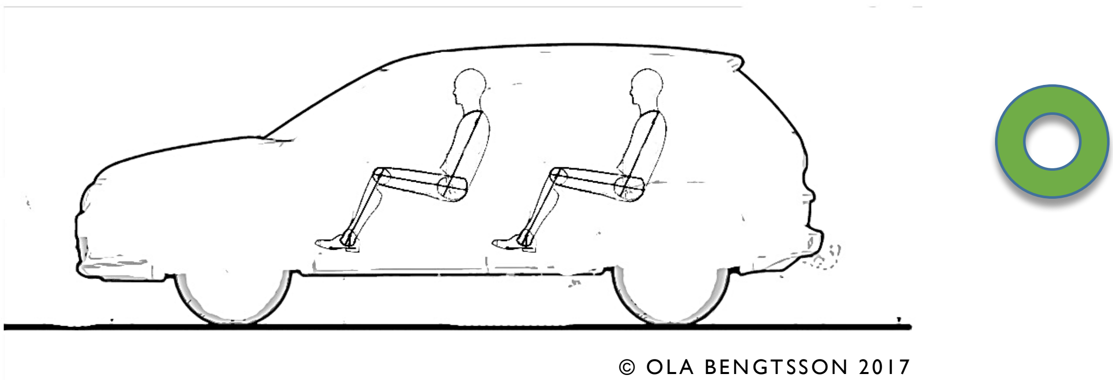


Figure 17: Concept layout 2

Concept 4 is ideal in a social context, and it is also very spacious. Seats can be reclined without affecting eachother (Figure 18).

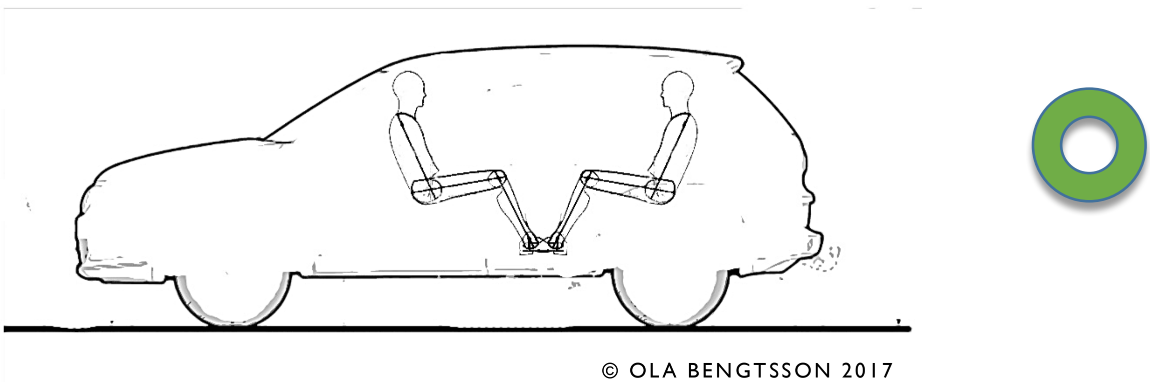


Figure 18: Concept layout 4

This concludes that the back seats should be fixed in a forward direction. Ideal for the front seats would be if they could vary between forward and backward direction. This gives the passengers the possibility to change between individual and social formations.

As this vehicle's main function is private commuting, it is also interesting to speculate if seats could be removed or folded when not used, like Volvo's lounge console (4.6: existing concept solutions). This maximizes the outside view and interior space which enhances comfort and minimizes risk for motion sickness. Having established that the back seats should be fixed in one direction, those should in that scenario become the primary seats, while the front seats is removable/foldable (Figure 19: Concept with folded/removed front seats..

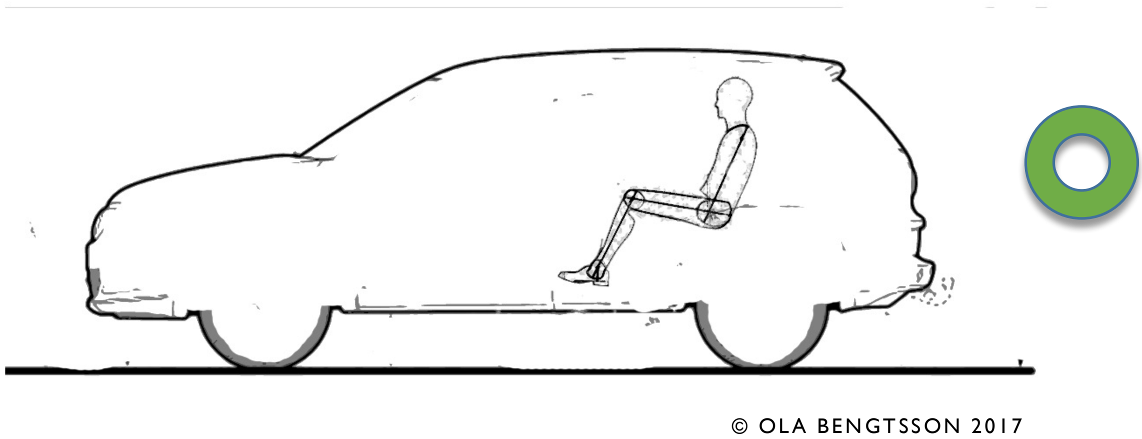


Figure 19: Concept with folded/removed front seats.

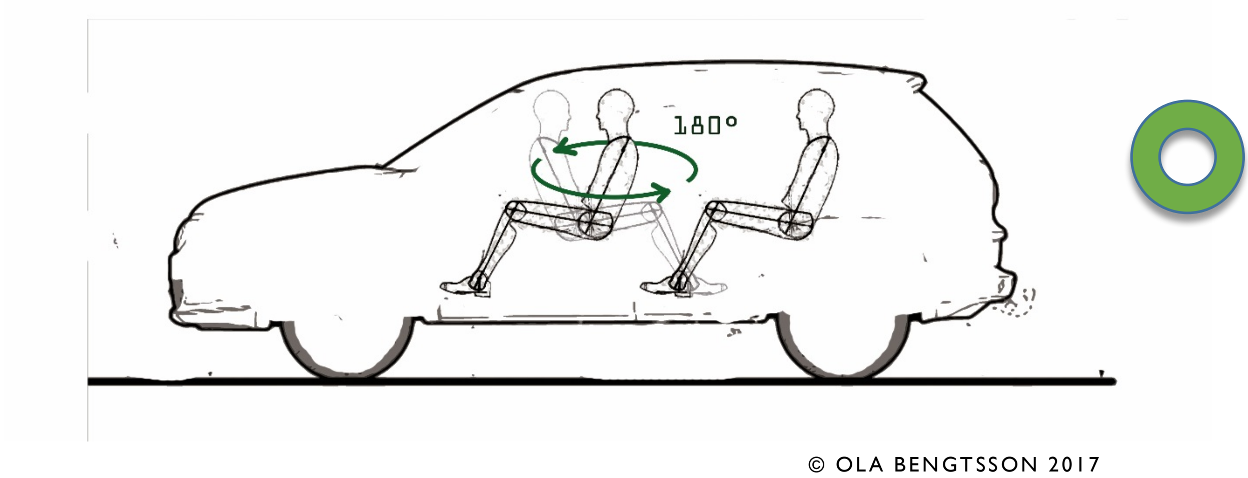


Figure 20: Concept with turnable front seats

The next step is to define how many passengers there should be in each row. Looking at a rough sketch (Figure 21) of the concept in an x-y perspective we see that fitting three passengers inside the defined width is an absolute maximum. However, this would limit the potential to use turning seats in the front row, and it would also limit the potential use of customization, as the space for armrests and other features would be constrained. Having the potential to pick up 6 people may be positive, but this vehicle is set to be more of a private vehicle, made for commuting.

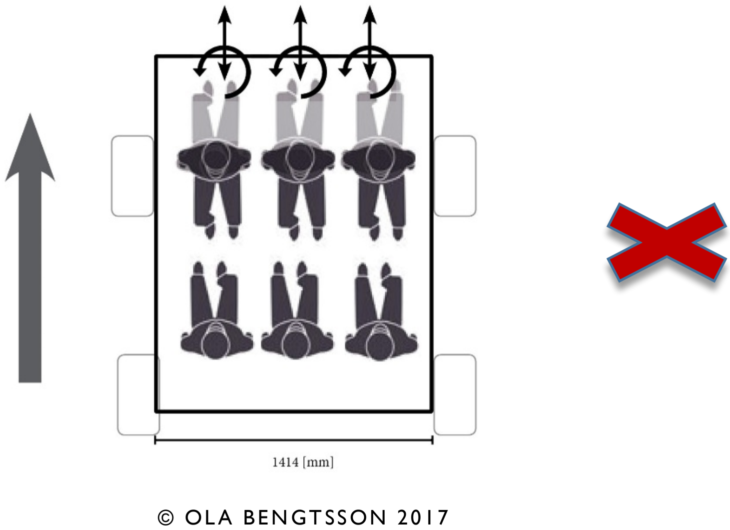


Figure 21: Concept layout facing each other, top view

A better concept for this kind of vehicle is a 2-2 formation (Figure 22). The two seats in the front are now able to turn, and the requirements of cabin width are no longer that intense. This enhances potential of designing a spacious and customized interior.

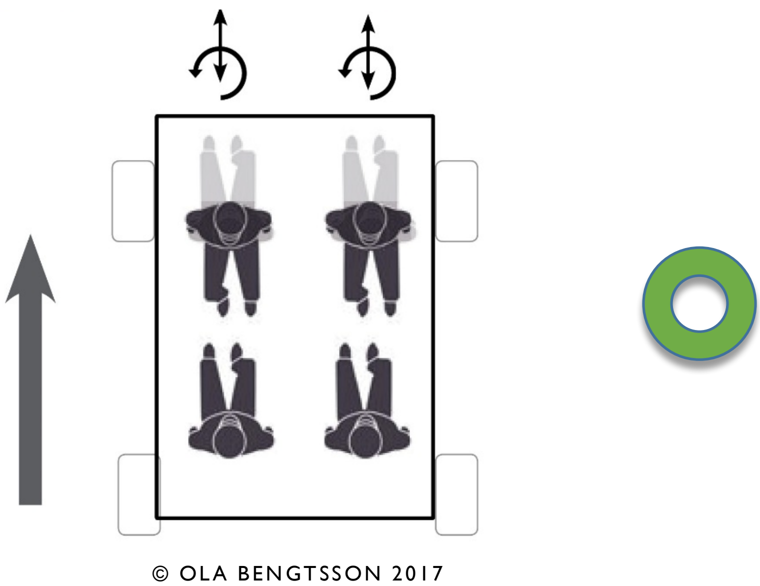


Figure 22: Concept layout with four passengers, top view

5.2. Provide stability

The first feature to conceptualize was *providing stability*. Inspired by tilting trains and the Lexus Kinetic Seat (attachment 2.6) ideas for different kinds of integrated tilting features was generated. The following concepts were taking in account to further concept development.

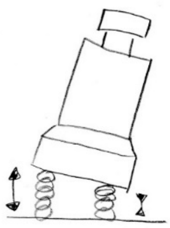
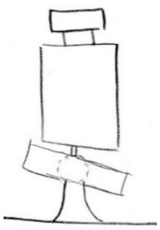
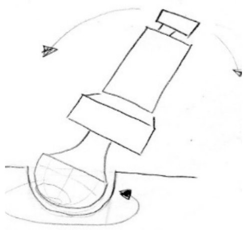
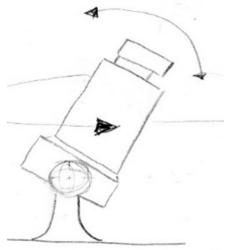
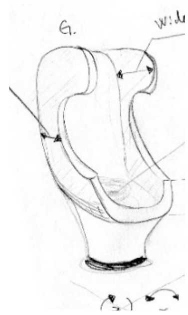
Tilting mechanism with floor attachments at (a minimum of) two points.	Seat cushion rotates around Y but back and neck support remain fixed.	Seat rotates around a half sphere hidden beneath the floor	Seat is attached to a sphere joint, elevated above the floor	Seat is mounted on a U-shaped groove, which makes it tilt in curves.	Side support in seatback, seat cushion and headrest.
					

Figure 23: Early concepts enhancing stability

Rotating seats could also provide extra stability in curves. Rotating towards the curve centre would give support in seatback while centripetal force is moving the car towards the curve centre (Figure 25: Seats rotating in curves to give extra support.

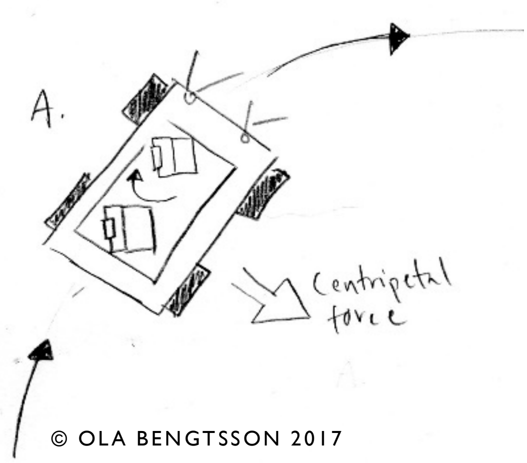


Figure 24: Seats rotating in curves to give extra support

5.3. Provide customization

The second focus need was to provide customization. *Folding the front seats into foot rests* is an interesting customization feature. Enhancing user pre-sets to a new level could be that the seat “knows” the body through pressure distribution analysis (Figure 26) and adjusts after it with possible detailed adjustments by the user. The pre-sets could instead focus on different positions like eating/drinking, fully relaxed or active (Figure 26).

Defined in chapter 2.6, pressure change by user altering seat position is important for a comfortable and healthy seat. Flat cushioning would allow the user to alter between many different positions, which is ergonomically favourable.

Adjustable lumbar, seat and head support are established functions of altering positions would naturally be discussed in further concept development.

Foldable (front) seats - use as foot rests	Position and user presets (Figure 26)	Pressure distribution analysis (Figure 26)	Flat cushions (position change by user).	Adjustable lumbar, seat and head support

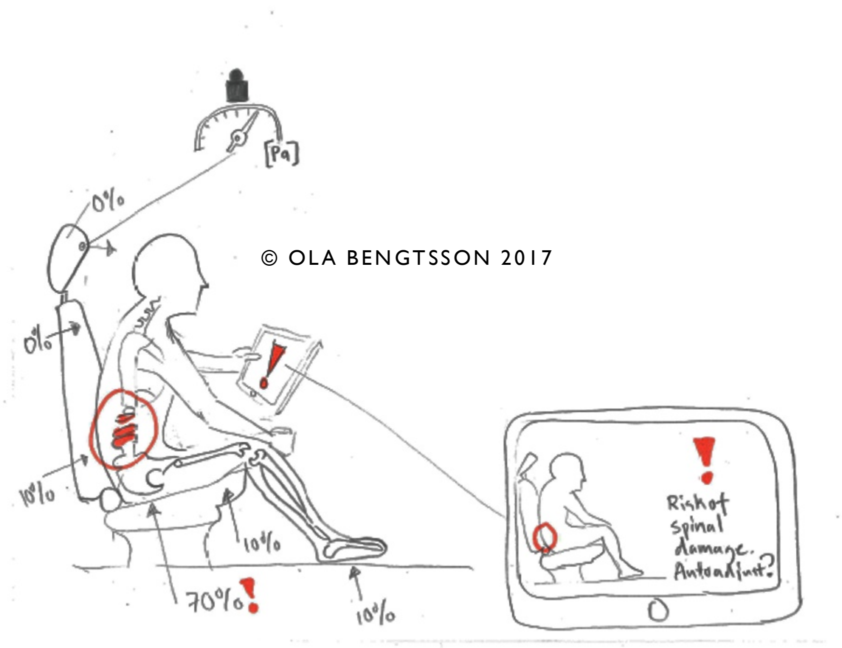


Figure 25: Pressure distribution analysis

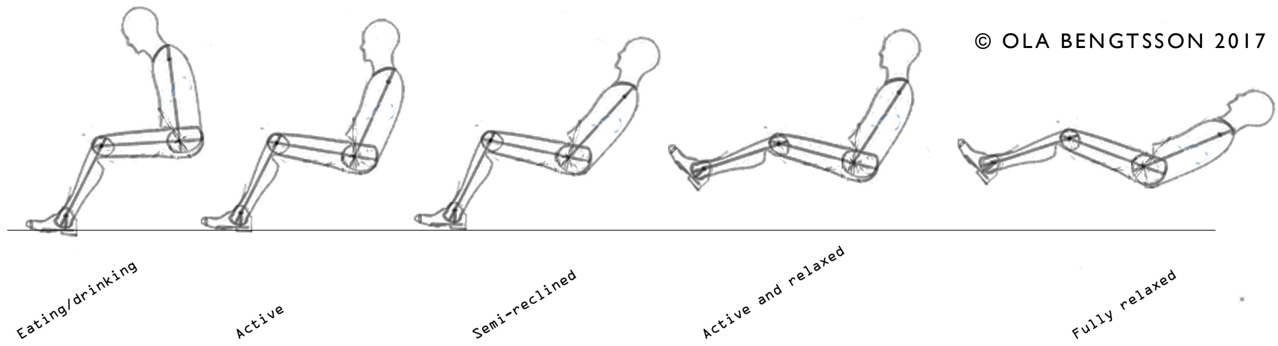


Figure 26: Example of position presets

5.4. Provide spaciousness and a clear outside view

The third focus need is to provide spaciousness and a clear outside view. Some functions generated that fulfil this need is minimizing seat volume, use of transparent materials, placing it in a non-obstructive position and removing or folding objects that are not used. One solution to minimize material volume would be to integrate the seat frame as a design feature that would minimize the use of plastics that covers it. Another solution could also be to build gaps between pressure points, e.g. seat cushion and seat back, dividing lumbar support and seat back or creating a free space beneath the seat cushion and the floor.

Gaps between peak pressure points.	Minimize volume	Transparent material	Visible frame	Foldable seats	Removable seats

5.5. Provide green status

Conceptualizing this last need, inspiration was taken from the *Ecodesign strategy wheel* (3.8). Minimizing amount and volume of material and consumed energy during use are both subjects that could reduce environmental impact according to this model. Minimizing the number of electronic features is also an important feature considering the shortening of copper defined in chapter 4.8.1. Multifunctionality is also suggested, as the seats could be used as home furniture when the vehicle is about to be scrapped. Modularity, or replaceable components, could also be a solution reducing environmental damage as it would be easy to repair and update the vehicle to remain a high market value. In the same theme, creating a aesthetically attractive product that remains attractive for a longer amount of time, is also a way of making the product sustainable.

Non-electronic features	Minimize material volume	Minimize amount of different materials	Multifunctional (outside the car)	Washable, replaceable and recyclable seat covers	Classic design.

5.6. Morphologic analysis

Having different solutions to the prioritized needs identified, they are fit into the table of the *morphologic analysis* (Figure 27). This table is then used to create three different concepts; *Turtle*, *Jetson* and *Ambassador*. Their chosen features are illustrated with a coloured dot assigned to the different concepts according to the colour theme below.

🟢 Turtle 🔵 Jetson 🟠 Ambassador

FUTURE AUTONOMOUS VEHICLE SEAT - solutions						
	A.	B.	C.	D.	E.	F.
Provide stability	Tilting mechanism with floor attachments at (a minimum of) two points. 🟢	Seat cushion rotates around Y but back and neck support remain fixed.	Seat rotates around a half sphere hidden beneath the floor 🔵	Seat is attached to a sphere joint, elevated above the floor	Seat is mounted on a U-shaped groove, which makes it tilt in curves. 🟠	Side support in seatback, seat cushion and headrest. 🔵
Provide customization	Foldable (front) seats - use as foot rests 🟢	Position and user presets 🟢 🟠	Pressure distribution analysis 🟢 🔵 🟠	Flat cushions (position change by user). 🟠	Adjustable lumbar, seat and head support 🟢 🔵 🟠	-
Provide spaciousness and clear outside view	Gaps between peak pressure points. 🟠	Minimize volume 🟢 🔵	Transparent material 🔵	Visible frame 🔵 🟠	Foldable 🟢	Removable seats 🟢 🔵 🟠
Provide green status	Non-electronic features 🔵	Minimize material volume 🟢 🔵 🟠	Minimize amount of different materials 🔵	Multifunctional (outside the car) 🔵	Washable, replaceable and recyclable seat covers 🟢 🔵	Classic design. 🔵 🟠

Figure 27: Morphologic analysis

5.6.1. Concept 1: Turtle

This chair is a mix of conventional vehicle seat design and new interesting tech features (Figure 28). It is designed to, in an aesthetically pleasing way, transform into a footrest. This creates a turtle-like shape with a shell foot rest on the seat back. This gives an extra dimension of arrangements into the seat cabin, without feeling misplaced.

It has four attachments in the floor which gives stability and durability to the product. Integrated springs enables tilting in curves which enhances seat stability.

- Foldable
- Conventional cushion design
- Spacious
- Customizable
- Stable

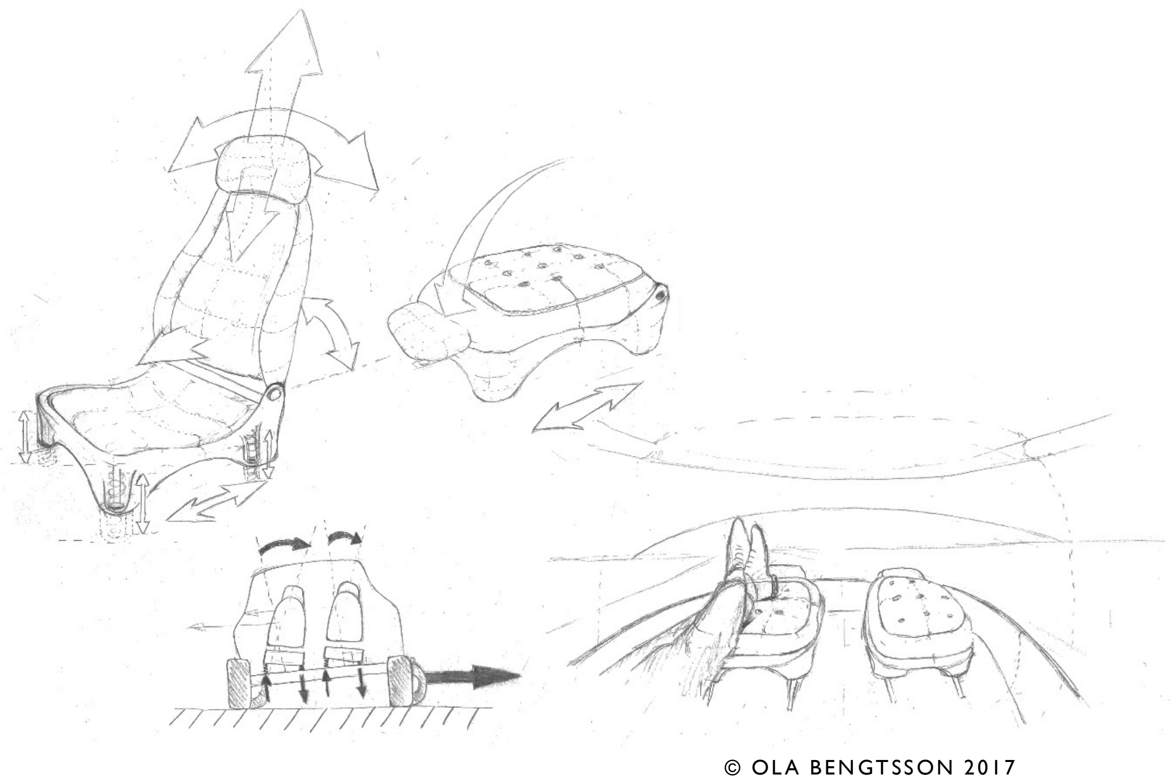


Figure 28: Turtle, seat concept

5.6.2. Concept 2: Jetson

This is a simplistic yet, classy chair (Figure 29) based on the design of the classic Jetson design by Bruno Mathson. A synthetic leather cushion is placed on a fabric net, making it partially transparent. Position adjustments are available but they are not powered (except rotation around y- and z-axis). Letting go of many kilograms of adjustment mechanisms, the chair becomes light and smooth, creating a spacious interior. It is also easy to repair or update. This chair is made for the car, yet it fit perfectly fine in your living room.

- Spacious
- Light
- Green
- Customizable
- Easy to replace components
- Stable

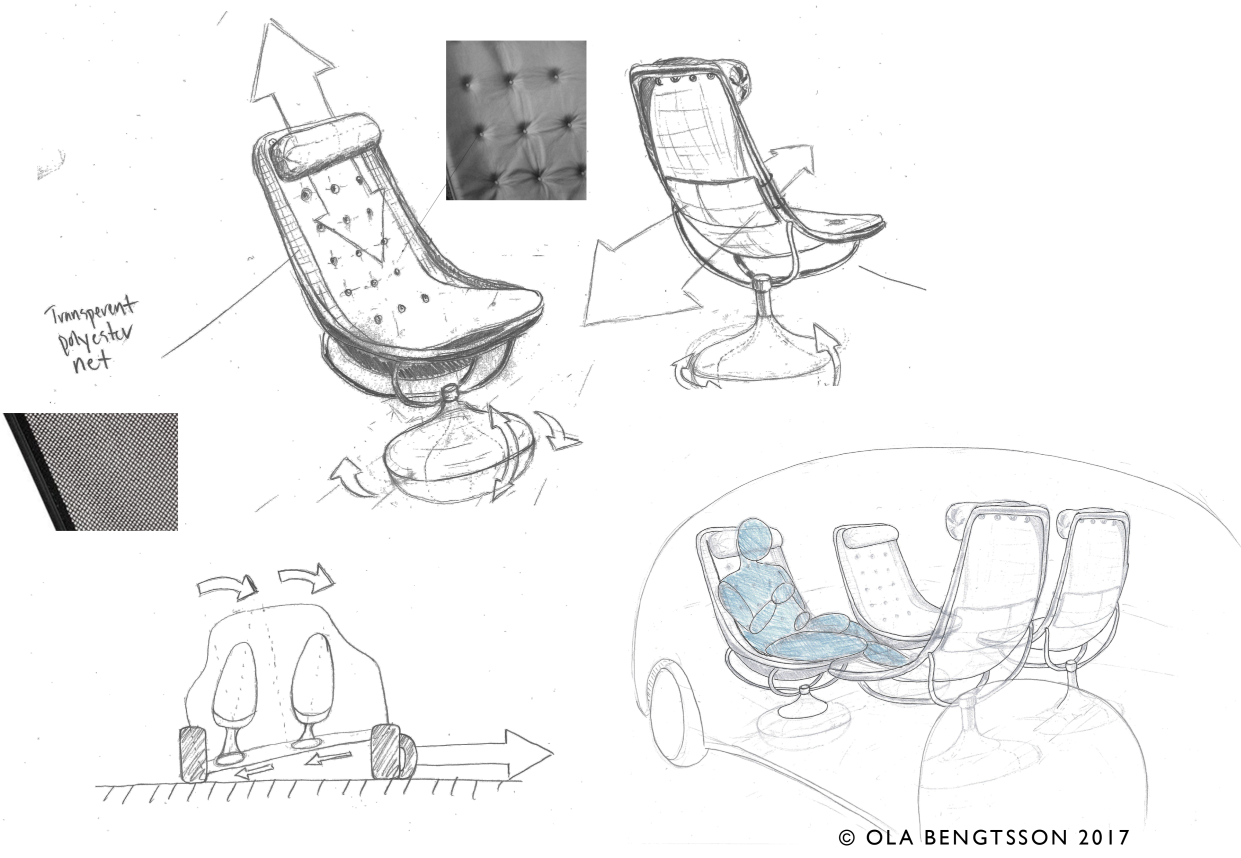


Figure 29: Jetson, seat concept

5.6.3. Concept 3: Ambassador

This elegant chair (Figure 31) with a design based on exclusive office chairs (hence the name ambassador) is packed with adjustment features to fit all kind of bodies and positions. Besides reclining and rotation features, it is equipped with 10 inflatable cushions divided at the peak pressure points. The seat does not use side support, giving the user the possibility to comfortably change position by own motion. Stability is instead supported through a leaning feature (Figure 31) and arm rests. Its curved visible bottom frame reflects a robust and elegant design.
Visual projections indicates which user the seat has adjusted to.

- Spacious
- Elegant
- Convenient
- Flexible
- Stable
- Includes "bed position"

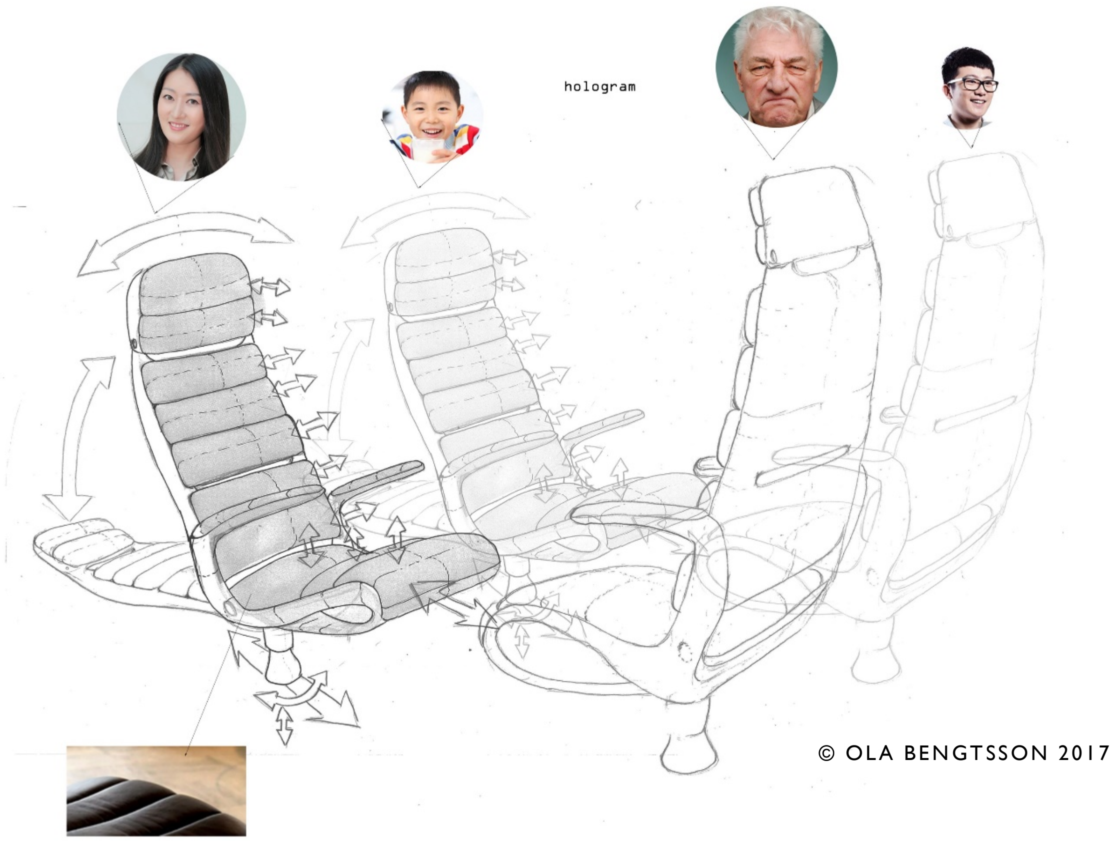


Figure 30: Ambassador, seat concept

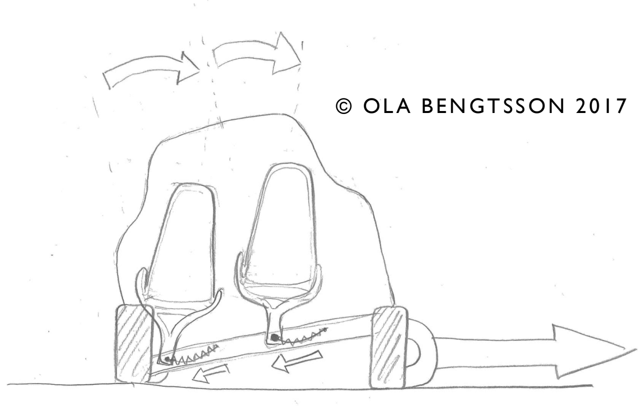


Figure 31: Leaning feature, Ambassador

5.7. Focus group evaluation at NEVS

A summary of the pre-study and the three concepts were presented to a focus group (method explained in 3.2) of seat engineers and at NEVS. Afterwards a discussion about the generated concepts was initiated.

Using the seat frame as a design feature was received in a very optimistic manner, with comments like *"this could be done today"* and *"this would spare us lots of plastic".* The refining of 3D printing as a manufacturing method was suggested as something that could support new innovative shapes.

The overall attitude before the future car seats were optimistic; the consensus was that the automotive industry is moving fast at the moment with the establishment of electric and autonomous vehicles. However, some safety aspects presented will probably be as relevant in the future as today. Integration of the seat belt is one of them. Today, seats with integrated seat belts need a more robust construction as the seat itself absorbs all the kinetic energy needed to fix the passenger in the event of a collision. Compared to car seats where the seat belt is attached in the car body wall. Another important safety aspect was that no hard components should be near the head of the user. This may affect the use of the frame as a design feature. The group also lifted softness in the cushions as an important safety feature, the cushion need a specific hardness to remain safe in the event of a collision.

The tilting functions presented in all the three concepts was considered important, but it would be more relevant to integrate it in the vehicle in a way that the vehicle itself tilts around its wheels instead. Mainly because it would lead to relative moment between the user and the interior which could lead to uncomfortable positions. However, gyroscope balancing was repeatedly suggested as an interesting technology to look at to provide a balanced seat. And instead of tilting, inflatable cushions could give extra stability when needed.

Foldable seats, as illustrated in concept 3 (“Turtle”), were also an appreciated idea, as it would give extra space passengers travelling in groups smaller than 4 people.

Ambient lighting was suggested as a feature to enlighten the space beneath the seat, gives spaciousness and availability.

Storage was also lifted as an important aspect when designing the seat layout.

Shared use was also discussed. Seat adjustment and other frequently used features must be designed to endure more frequent use.

The ambassador concept, where several seat cushions independently adjusts after the body weight appealed to the group. It was suggested that inflatable cushions would fulfil that function.

One participant also lifted choice of material, and suggested organic polymers as a relevant material.

5.8. Concept 4: Phoenix

After the focus group evaluation at NEVS a new concept was developed, merging different functions from the previous concepts and tweaking them based on the input from the focus group evaluation. This one was named Phoenix, because of its egg shape (Figure 32) and the fact that it came to life after the morphologic analysis. This time, focus was on integrating the seat frame as an exterior design element and removing the tilting function as favoured by the focus group. Making the seat frame visible may lead to incoherent exterior design. Therefore, elastic material is used as a cover of the lower seat to the centre of the seatback, creating an egg-shaped design. The solution eliminates plastic components usually placed to cover up these areas. A new, more elastic net material will maintain a coherent design even in a reclined position.

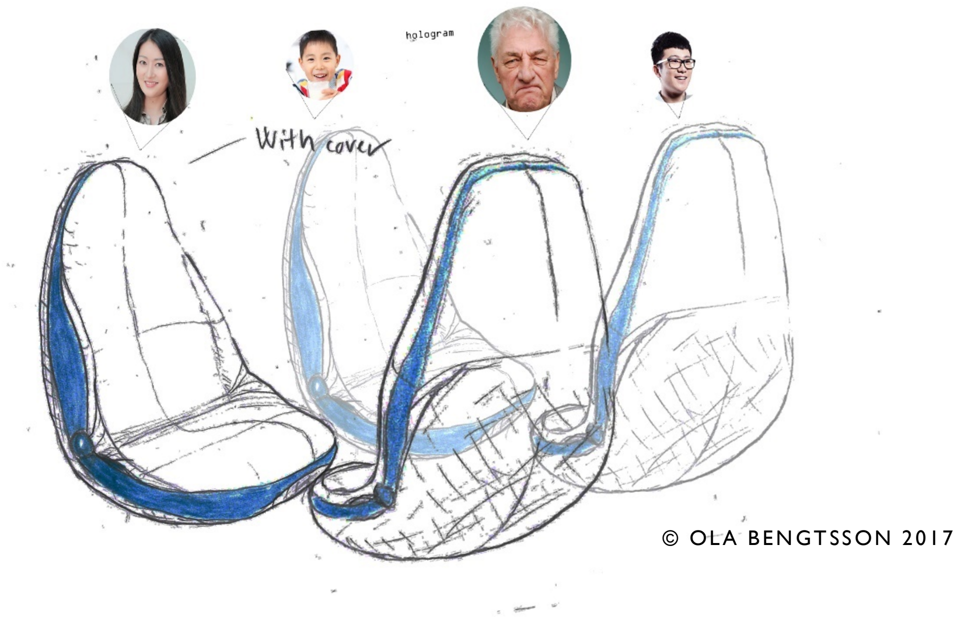


Figure 32: Concept in group formation. An elastic material is used as cover of the seat cushion up to the centre of the seatback. The blue colour highlights the naked frame.

A foldable seatback that gives spaciousness and a footrest on demand was initially created for this concept, but was eventually ignored as the chair in folded position became too high for a comfortable footrest. Instead, the idea of a seat rotating around its y-axis, enhancing both spaciousness and comfort, was installed (Figure 33: Concept with seat rotating around y-axis.

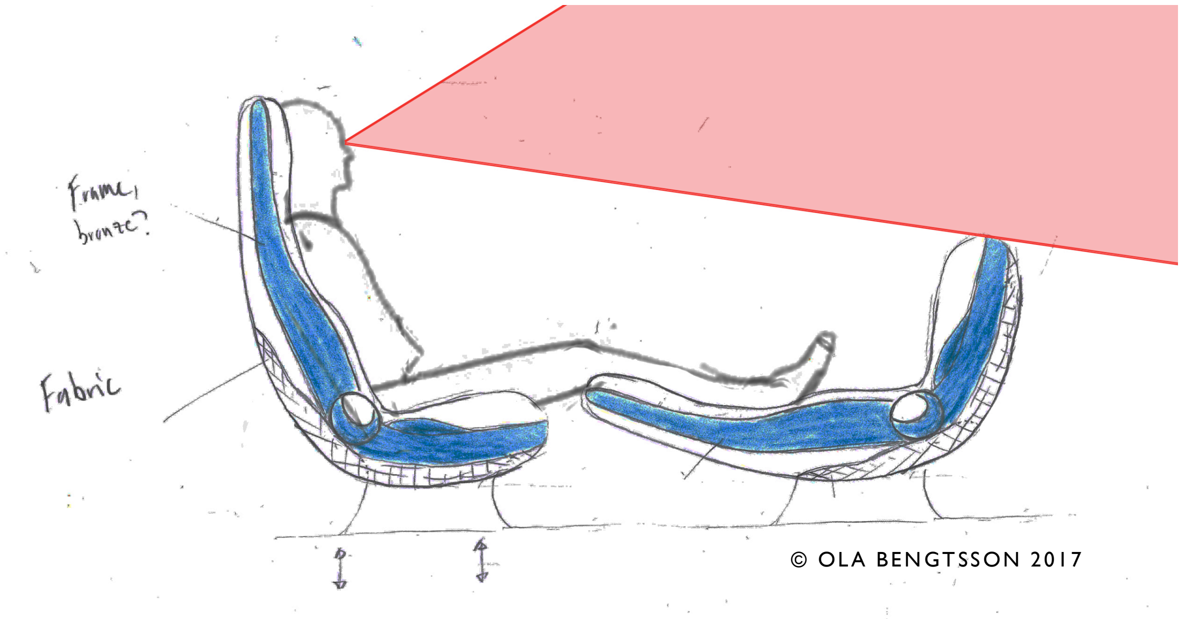


Figure 33: Concept with seat rotating around y-axis.

Just like Ambassador (concept 3) this concept also has weight analysis and user presets (5.3) – illustrated by a visual projection, illustrated in this concept at Figure 32).

Seats rotate around z-axis enabling a face-to-face seat layout. The front seats need this rotation to adjust to a foot rest. The rotation will also help in curves, providing a more comfortable position while exposed to centripetal force (Figure 34).

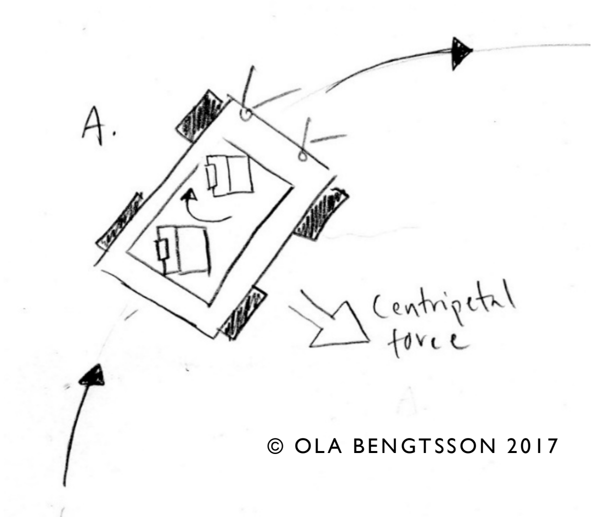


Figure 34: Seats rotate in curves, giving comfort while passengers are exposed to centripetal force.

Inflatable lumbar support and headrest provides essential ergonomic support, while neutral shaped padding enables variation in seat positions by the user. The back of the seat cushion can be lowered, reducing pressure on the ischial tuberosities as defined in 2.3.

The soft materials of the seat have dark appearance as it should endure frequent use by different users. The seat frame, supposedly made of a tougher material, may have a lighter hue.

5.9. Concept evaluation matrix

The evaluation matrix (described in 3.10) is iterated in two stages. The first one rates all the concepts according to the four prioritized needs, comparing them with a reference solution (Volvo XC90 seat, chapter 2.3). The purpose of this first matrix is to confirm that the new solution has better potential than a existing product. In the second matrix, the concepts are compared with each other, pointing out which concept is favorable in the different aspects.

The concepts are; 1: Turtle, 2: Jetson, 3: Ambassador and 4: Phoenix. The concepts are presumed to perform better, worse or similar in the different aspects, resulting in a (+), (-) or a (0) in the table.

Stability was suggested to be enhanced in concept 1,3 and 4 compared to the reference as the tilting function could give stable support to the passenger while exposed to centripetal force. Customization is suggested to be better in 3 and 4 as they are equipped with high flexibility cushions, and offers a variety of seat positions.

Spaciousness/outside view is presumed to be better in all new concepts as they all include a design of a visible frame which could eliminate redundant material, making the seats thinner. Foldability described in 1,3 and 4 also enhances this performance.

Green status is suggested to be enhanced in concept 2 and four because of their minimalistic design, while concept 3 is presumed to be worse in this aspect as it is packed with flexibility features demanding more electrical and mechanical components.

No.	Description	Ref.	1.	2.	3.	4
1.	Provide stability	0	+	0	+	+
2.	Provide customization	0	0	0	+	+
3.	Provide spaciousness and outside view	0	+	+	+	+
4.	Provide green status	0	0	+	-	+
	Total +	0	2	2	3	4
	Total -	0	0	0	1	0
	Net worth	0	2	2	2	4
	Rank	5	2	2	2	1
	Continued development	-	Yes	Yes	Yes	Yes

Figure 35:Evaluation matrix #1

Summarizing the first matrix (Figure 35) the reference gets the lowest net worth. All four concepts are taken into another matrix where concept 4 is made reference as it was ranked no 1 in the first matrix. The purpose of the second matrix is to get a more detailed view of which of the concepts performs best in the separate categories.

In this matrix (Figure 36), where concept 4 is reference, the net worth is very similar between the concepts, with a maximum deviation of only 1 point.

Stability is suggested to be worse in concept 2 (Jetson) as it does not have a tilting function. Customization is also suggested to be worse in Jetson, as it does not offer its user reclining nor cushion flexibility. Concept 3 (Ambassador) is suggested to perform better in this aspect, having full flexibility.

Spaciousness/outside view has best potential in concept 2 (Jetson) because of its minimalist design. Green status is presumed to better in that concept as well because of the same reason, and worse in concept 1 and 3 because of their need of new mechanical and electronic components.

No.	Description	4 (ref.)	1.	2.	3.
1.	Provide stability	0	0	-	0
2.	Provide customization	0	0	-	+
3.	Provide spaciousness and outside view	0	0	+	0
4.	Provide green status	0	-	+	-
	Total +	0	0	2	1
	Total -	0	1	2	1
	Net worth	0	-1	0	0
	Rank	1	4	1	1
	Continued development	Yes	No	Yes	Yes

Figure 36: Evaluation matrix #2

Concept 1, 3 and 4 are all ranked as #1, having the highest net worth. Concept 1 are however in priority, as it is a compromising solution fulfiling all the prioritized needs, while all the other concepts have at least one disadvantage.

The similar results of the concepts in this matrix hint that there are features in the different concepts that should not be eliminated this early in the design process. Features that are suggested to be of special interest are:

- ***Tilting functions*** (enhancing stability).
- ***Foldable seatbacks*** (increase customization and spaciousness/outside view).
- ***Visible curved bottom frame*** (enhancing spaciousness/outside view as well as green status).

To evaluate these features further before eliminating any of them, they were conceptualized in a more realistic context in the following chapter.

6. CONCEPT DEVELOPMENT IN 3D

The results of the concepts in the previous evaluation matrix gave a hint that there are features in the different concepts that should not be eliminated this early in the design process. Therefore, some of them were conceptualized in a more realistic context – in CAD.

Interesting key functions that had been conceptualized in the previous chapter were; *converting the seat back into a footrest* (5.2), *curved bottom frame* (5.6.3), and *tilting around x-axis* (5.2). These features were constructed digitally in 3D and are described in the following to paragraphs (6.1 and 6.2). The third and final 3D concept is the last iterative stage, including the most relevant features identified throughout project. It is evaluated at the end of this chapter.

6.1. Converting the seat back into a footrest

Building the first concept in CAD (Figure 37) some changes to the concept were made. Using the seat cushion as footrest was eliminated because of hygienic reasons – dirty shoes on seat cushions in combination with multiple users could lead to problems with cleanliness and quality. Instead, the foldable foot rest function on the back of the seatback from the concept *Turtle* (chapter 5.6.1) was applied. Seat dimensioning has been made using the blueprint from a SAAB 9-3 seat (attachment 1) as a template.

Figure 37: Concept with a seat transforming into a footrest.

6.2. Curved bottom frame and tilting functions

The second 3D model has a reinforced bottom frame with an integrated arm rest in the seat back (Figure 38), based on the curved bottom frame described in 5.6.3. Because of its spherical bottom joint, it may be rotated around its x, y and z axis (Figure 39-42). The main function of the tilt around z and x axis, is to enhance stability for the passenger while the car is affected by centripetal force (2.6). The digital simulation show that the seat may tilt without demanding movement of passenger feet, if the rotation is made around the relevant axis of pelvis.

In this concept, colours and material shaders were applied digitally to create a more realistic rendering of the product. In this render, it is seen that a deep green tough fabric provides a potential resistance to wear and tear.

Figure 38: Concept with curved seat frame bottom.

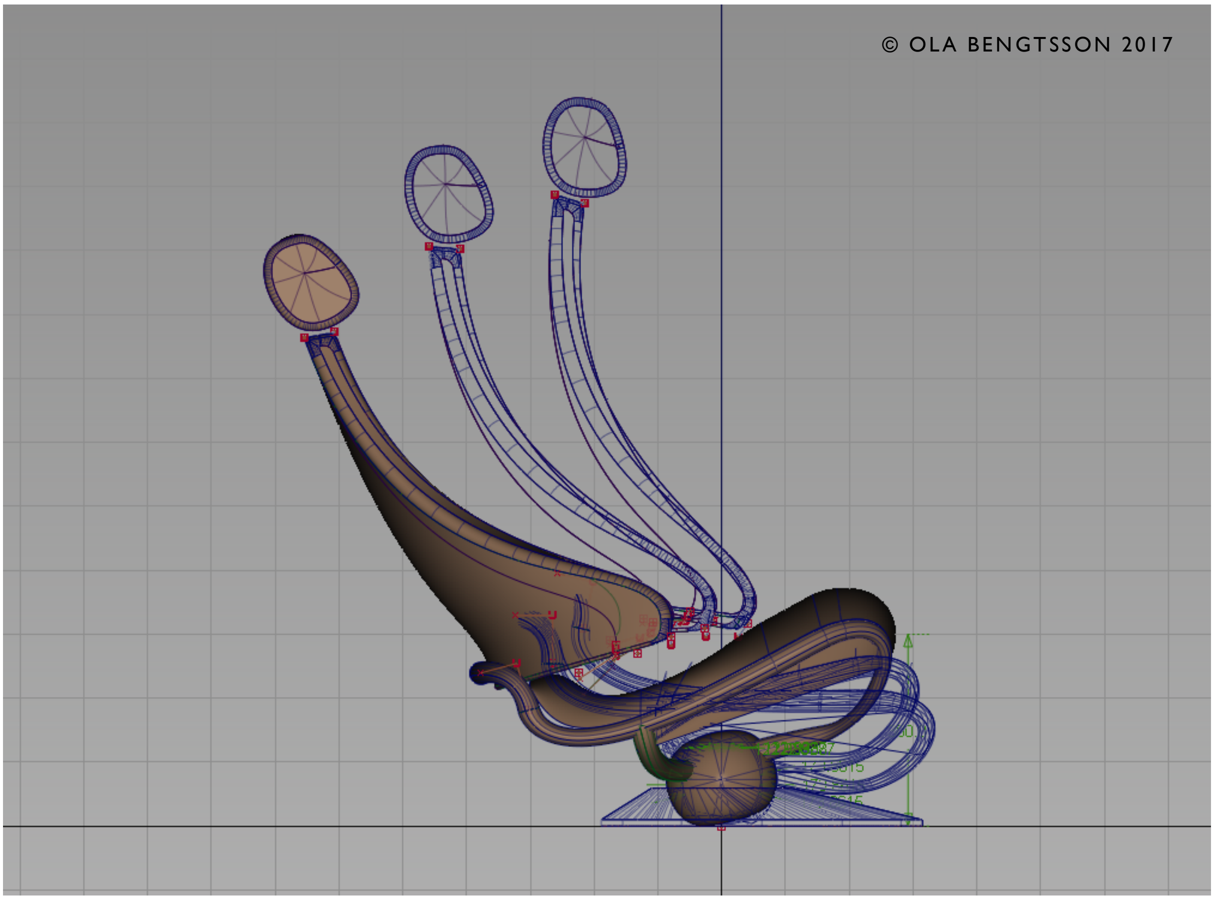


Figure 39: Concept seat, rotating around the y axis of the spherical joint.

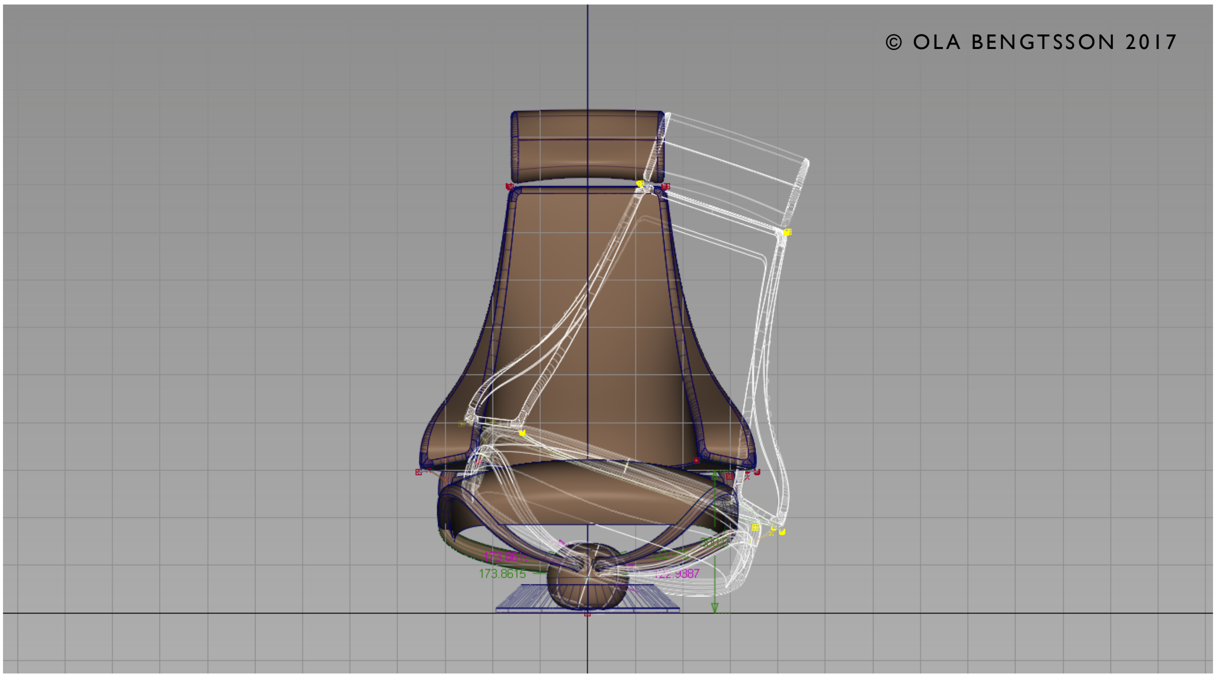


Figure 40: Concept seat rotating around the x axis of the spherical joint

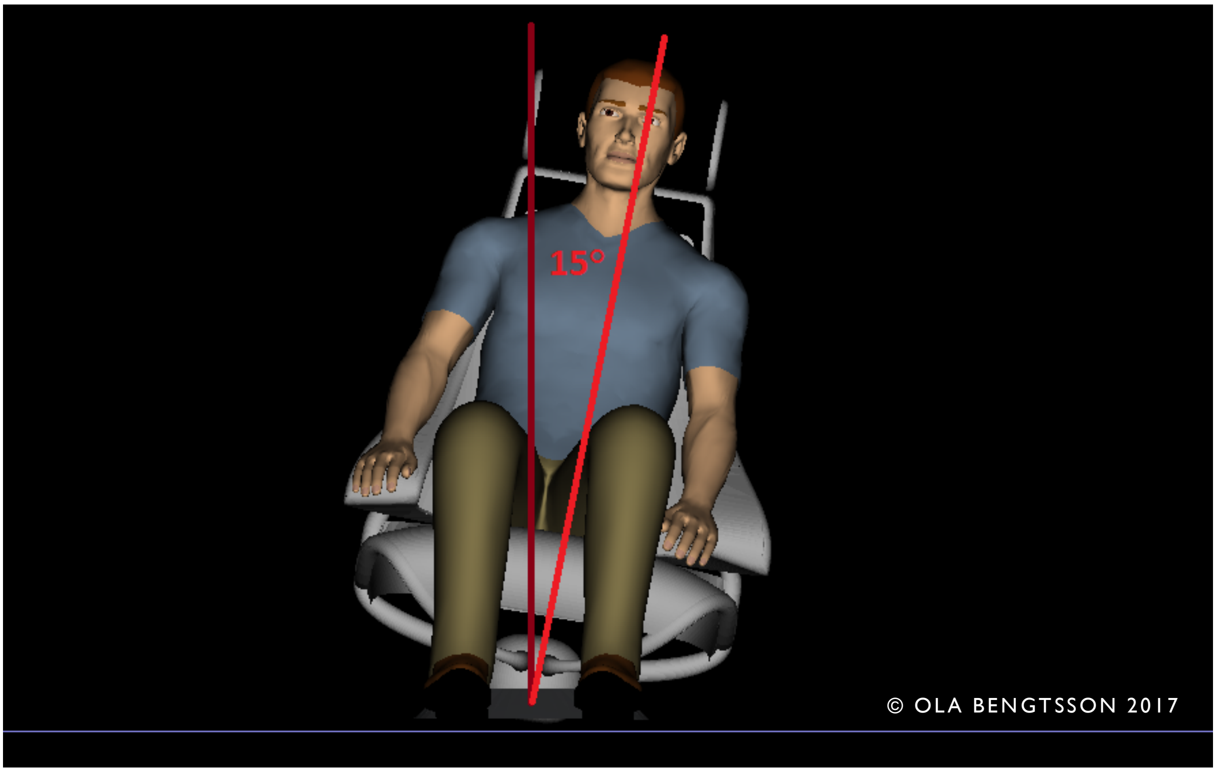


Figure 41: Seat rotating 15 degrees around x axis, with feet fixed on the floor, only pelvis rotation around x axis

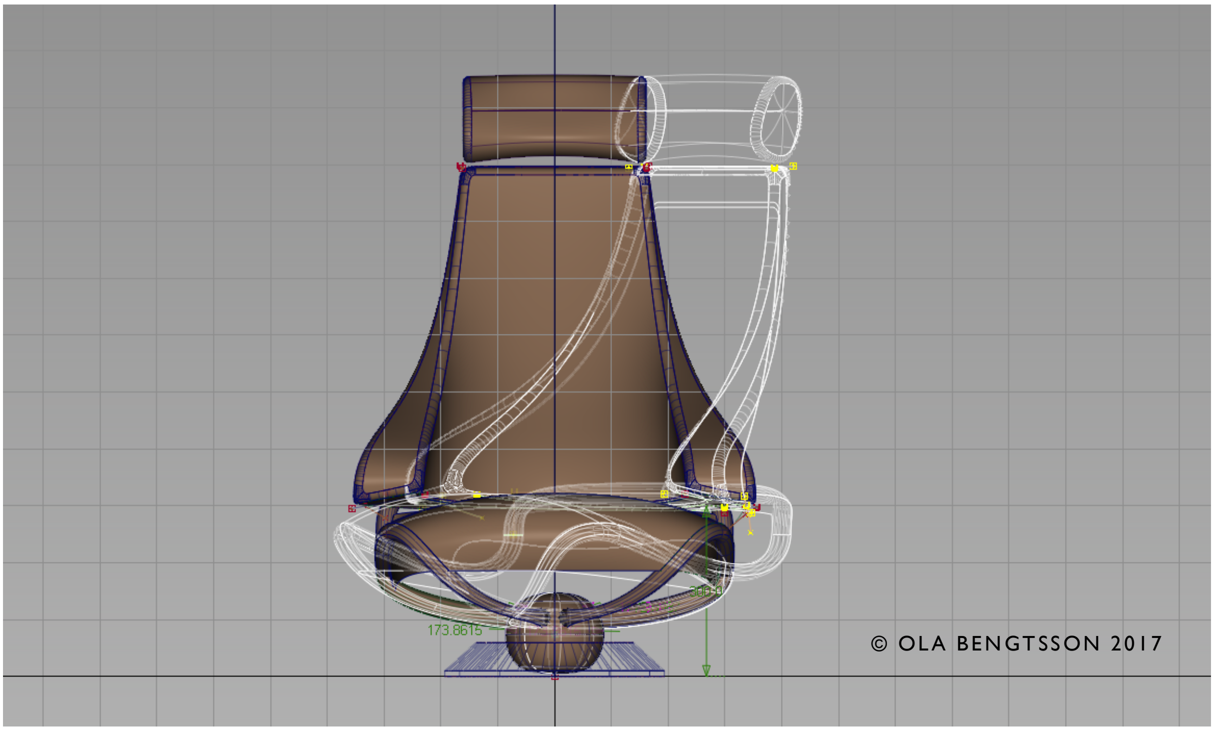


Figure 42: Concept seat rotating around the z axis of the spherical joint

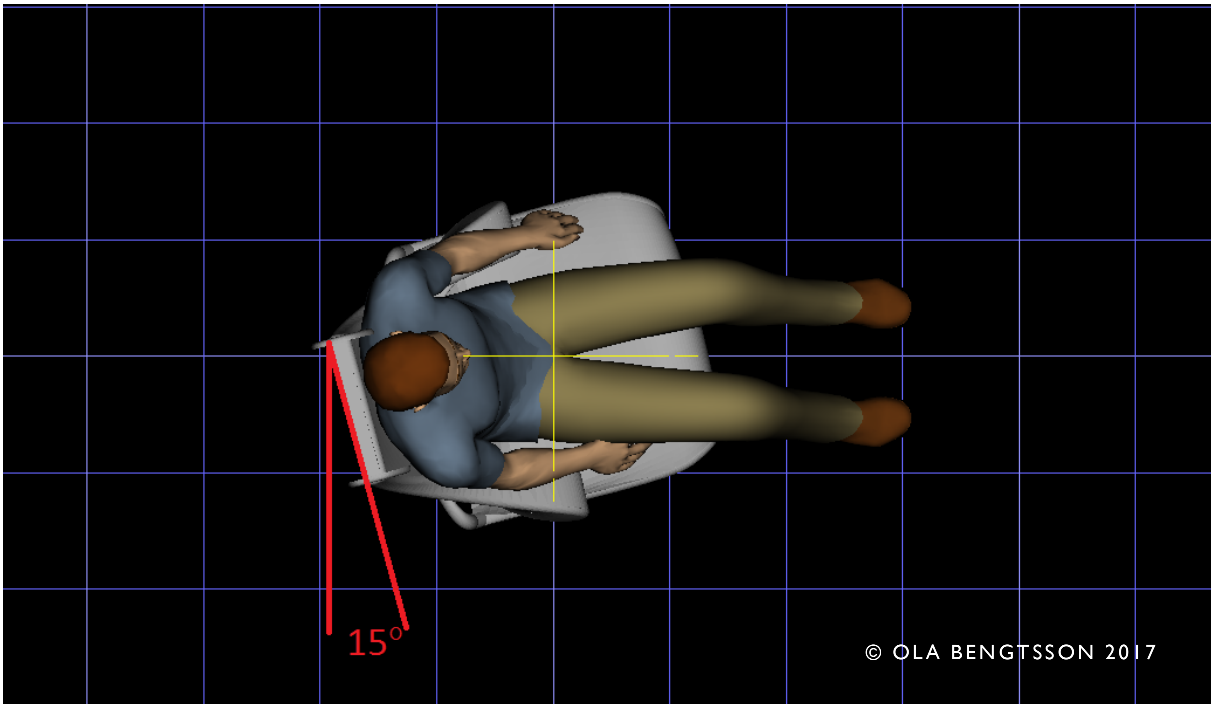


Figure 43: Concept seat rotating 15 degrees around z axis, with feet fixed on the floor, only pelvis rotation around z axis.

6.3. Evaluation of 3D conceptualization

The foldable seat concept in 6.1 may not integrate cushion side bolsters as they would clash making the forward fold. Therefore, functions handling centripetal force need to be provided in another feature, which according to this report would be tilting around x or z-axis.

Using the back of the seatback as a foot rest would naturally protect the cushions from direct contact from shoes, reducing impact on cleanliness. But using the seat back as a foot rest would nonetheless increase the risk of wear and tear of the foot rest material. A risk that would not be suitable for a shared product.

The second 3D model describing curved bottom frame and tilting functions (6.3) enhances customization and stability, as its spherical joint delivers both different postures as well as enhanced stability in curves with tilt assist. A problem with this seat is that it has a complex frame, both in shapes and in functions. The curved frame would need to be thick, as aluminium, the material of choice, is much weaker than steel (see paragraph 4.8.4.). The tilting function would also lead to a relative movement between the seat, floor and walls which would also require a flexible belt system that would probably need to be integrated into the seat – increasing the weight even further as defined in paragraph (5.7).

Because of these conclusions, it is suggested that the concepts including tilting functions and the curved bottom frame are eliminated in the final seat concept. Foldability is eliminated in the way that it transforms into a foot rest, but the function itself could also deliver enhanced spaciousness and outside view which is further described in the next chapter.

7. FINAL CONCEPT

The final concept (Figure 44) is generated based on all the previous conceptualization. The concept is digitally modelled in 3D and applied in a modelled car body dimensioned according to 4.4. This concept breaks the previous pattern by not having an arrangement with four identical seats. Instead, two back seats are in focus as the two front ones has been turned into a sofa. This variation gives the concept a new dimension, creating more of a living room atmosphere rather than a car. Its static position also liberates the concept from mechanical adjustment components, making the area beneath the sofa available for storage e g. Tilting functions described in the previous concept are eliminated, making integrated seat belts inevitable, increasing the requirements of frame material strength. The function may be applied in the vehicle platform instead.

Figure 44: Final concept, placed in a vehicle

7.1. Foldable sofa

In the previous concepts, foldability has been wanted because the potential transformation to a foot rest. The foot rest concept was eliminated being a risk of hygiene and quality issues if the vehicle is to be shared among many users; however, the function has other strengths. The function creates a more spacious interior and enhances the outside view. The seat back of the sofa may be tilted around a y axis which folds it into a plane surface that can be used for other interior features (Figure 45 and Figure 46).

The fixed position of the sofa gives leads to a more ways to use the area beneath the seat, as adjustment features is no longer needed. In this concept, this area is used to create two drawers, enhancing storage space in the vehicle (Figure 45).

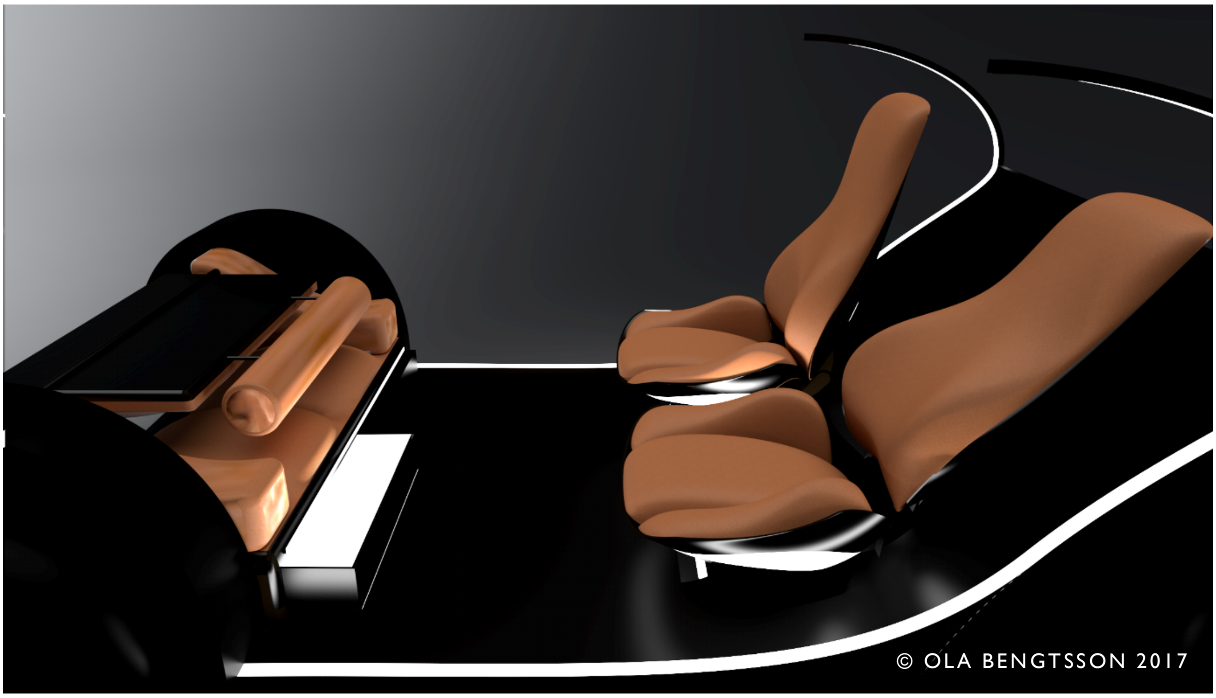


Figure 45: Final concept with folded sofa in the front of the vehicle. Two drawers are located beneath the sofa cushions.

Figure 46: Illustration of how a foldable sofa could lead to enhanced outside view and interior space.

7.2. Human simulation and dimensioning

Dimensioning the final concept, the seat of the SAAB 9-3 from 2012 (attachment 1) was once again used as a template. Human simulation in the Siemens Jack software indicated that the seat was too big for Chinese users, as the seat cushion gave pressure on the back of the knee which is not a favourable ergonomic preference (0). Therefore, the seat was shortened in x direction. Looking at anthropometric data in Jack, there is a big difference in weight and length between Chinese and American citizens (ANSUR anthropometric data). The Chinese are both shorter and lighter which indicates that the seats aimed for this market segment could be smaller.

As women are generally smaller and lighter than men, simulants were programmed to be of 95th percentile man and 5th percentile woman in both size and weight, rendering the following anthropometric data:

Digital simulants	Weight [kg]	Length [cm]
95th percentile Chinese man	75	177,5
5th percentile Chinese woman	42	148
95^{th} percentile American man	101	187
05^{th} percentile American woman	51	153

The simulation shows, if only two passengers are travelling (Figure 47), that interior space and outside view is greatly enhanced compared to a trip with four passengers (Figure 48).

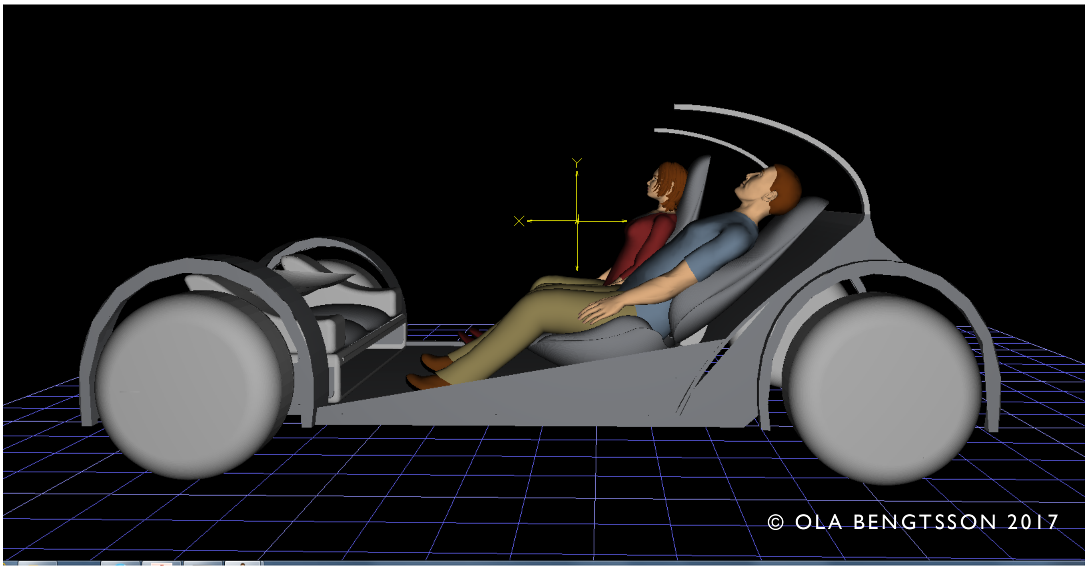


Figure 47: Human simulation with 95th percentile man and 05th percentile woman, both Chinese. The sofa is folded.

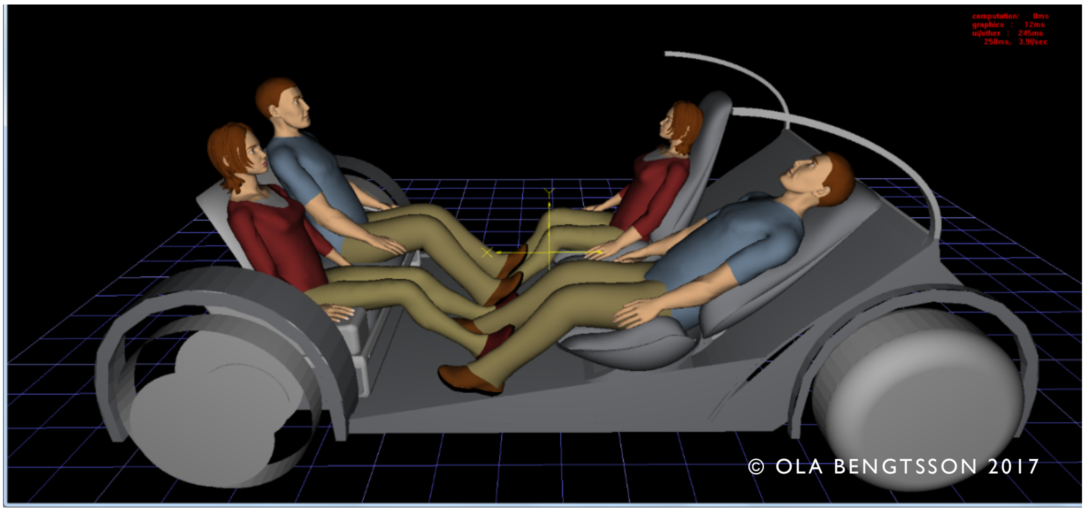


Figure 48: Human simulation with two 95th percentile men and two 5th percentile women, all four Chinese. The front sofa is unfolded.

If four people travels together, the simulation shows that there is enough space for the passengers to stretch their legs in x direction, but they would need to share the space in y direction (Figure 49).

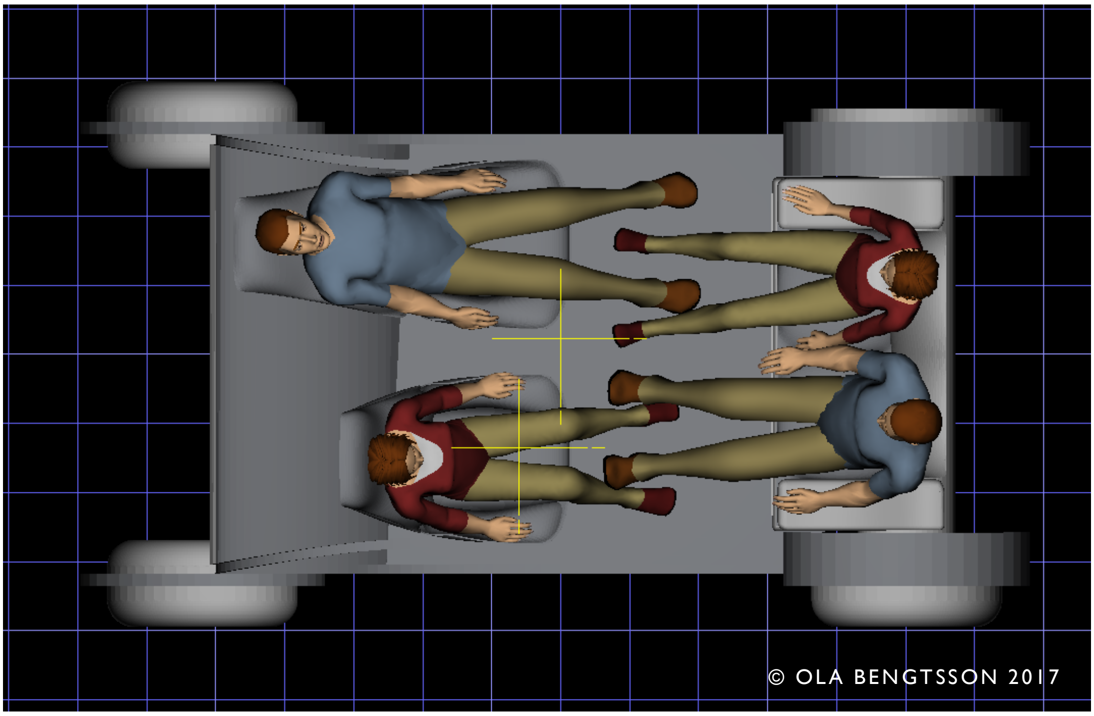


Figure 49: Top view of human simulation with four passengers.

7.3. Seat frame

Defined in 4.6, an aluminium frame was the most sustainable material alternative. Looking at the reference aluminium frame in **Error! Reference source not found.** it is designed as a complete seat bucket shell with punched patterns. This concept has used that as reference and is also based on an aluminium bucket shell. This shape has similarities with the plastic ABS cover described in (2.3) which have the potential of eliminating these kinds of plastic components.

Large parts of the aluminium shell are visible, and therefore need a more aesthetic touch. Because of that, the shell has been given a more rounded shape completed by curved ambient LED lighting making the space beneath the seat more visible (Figure 50).

Figure 50: The back seats

The back seats are placed against the back wall of the interior space, and has no adjustment features in x direction. This because foot space is already maximized in this position. Because of this formation, some areas of the seat will hardly be visible. The back of the seat back for example, turned against the wall, no user will probably pay attention to its design. Therefore, this area could be used for features that are usually hidden, it may be mechanical components or a punched pattern that reduces weight (Figure 51). This opportunity could also be used to make servicing easier, like having replaceable components more available in the back.

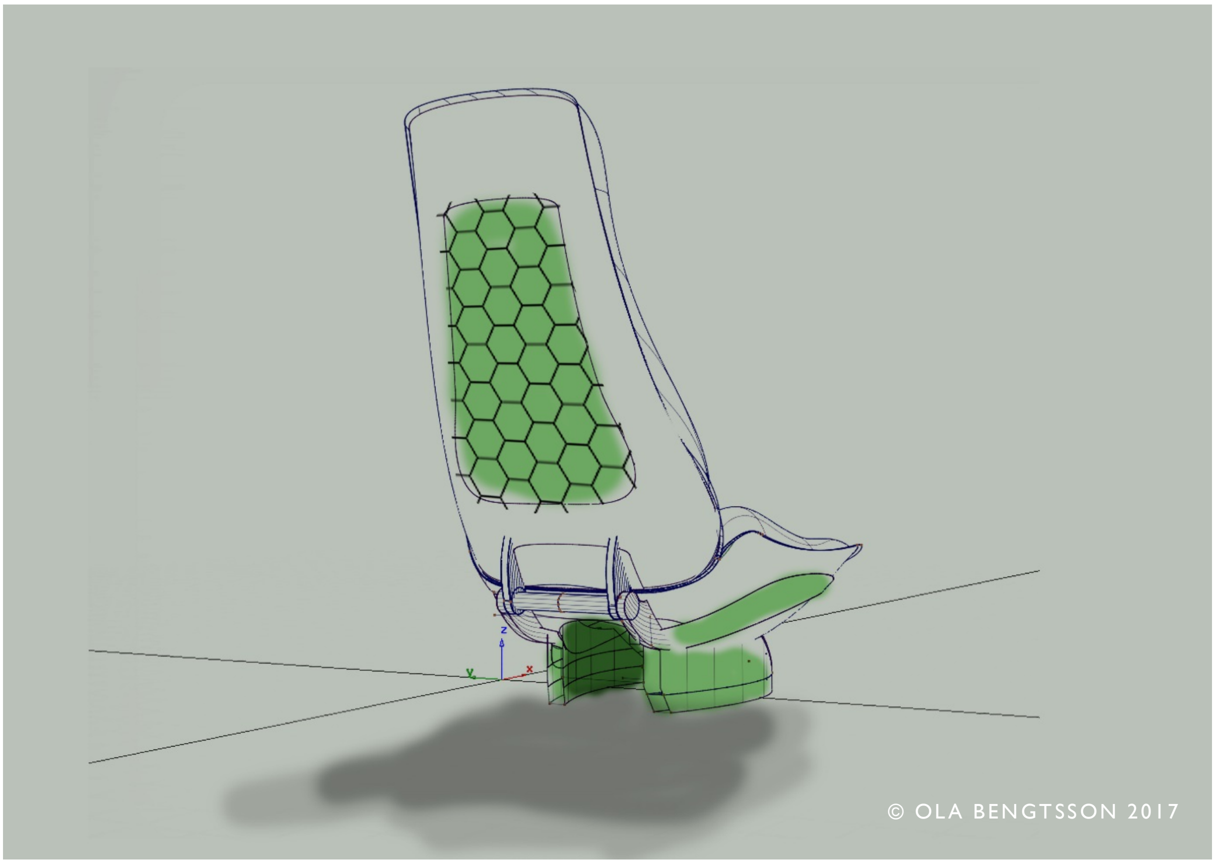


Figure 51: Back seats from behind. The green colours indicate areas that could be used for patterns.

Areas like these are also located on the bottom front the seat frame. The space beneath the seat cushion, between the two frame edges of the seat base (Figure 52), could also be used for functional features that needs to be hidden. The front of the seat base could on the other hand be used to expose a design feature, it is suggested that the NEVS logotype is shown there. (Figure 52).

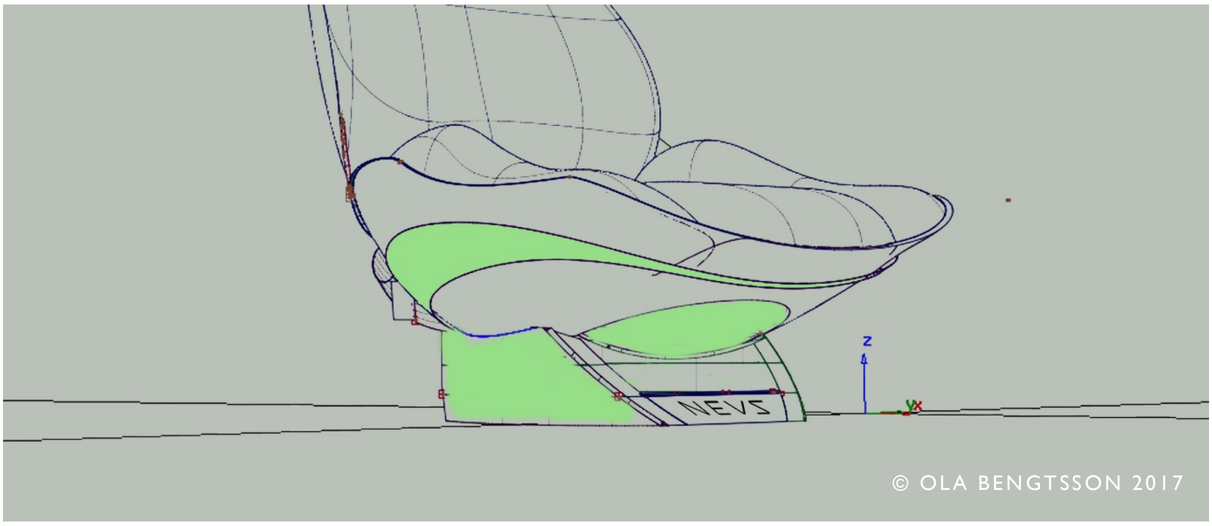


Figure 52: Back seat bottom. Green colours indicate areas that could be used for functional features. The NEVS logotype is suggested to be applied on the lower frame front.

7.4. Seat cushions

The seat cushion is inflatable, with the purpose of providing an ergonomic adjusted pressure considering body weight of the user (Figure 53). An inflatable lumbar support (Figure 53), in combination with a slightly backward tilt of the seat cushion, reduces peak pressure points and vibrational damages on the body (0). The seat cushion is flat in its surface, this because the user should be able to change pressure points by changing position – letting go of the steering wheel and pedals give this opportunity.

Side bolsters in the seat cushion are high and wide, giving both stability and armrest. Side bolsters in the seat back are only present in the bottom half of the seat back, this in favour of outside view.

Head rest is integrated behind the seat cover, and may be inflated like the lumbar support (Figure 53) to give stability to the user´s neck – increasing comfort and reducing risk of motion sickness (see paragraph 4.2.7).

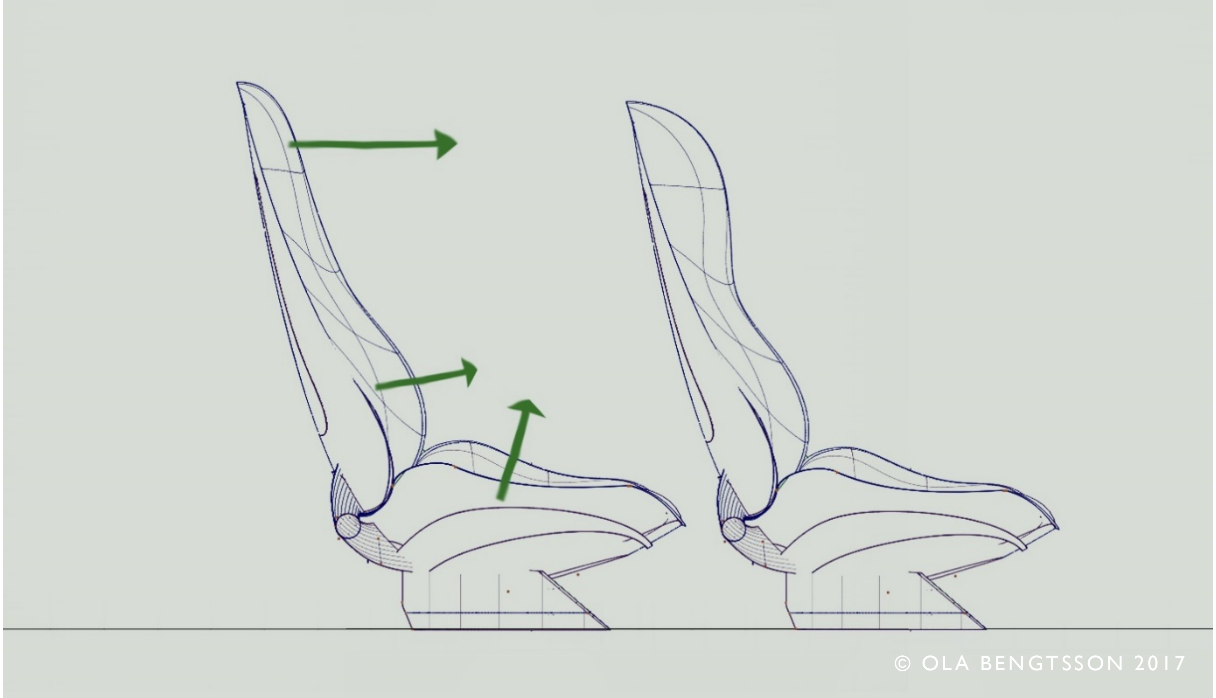


Figure 53: Inflatable cushion support. Headrest and lumbar support may be extended in x, seat cushion may be hardened in z direction. The image to the right illustrates an extended head rest.

7.5. Seat cover

Seat covers are not analysed in this project, but it is suggested that it is sustainable, replaceable, made of a strong material that endures wear and tear as it may be shared among many people (4.2.10).

7.6. Seat belts

Defined in chapter 2.7, the risk travelling in an autonomous vehicle will probably be much higher than riding with a train or an airplane. Three-point seat belts are therefore applied in the seats both in front and back. Eliminating the tilting functions around z and x, the seat belt may be attached in the floor behind the passenger or in the floor (Figure 54).

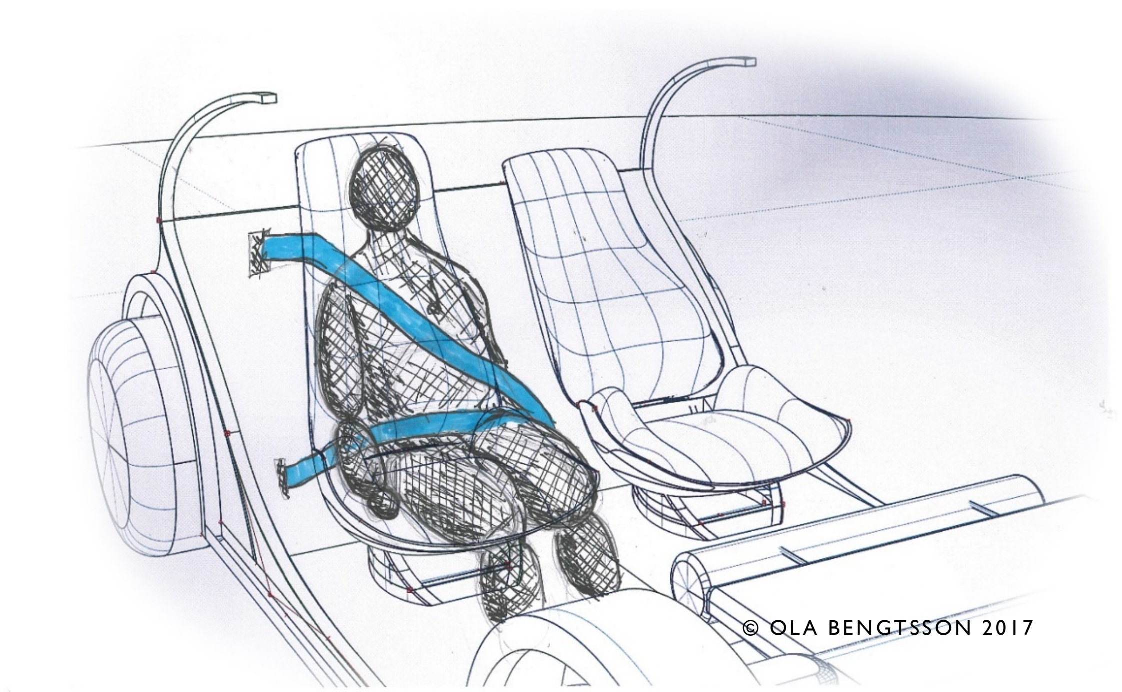


Figure 54: Person belted with a three point seat belt in the back seat. Belt is attached in the wall behind the passenger.

In the front sofa, three point belts are attached in the frame of the sofa (Figure 55).

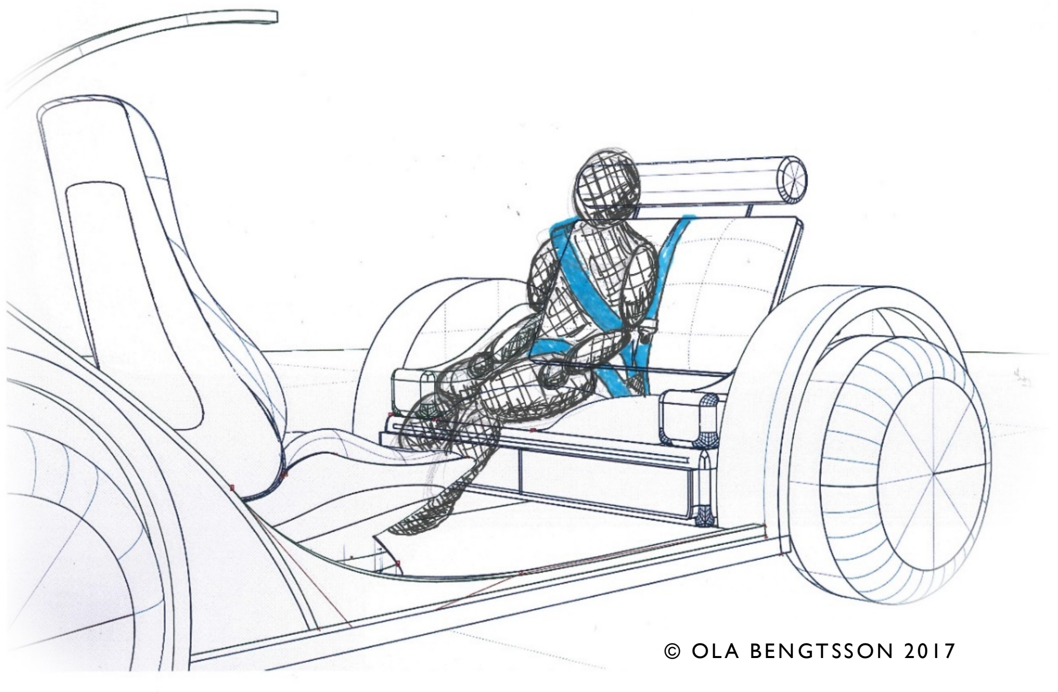


Figure 55: Person belted with a three-point seat belt in the front sofa. Belt is attached in the frame of the sofa.

7.7. Intelligent presets

Defined in 4.7, customization is of most importance. In this concept, the seat knows the user and adjusts after his or her preferences. Using a personal key, a cell phone app for example, for the car when it comes to pick the user up, it adjusts according to relevant factors like; adjustments the user have done before, time of day or mood (Figure 56).

Figure 56: The seat knows the user, and prepares a seat for him/her.

7.8. Conclusion of final concept

To get a wider understanding of how this concept would stimulate its user, it was analysed according to the full *specification of requirements* (4.6) in a Pugh evaluation matrix (Figure 57, method further explained in 3.10). The requirements are compared with the reference solution (Volvo XC90 chapter, 2.3) except requirement 3.5 that is based on the dimensioning of a SAAB 9-3 seat (attachment 1).

Looking at this evaluation the new concept has advantages compared to the reference seat (2.3) in both ergonomic and user needs aspects. It performs better in 12/20 of the user needs requirements many of which may be derived to the new seat arrangement and the foldable sofa. One interesting finding here is that stability, which was a prioritized feature, was not presumed to be increased in the new concept. Modern car seats today give stability to its users through bolsters, which is a function integrated in this new concept. The tilting functions described would probably enhance stability even further, but should probably be integrated in the car platform as there are negative side effects having relative movement between the seats and the car interior.

The other three prioritized requirements, provide green status, customization and spaciousness/clear outside view, all have obvious advantages in the new concept. Using an aluminium frame and eliminating redundant plastic components enhances green status. Folding the seat back of the sofa and pushing the furniture against the opposite walls stimulates customization and spaciousness/clear outside view. The foldability and simplicity of the sofa also give potential of extra storage space and surfaces for entertainment or other activities. Depending on how a working position is defined, it is hard to draw any conclusions whether that has been enhanced in this concept.

The concept seat is suggested to be better in some of the ergonomic aspects. Risk of motion sickness is an important factor that is reduced by enhanced outside view and minimized need for backward glancing as passengers now are facing each other. Digital human simulations dimensioned according to Chinese anthropometrics showed that the early concept seat cushion dimensioned according to the SAAB 9-3 (attachment 1) had such length that it would lead to an extensive clash on the distal half of the thigh of a 05th percentile Chinese woman. As this concept was later shortened in x direction, pressure on distal half of thigh was reduced. Having increased leg room extensively, that will also contribute to a more ergonomic pleasing situation as seating positions may be adjusted in a greater extent.

In the dimensional aspect, the final concept only provides seats for four people, as the reference provides five seats. The concept seat cushion is however slightly shorter in x direction compared to the reference, which relieves interior space.

No.	Description	Weight	Ref.	=	New	=
1.	**General user needs**					
1.1.	Express safety	3	0	0	0	0
1.2.	Provide fixed seat (when needed)	4	0	0	0	0
1.3.	Provide working position	6	0	0	0	0
1.4.	Provide outside view	6	0	0	+	6
1.5.	Provide entertainment position	6	0	0	+	6
1.6.	Support relaxing/sleeping position	5	0	0	+	5
1.7.	Support active position	6	0	0	+	6
1.8.	Provide a social environment	5	0	0	+	5
1.9.	Provide convenience	4	0	0	+	4
1.10.	Provide personal expression	4	0	0	+	4
1.11.	Provide eating position	5	0	0	0	0
1.12.	Provide drinking position	3	0	0	0	0
1.13.	Provide customization	6	0	0	+	6
1.14.	Provide leather seats	4	0	0	0	0
1.15.	Minimize servicing	5	0	0	+	5
1.16.	Provide heat	5	0	0	0	0
1.17.	Avoid light coloured seat material	5	0	0	+	5
1.18.	Provide green status	6	0	0	+	6
1.19.	Express trendiness	4	0	0	0	0
1.20.	Provide storage	5	0	0	+	5
	Net worth, user needs	*0*	*0*		*12 +*	*63*
2.	**Dimensional constraints**					
2.1.	Provide seats for a minimum of 3 people	5	0	0	-	-5

2.2.	Fit inside defined width	4	0	0	0	0
2.3.	Fit inside defined height	4	0	0	0	0
2.4.	Fit inside defined length	4	0	0	+	4
	Net worth, dimensional constraints		*0*	*0*	*0*	*-1*
3.	**Ergonomics**		0	0		
3.1.	Provide stability	7	0	0	0	0
3.2.	Provide spaciousness	6	0	0	+	6
3.3.	Support head	5	0	0	0	0
3.4.	Minimize glancing backwards	4	0	0	+	4
3.5.	Minimize pressure on distal half of thigh	5	0	0	+	5
3.6.	Support ischial tuberosity	5	0	0	0	0
3.7.	Support back	5	0	0	0	0
3.8.	Provide lumbar support	5	0	0	0	0
3.9.	Provide change of pressure by user movement	5	0	0	+	5
	Total, ergonomics		0	0	4	20
	TOTAL, ALL CATEGORIES		**0**	**0**	**16**	**82**

Figure 57: Evaluation matrix of the reference seat and the new concept seat. Green colours indicate where the new solution is defined to perform better than the reference solution, and red cell indicate where it has performed worse.

Summarizing this evaluation, the final seat concept has great potential of enhancing fulfilment of presumed user needs in future autonomous vehicles, focusing on outside view, spaciousness, green status and customization.

8. DISCUSSION

The discussion chapter of this report is twofold; initially the results and conclusions from the pre-study will be discussed, followed by the results and conclusions from the conceptualizing phase.

8.1. Discussion of pre-study results

A modern car seat is very complex product, with a wide list of requirements to fulfil. The user takes many functions for granted, simultaneously as the production cost must be minimized and material strength maximized - with every single gram of weight calculated carefully. As autonomous vehicles enter the market, this complex list of problems will elongate, as the car interior becomes more than just a car interior – now it will be a living room, bed room, an office or a private cinema – all at the same time. Therefore, this research naturally has its gaps, because if all these aspects would be taken in account, no progressive ideas would have been generated.

This project focused on user needs, because that will probably be the major driving force of the development of autonomous vehicle seats at the expense of driving experience and performance. A finding that may be key in the user needs analysis, is that several functions are able to contribute to more than just one need, which is crucial as the list of specific needs may be too diverse to fulfil individually. Customization, stability and spaciousness are all features that affects many areas of user needs like ergonomics, motion sickness, the need for different activities, working and socializing to mention a few, and because of that, they should have high priority.

Another important finding is that needs differ a lot between different groups of people, especially when it comes to the opinion towards autonomous vehicles in general, but also for specific activities. According to the polls performed to the wider public, not many would work in an autonomous vehicle, while in the more niche interviews, that was the most probable activity. This may be a key issue for the car manufacturers, how to develop a product that requires mass production, but has such a diverse range of user requirements.

If this pre-study was to be developed further, it would be relevant to analyse the user needs further, but maybe more focused on market segments that are the most probable to be the first users – suggesting *early adopters in Chinese mega cities*. Another relevant area of research would have been implementation of aluminium seat buckets in private cars as the eco-audit of this research show that it has a lot of potential in the area. The eco-audit can also be performed in a more specific manner, as the audit in this research handled relevant material groups in general with typical amounts and methods of recycling. The eco-audit could also be extended to other relevant components, like ABS plastic or PUR foam that are common in the products.

8.2. Discussion of the generated seat concept

The new seat arrangement is the key feature in the final concept. It is basically a standard seat arrangement flipped horizontally, where the back seats become priority seats. The word *driver seat* does not even exist in these cars and that is a big change considering that the design of these products has been more or less the same recent decades. This concept shows that, the most relevant thing would be to put the extra effort in the back seats instead, enhancing spaciousness/outside view and making several materials and adjustment features redundant as the seats now are in ideal position with their backs against the front and back wall.

Analysing how other car manufacturers have approached autonomous vehicles, many have clearly focused on new seat arrangements, which also have been prioritized in this research. Some manufacturers, exemplified by BMW, presents innovative solutions for interface technology that probably will affect several areas of interior design. Looking at their holographic display solution, that could a future technology that would be compatible with the *intelligent seat concept* (7.7) generated in this project.

Implementation of seat belts has high impact on the seat design. If the seats are to be flexible in various directions and angles, the belts need to be integrated in the seat frames. This leads to increased weight in the seat as it requires a tougher frame in the event of a collision. Because of that, adjustment features were avoided as much as possible, without making the seat uncomfortable or too static.

There are features in the generated concept seat that may be relevant in today´s seats as well. One of those is that the seat frame could be used as a visible design element, eliminating plastic that contributes to extra weight and negative effect on the environment. Using aluminium is also a feature that could be implemented today, especially in electric cars as it is both lighter and better in a sustainable perspective. It is more expensive compared to steel, but as some car manufacturers focuses a lot on carbon fibre components as the lightweight material of the future, which is also more expensive, aluminium is a much more sustainable alternative according to the *eco-audit*.

One aspect that has not been investigated, is the function of the airbag. Having a face-to-face seat arrangement requires new thinking about this safety feature, as there is no longer an object in front of the passengers where the airbag could be mounted. The ceiling, floor and side walls could be possible areas for this function instead.

In the final concept, tilting function around x and z-axis were eliminated because of probable weight and sustainability reasons. Whether it is installed in the vehicle platform or in the seat, the feature should be further discussed nonetheless. It has both high potential of increasing stability and comfort for the passenger, and just like the trains with this technology, the potential of maintaining a higher speed in curves it increases traffic flow hence a lower risk of congestion.

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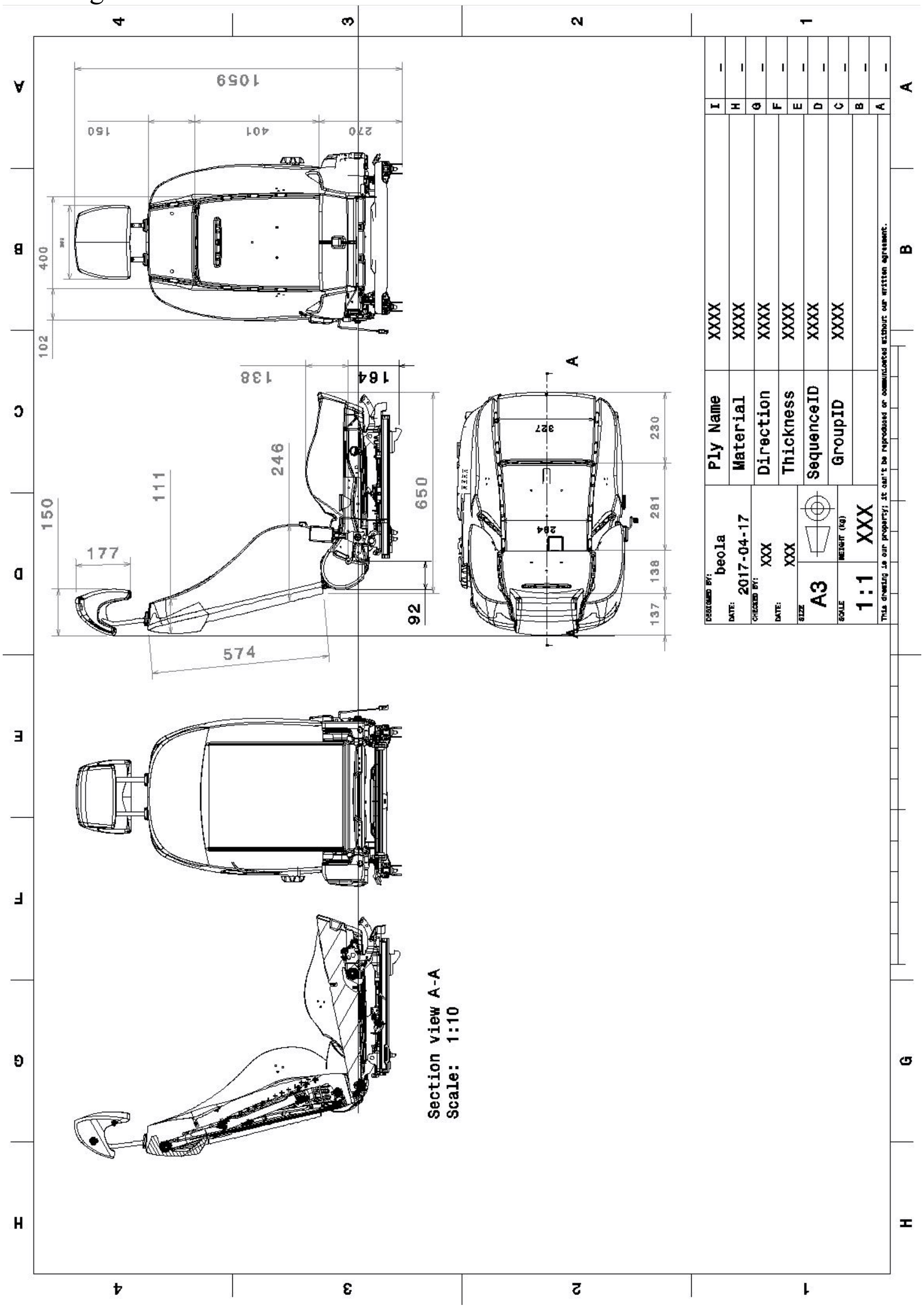
Attachments

Attachment 1: Drawing of a modern car seat

The following drawing describes a driver seat of a SAAB 9-3 that was in production until 2012. It was part of the platform Epsilon that was developed in cooperation with GM. The drawing is made by the author based on a CAD model provided by NEVS. The image is adjusted to A4, resulting in an inaccurate scale in this document.



Attachment 2: Other concept solutions

Relevant concepts from other car manufacturers have been analysed with the PNI-method. This method categorizes feedback in positive (+), negative (-) and interesting (I).

2.1. Volvo S90 excellence lounge console concept

In this concept, the front passenger seat is removed, and instead a multifunctional console is installed.

+ Comfortable - Maximum of only 3 passengers I: Focusing on luxury

+ Productive - Sensitive colours

+ Spacious

+ Prestigious

+ Compact

+ Seat stability

+ Feels safe

Figure 58. Volvo S90 Excellence console concept (http://teknikensvarld.se/volvo-visar-s90-excellence-med-lounge-console-288994/)

2.2. Nio Eve

Nio is an American startup who recently showcased the supercar Eve. It has an asymmetric seat arrangement with one permanent seat turned backward and one foldable seat that also could be used as leg support.

+ Spacious - Requires large dimensions I: Cost 1 million $

+ Productive - Seats has thin side cushions

+ Social - Stability

+ Large passenger capacity

+ Flexibility

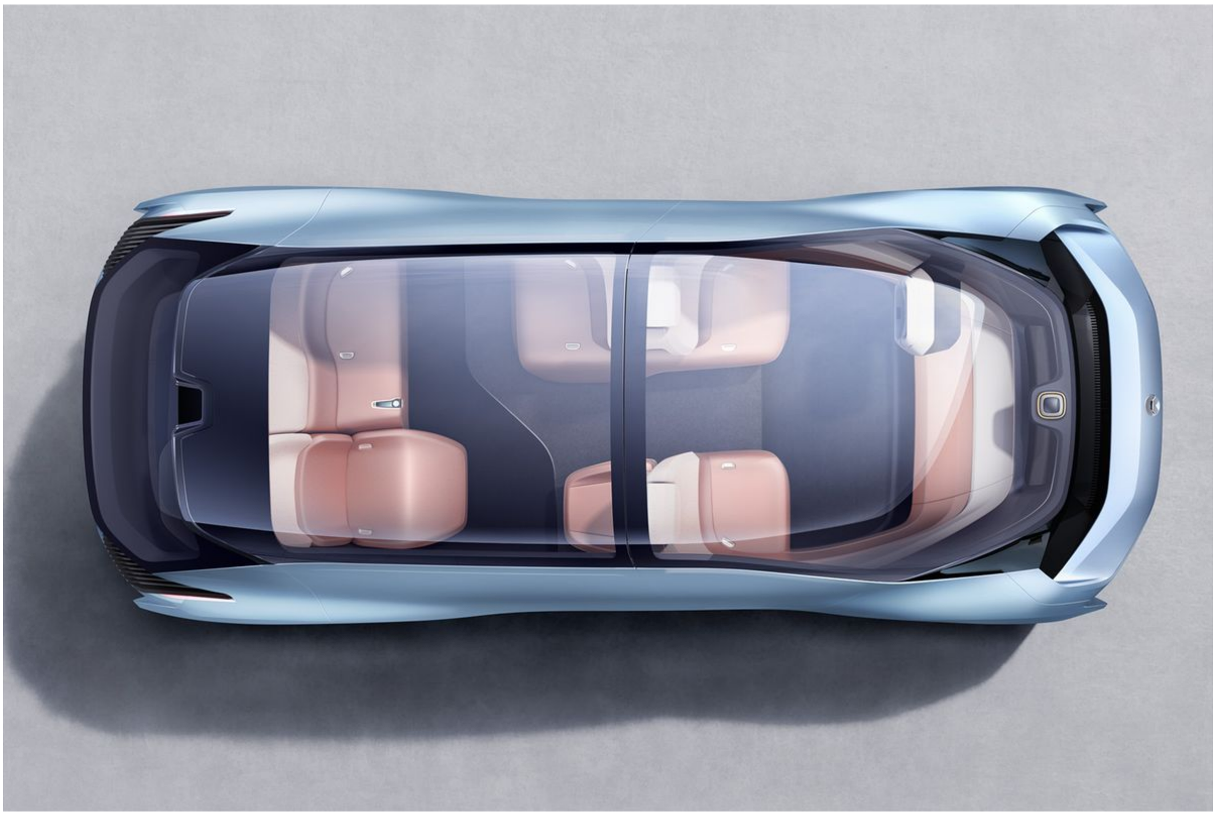


Figure 59: Nio Eve (Theverge.com)

2.3. Local motors Olli

Olli is a vehicle designed to be shared among many users. The manufacturer is Local motors. The vehicle is supposedly meant to drive at slow speeds and over short distances – Local motors exemplify the use of the vehicle like it could *"…transport students across campus efficiently"* (Localmotors.com, 2017).

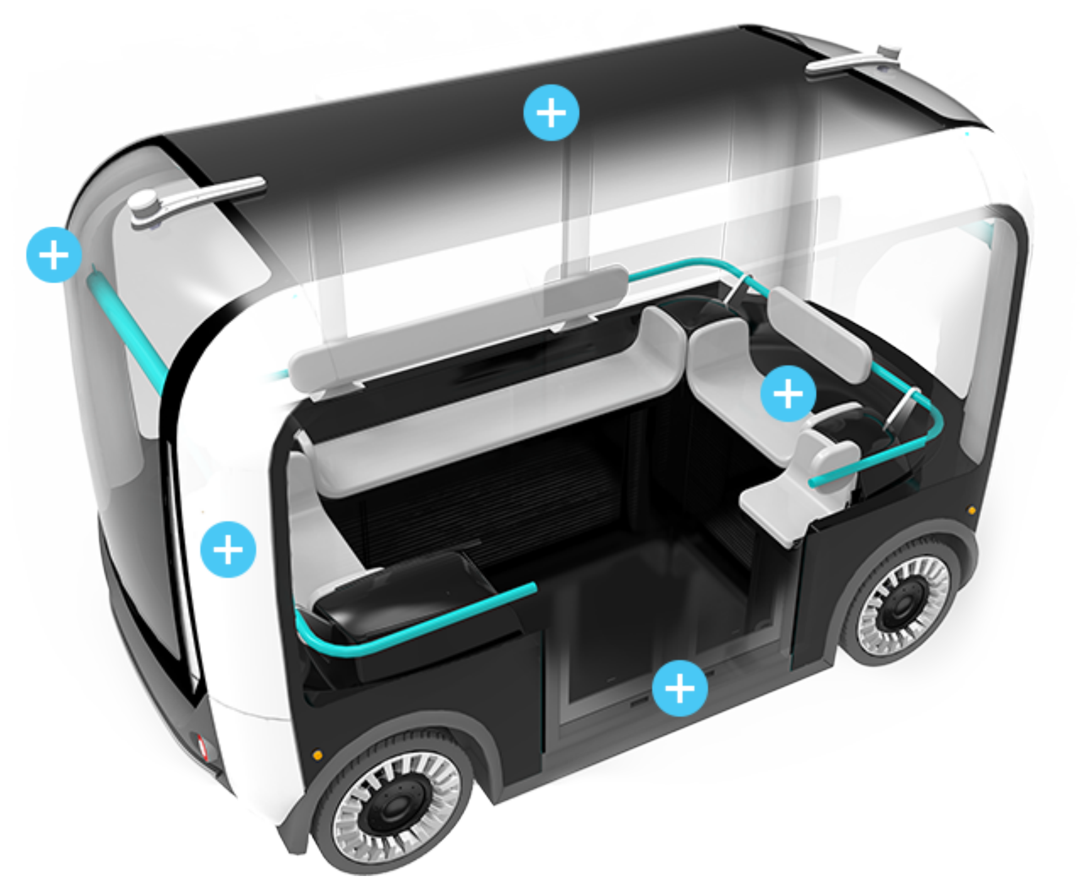


Figure 60: Local motors Olli (Local motors.com)

+ Spacious	- Requires height	I: This may be good at slower speed and shorter journeys
+ Supports standing	- No head support	
+ Social	- Not very stable seat	
+ Outside view	- Sensitive colours	
	- Does not feel safe	

2.4. BMW interior concept from CES 2017

BMW showed off an interior where the four seats had a lot of interesting functions. Head rest had built in speakers. The seat could monitor its user´s heartbeat and helps its him/her make decisions based on that information. Controlling the front display were holographic, which meant that the seat does not have to be near it while interacting. In the back, touchscreens are integrated in the armrest. Holographic displays are further described here:
Wired.co.uk (2017-01-04) *Holographic screens are coming to cars, courtesy of BMW,* by Heathman, Amelia, retrieved 2017-05-16 at http://www.wired.co.uk/article/bmw-holiactive-touch-system-ces

Figure 61: BMW interior concept (https://www.cnet.com/roadshow/news/bmws-ces-sculpture-forecasts-our-in-car-future-ces-2017/)

+ Spacious - Sensitive colours I: Head rest mounted in roof

+ Outside view - Flexibility

+ Productive position

+ Stability

+ Intelligent

2.5. Mercedes F015

Mercedes luxurious autonomous concept F015 has an interior filled with exclusive materials like nappa leather and walnut. It is supposed to reflect Mercedes style of "…modern luxury, emotion and intelligence" Referens.

Figure 62: Mercedes F015 (https://www.mercedes-benz.com/en/mercedes-benz/innovation/research-vehicle-f-015-luxury-in-motion/)

+ Spacious - Sensitive colours I: Seats has an interesting mix of classic

+ Prestigious - Expensive car seat and a lounge chair

+ Productive position - Requires large dimensions

+ Stability

+ Flexible

+ Intelligent

+ Calm

2.6. Lexus kinetic seat

This seat is supposed to follow the movement of the user while in motion. The seat and the back rest can rotate in the direction of the vehicle which *"...helps stabilize head movement caused by vehicle motion, keeping the field of vision steady"*. The environmental friendly spider web-like back rest (*QMONOS™ material developed by Spiber Inc.) is supposed to give customized support to the user.

Figure 63: Lexus Kinetic Seat (https://www.lexus-int.com/press-room/lexus-kinetic-seat-concept-world-premiere-at-the-2016-paris-motor-show)

+ Spacious - Sensitive colours I: Could this be a solution for stability

+ Unique look - Head rest seems thin in curves and acceleration?

+ Productive position - Requires large dimensions

+ Stable

+ Organic material

+ Insensitive colours

2.7. Tesla Concept Model X 2013

Tesla has become one of the most influential actors on the car market today. This model is chosen in the benchmark mainly because of its simple seat attachments in the middle row.

Figure 64: Tesla Model X (https://www.a2mac1.com/AutoShowsNew/autoshow.asp?service=1&sourceid=230&level1id=0#photos|DE13Car207|0)

+ Spacious - Messy look I: Middle seats' attachment in floor

+ Feels safe - Mixed colours is very simplistic

+ Productive position - Requires large dimensions

+ Stability

+ Flexible

2.1. Hyundai mobility vision concept

In this concept, Hyundai uses the car as an extension room of the home. This may reflect the needs of the crowded mega cities in Asia.

Figure 65: Hyundai mobility vision (https://www.cnet.com/roadshow/pictures/hyundai-mobility-vision-concept-joins-the-home-and-car-into-one-ces-2017/4/)

+ Spacious	- Hospital look	I: Extension of home
+ Comfortable	- Mixed colours	
+ Productive position	- Insensitive colours	
+ Stability		
+ Flexible		