



**CHALMERS**  
UNIVERSITY OF TECHNOLOGY



# Exploring Future Steering Devices for Automated Cars

*A user centered design project to develop an intuitive,  
user accepted, and safe steering device*

**Master's Thesis in Industrial Design Engineering**

**ANNA GUSTAFSSON  
EMELIE JANSSON**

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2023  
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MASTER'S THESIS 2023

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Anna Gustafsson

Emelie Jansson

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Supervisor: Sebastian Rutelin, Volvo Cars, Department Airbags and Steering Wheel

Supervisor: Helena Strömberg, Senior Lecturer at Design & Human Factors in the  
department of Industrial and Materials Science

Examiner: Helena Strömberg, Senior Lecturer at Design & Human Factors in the department of  
Industrial and Materials Science

Master's Thesis 2023

Department of Industrial and Materials Science

Chalmers University of Technology

SE-412 96 Gothenburg

Telephone +46 31 772 1000

Cover:

Picture illustrating the final concept in interior.

Göteborg, Sweden 2023

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## **ABSTRACT**

Automation have brought a significant change to the automobile industry, increasing the comfort, convenience, safety, and space of cars. As we move towards a future where cars will be responsible for a larger proportion of driving, estimated at 80%, new circumstances and expectations are bound to arise for car travel. With the focus of users shifting towards attending other activities rather than driving, there is an opportunity for a new design for the car's steering device. Therefore, it becomes important to explore and develop new steering devices beyond the conventional steering wheel to meet the new expectations of car travel.

This thesis aims to investigate future lateral steering devices for highly automated cars, with a timeframe of about two decades from now. The objective of the project is to design a realizable steering device that prioritizes user acceptance, ease-of-use, convenience, and safety. To achieve a suitable result for the future context and the objective of the project, a user centered design process is adopted, involving potential future users' attitudes in the product development process. The methodology entails conducting workshops where simulated scenarios of the future are used and where potential future users can give input on various steering devices.

The final concept aims to enhance user convenience by increasing the roominess in front of the driver, allowing the driver to engage in other activities while in automated mode. Additionally, the concept prioritizes safety through facilitating a smooth transition between automated and manual modes, and by considering airbags in the design. The findings of the project suggest that developing a feasible product in a future scenario is difficult due to the potential changes in the anticipated circumstances, which can affect the implementation success of the final concept. Consequently, it is crucial for future research to continue exploring the expectations and context of lateral steering devices for highly automated cars.

Keywords: Automated Cars, Lateral Steering Devices, Intuitive Steering, Transition Phase, Airbags, Roominess, User Acceptance

## ACKNOWLEDGEMENTS

We would like to express our gratitude to several people who have played an essential role in the completion of this thesis. Firstly, we extend our appreciation to Helena Strömberg, our academic supervisor and examiner from the department of Industrial and Materials Science at Chalmers University of Technology. Her continuous support and guidance have been invaluable to the project.

Additionally, we would like to extend our warmest thanks to our client supervisor, Sebastian Rutelin, from the "Airbags and Steering Wheel" department at Volvo Cars. Sebastian's extensive expertise and guidance have been instrumental in both challenging and supporting us throughout the project, providing us with the optimal conditions to successfully execute this thesis.

Lastly, we would like to express our gratitude to all the workshop participants for their valuable contributions, which greatly enriched the project with user input. We would like to extend a special thanks to the people at the "Airbags and Steering Wheel" department, which enriched the project with their expertise within safety.

Thank you!

Anna Gustafsson, Göteborg, 2023

Emelie Jansson, Göteborg, 2023

# TABLE OF CONTENTS

LIST OF ACRONYMS .....	I
1. INTRODUCTION .....	1
1.1. Demarcations.....	2
2. FRAMEWORK .....	3
2.1. Automated Driving (AD) .....	3
2.2. Users' Experience .....	6
2.3. Safety.....	8
2.4. Ergonomics.....	10
2.5. Sustainability.....	13
2.6. Summary of Framework.....	15
3. METHODOLOGY .....	16
3.1. Pre-Study .....	16
3.2. Development Loop 1 .....	18
3.3. Development Loop 2.....	20
3.4. Evaluation.....	24
3.5. Development Loop 3.....	25
4. RESULTS.....	27
4.1. Design Brief .....	27
4.2. Results of Development Loop 1 .....	34
4.3. Results of Development Loop 2.....	37
4.4. Evaluation.....	45
4.5. Results of Development Loop 3.....	50
4.6. The Final Concept .....	53
5. DISCUSSION.....	65
5.1. Answering the Research Questions.....	65
5.2. Reflection on Findings .....	66
5.3. Achievement of Client Expectations.....	67
5.4. Limitations .....	67
5.5. Future Work .....	70
6. CONCLUSION .....	73
APPENDIX.....	78

## LIST OF ACRONYMS

The following is a list of acronyms that have been used in this thesis, arranged alphabetically:

Acronym:	Description:
AD	Automated Driving
AV	Automated Vehicle
CAB	Curtain Airbag
CAD	Computer Aided Design
DAB	Driver Airbag
DFA	Design Format Analysis
DFMEA	Design Failure Modes and Effect Analysis
FAB	Far-side Airbag
KnAB	Knee Airbag
NDRTs	Non-Driving Related Tasks
PAB	Passenger Airbag
RULA	Rapid Upper Limb Assessment
SAB	Side Airbag
SbW	Steer-by-Wire
TOR	Take-over Request
UX	User Experience

# 1. INTRODUCTION

Projected global sales goals by 2025 of varying automated cars could potentially reach millions, including highly automated cars at 9 million (Borenstein et al., 2017). Automated cars are expected to be a facilitating element of future societies. The advent of automated vehicles has indicated significant changes in the history of automobiles, bringing forth new levels of comfort, convenience, safety, and space, as suggested by Pettersson and Karlsson (2015). As we move towards a future where cars will be responsible for a larger proportion of driving, estimated at 80%, new circumstances and expectations are bound to arise for car travel. With the focus of users shifting towards attending other activities rather than driving, there is a growing opportunity for a new design for the car's steering device. To cater to the expectancy of increased space, convenience, and safety, it becomes imperative to explore and develop new steering devices beyond the conventional steering wheel.

The steer-by-wire system is an additional factor that opens the opportunity for new types of steering devices (Mortazavizadeh et al., 2020). With the technology, it's possible to create a steering device that looks and works differently from today, as it is not constrained by the fixed steering column in front of the driver as in today's cars. However, today's driver safety is well developed according to the conditions established by the conventional steering wheel and its position in relation to the driver. With the technological development of automated cars, the level of safety must not degrade to secure a safe future on the road. Safety aspects such as if the driver is willing to use automated driving (AD) correctly, trusts the system and is prepared for the transition required, affects the overall safety (Pettersson & Karlsson, 2015). The new technology needs to be trusted, and the driver needs to feel confident in using it by learning and interacting with the system (Lindgren et al., 2021). The steering experience might be affected if new configurations of lateral steering devices are implemented in cars, which differ from the conventional steering wheel in terms of shape and placement. The experience may differ in terms of comfort, safety, and acceptance. The new technological development of automated cars and active systems can be challenging, due to the new relation between driver and car. The relation affects how the interaction plays out between the driver and the system of the car (Pettersson & Ju., 2017), which could potentially affect the overall experience of using the steering device.

Given the opportunities afforded by automation and steer-by-wire technology, this thesis aims to develop a lateral steering device for future automated cars, that takes into consideration the developing relationship and interaction between driver and car as well as safety systems. To be able to do so, the following research questions will be answered:

- *What steering device will be relevant to use when steering AD cars in the future?*
- *What type of steering experience is desired and relevant when steering AD cars in the future?*
- *What type of steering device is desired or needed to preserve the safety of today?*

## 1.1. Demarcations

As requested by the client, the expected output of the thesis is a developed steering device for a future AD car. The term client refers to Volvo Cars Corporation in this report. The final concept needs to be suitable for the future, realistic in regards of what is known today, safe to use, and accepted by future users. The concept should then be realizable based on these aspects within the year of 2040. The final concept will be expected to be on a conceptual level, implying that the concept should be realizable, but further material and manufacturing issues will not be dealt with. The project is limited to level 4 of SAE J3016 levels of driving automation (SAE International, 2021), since level 4 seems reasonable within the set timeframe.

Safety is important for the client, as safety cannot be compromised. The client expects the project team to be open-minded and innovative as well as to focus on a high level of AD. The timeline for the final concept to be realizable is estimated to be 15-20 years in the future and resultingly assumptions must be made for some aspects. The client is expecting one final concept, including a requirement list considering aspects for real use, safety, airbags, and the driver's position. The final concept should be delivered as a prototype, based on a computer aided design model.

Assumptions of the car's condition have been made and are listed below. The assumptions have limited the scope of the project.

- The car has steer-by-wire.
- The automated car is owned by the driver and collective usage will not be dealt with.
- The seats are in a fixed position in the direction of travel and the driver will not be able to rotate the seating (e.g., backwards facing, or swiveled seating).
- The driver should be able to take over control of the automated car when needed/desired.
- The safety functions and systems of the car have been developed during this timeframe to better meet the new expectations of the driving scenario, contributing to better interaction between the car and the driver.

## 2. FRAMEWORK

This chapter provides information on previous research, principles and theories within automated driving, steering techniques, safety, and users' expectations. In detail, e.g., takeover situations, universal design, cognitive and physical ergonomics, as well as sustainability have been investigated, to give context and background of what is important when developing a future steering device for automated cars.

### 2.1. Automated Driving (AD)

An autonomous vehicle can be described as a vehicle that can drive itself and includes navigation of varying kind of environmental contexts with little or no human input (Dingyi et al., 2018). Automated vehicles (AV) and automation of cars, on the other hand refers to cars automated attributes and are not fully automated, there is still a need of a driver. The automation of cars lessens the burden on the driver and as a result makes space for attending to non-driving related tasks (NDRTs) during travels, such as socializing with passengers, working on computer, or reading books (Schartmüller et al., 2019). Depending on the car's level of automation the driver needs to be able both mentally and physically to take control of the driving in different situations, so-called takeover situations. During those takeover situations, some tasks might take longer time to recover from than others, and the NDRT could potentially act as a distraction depending on how the driver values the task (Kraus et al., 2018). Hence the importance of being able to take control no matter the distraction, e.g., attending to an easily interrupted task, or attending to a difficultly interrupted task. Both the influence of the task at hand, as well as the recovery time, willingness to take control, and influence are important when discussing NDRTs. Automated cars' capabilities can be classified according to the SAE scale, which ranges from no driving automation at level zero to full driving automation at level five (Figure 1). They are further described below.

- At level zero, the driver is fully responsible for the vehicle and carries out all aspects of the driving tasks. There are no driver assistance systems available.
- At level one, the driver can delegate one of the driving tasks steering, accelerating, or braking to the driving system.
- At level two, the driving system of the car can perform several driving tasks, but the driver must permanently monitor the system.
- At level three, the driver can turn away their attention when driving in specific situations but must always be ready to take over control of the vehicle again. The system can at this step autonomously control the vehicle on defined routes.
- At level four, the system can perform all driving related tasks and the driver can completely transfer control to the system and attend to NDRTs. However, if needed or desired the driver should be able to take over control of the vehicle at any time.
- At level five, there is no need for a driver since the system controls the vehicle autonomously in all contexts. The car is referred to as autonomous.

An important aspect to take into consideration during the development of the final steering device would be the levels of driving automation. The levels affect what type of NDRTs the driver can attend to, and what type of situations the driver needs be ready for when doing a take-over or hand-over of the vehicle.

	SAE LEVEL 0™	SAE LEVEL 1™	SAE LEVEL 2™	SAE LEVEL 3™	SAE LEVEL 4™	SAE LEVEL 5™
What does the human in the driver's seat have to do?	You are driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You are not driving when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
Copyright © 2021 SAE International.						
What do these features do?	These are driver support features			These are automated driving features		
	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/acceleration support to the driver	These features provide steering AND brake/acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met	This feature can drive the vehicle under all conditions	
Example Features	<ul style="list-style-type: none"> <li>• automatic emergency braking</li> <li>• blind spot warning</li> <li>• lane departure warning</li> </ul>	<ul style="list-style-type: none"> <li>• lane centering OR</li> <li>• adaptive cruise control</li> </ul>	<ul style="list-style-type: none"> <li>• lane centering AND</li> <li>• adaptive cruise control at the same time</li> </ul>	<ul style="list-style-type: none"> <li>• traffic jam chauffeur</li> </ul>	<ul style="list-style-type: none"> <li>• local driverless taxi</li> <li>• pedals/steering wheel may or may not be installed</li> </ul>	<ul style="list-style-type: none"> <li>• same as level 4, but feature can drive everywhere in all conditions</li> </ul>

Figure 1 – Automation levels. From SAE Levels of Driving Automation [Table], by SAE International, 2021, 03 May. (<https://www.sae.org/blog/sae-j3016-update>).

### 2.1.1. Transition Phase

Transition phase refers to the switch between autonomous or automated drive to manual drive or the other way round (Pettersson & Karlsson, 2015). The transition phase is dependent on various aspects to make the switch as easy and safe as possible. Following chapter mostly discusses the transition phase in terms of take-over situations, since they could be seen as uncertain and having a big impact on the safety. Hand-over situations will be further discussed in 2.2.2, since the driver needs to give up control of the vehicle to the system.

The drivers' needs related to the take-over transition differ between automation level three and four. At level three the driver is supposed to monitor the driving during AD mode, compared to automation level four where the monitoring disappears which puts other demands on the take-over situation. The other demands regard the ability to instantly take over control of the driving when alerted by a take-over indication or a take-over request (TOR) from the car (Schartmüller et al., 2019; Kraus et al., 2018; Melcher et al., 2015).

The situations when the driver needs to take over control of the car can be categorized into intended and unintended steering takeovers. They differ in terms of the preparation time the driver is given to takeover when switching from automated to manual mode. The intended steering takeover can be predicted by the car in advance and resultingly give the driver the opportunity to prepare for the takeover (Johns et al., 2014). The unintended steering takeover on the other hand is caused by contextual factors that are hard to predict, e.g., weather conditions. They give resultingly less time or minimal warning to prepare the driver for a takeover. According to Melcher et al. (2015) a suitable and comfortable fixed transition time is estimated to be 10 seconds in a highway scenario with a highly distracted driver, no matter where the TOR are presented, even if previous studies recommended 8 seconds as sufficient. This transition time is estimated for intended steering takeover situations.

The transition when the driver takes over the driving from the automated mode ought to be dependent on the situation and the ability of the driver. The transition phase needs to be adapted to fit the individual needs. The takeover depends for instance on the driver's capacity to prepare, their age, driving experience, habits, or driving preferences. The transition itself can be seen as a moment of uncertainty for the driver (Pettersson & Ju., 2017). The study of Pettersson (2017) proposed that the preparation for the transition could be similar to the indication at the end of a long flight, with gentle light and voice indication giving information about the route and remaining distance.

Important aspects to take into consideration during the development of the final steering device would be that the switch between AD mode and manual mode needs to be clear and smooth to give a preparedness to take over. The indications need to some extent be adjustable to one's preferences. Followingly, the driver needs to be able to take control easily when desired or needed, with little preparation time.

### **2.1.2. Steer-by-Wire**

Steer-by-wire (SbW) is a technology used in AV where the mechanical link between the steering wheel and the front wheels is replaced by electronic signals (Mortazavizadeh et al., 2020). In a traditional steering system, the steering wheel is directly connected to the front wheels through a series of mechanical parts. In a steer-by-wire system, the steering wheel sends a signal to an electronic control unit, which then sends signals to actuators that control the movement of the front wheels. This increases the design freedom of steering devices since the steering column and its location does not need to be considered anymore. SbW also increases the design freedom in terms of e.g., manipulating the feeling of the steering device through software according to personal preferences, variable steering ratio, change the position of the steering device or its features, etc. The key benefits of SbW are increased flexibility and enhanced vehicle dynamics since the system may be arranged to operate in a particular way due to various driving situations. This may lead to better stability and handling, as well as a more comfortable driving experience. SbW systems can also be used in conjunction with other technologies, like lane departure warning systems and automated driving features.

An important aspect to take into consideration during the development of the final steering device would be that the electronic control unit which makes SbW possible, needs to be considered when designing, e.g., consider the space needed for the electronic control unit in the steering device.

## **2.2. Users' Experience**

The number of interactions with other devices (e.g., phones) or fellow travelers are expected to increase in AD cars since the driver will be able to focus on other activities than driving (Pettersson & Ju, 2017).

The interaction between the driver and the car may be dynamic in terms of actions, reactions, and communication, which then can lead to expectations, emotions, behaviors, or adaptation to the system. To be able to investigate the users' experience and their acceptance, varying factors can be determined. Important experience factors could be trust and joy, and acceptance factors could be perceived ease-of-use and perceived behavioral control (Rödel et al., 2014). Furthermore, previous experiences with similar or alike systems to AD, can further have a positive effect on the users' experiences.

### **2.2.1. Trust & Acceptance**

The willingness of using AD includes creating user confidence in the technology and create experience of using and learning it. The study of Lindgren et al., (2021) shows that the perception of people being willing to hand over the driving to the vehicle from one day to another might be misleading and should be considered carefully. Trust has been identified as important to create willingness and for creating the opportunity to ensure correct usage (Ekman et al., 2017). Trust can be formed by attitudes regarding information, impressions, and experiences. It is important to create an "appropriate" level of trust to not risk misuse or disuse and to strive for what is reasonable in relation to the system's performance. To create the foundation of appropriate levels of trust during the transition phase it may be interesting to take audio into consideration, as well as haptic or visual feedback, without potential for mental overload (Ekman et al., 2017). It is important that the driver can adjust or modify presented information while in automated mode, to create trust and insight into the system process. During AD mode it is important to be aware of what could generate high or low cognitive workload, to increase situational awareness and hence more conscious decisions.

Furthermore, attractive design and high-quality works as an enabler to increase trust in the technology and makes users want to use it (Pettersson & Karlsson, 2015). The trustworthiness of a system can be affected by users' perception of the interior physical aesthetics and "expert" feeling (Ekman et al., 2017; Pettersson & Karlsson, 2015). In line with this, the user interface

plays an important role in trust, e.g., if a system looks old it can cause depreciation in the systems capabilities (Kraus et al., 2018). Additionally, ease-of-use is highly connected to trust building and acceptance of users, which is an effect when gaining self-confidence through experience (Pettersson & Karlsson, 2015). Familiar driving interfaces and stimulating usage can work as enablers in this purpose and help the user feel confident in using AD (Pettersson & Karlsson, 2015).

Important aspects to take into consideration during the development of the final steering device would be to strive to create trust in the steering device, resultingly creating willingness to use it and ensure correct usage. Also, to strive for attractive yet familiar design that the driver can adjust to some extent, to be able to create “appropriate” levels of trust.

### **2.2.2. Control**

In studies of AD cars at level 3 (Lindgren et al., 2021), users have expressed the need to be in control, to decide when and where they desire to drive or hand over parts of the driving to the AD car. Even though the users expect the car to handle most of the driving in level 4, they do not want to leave all the decisions to the system. In Pettersson’s study (2017) users mentioned the need of being able to instantly take over the control of the vehicle when in AD mode, and having the final say; *“Like the Internet, you’re relying on a network and it’s only as strong as the weakest link, you’d need a default kill switch to the manual mode”* (Pettersson, 2017, p.3). To some extent it is necessary to give up control when in AD, but it could be difficult for some users. The difficulties might be based on each individual’s tendency to handle and process occurring events (Kraus et al., 2018). Individuals with lower tendencies could be less positive towards AD. Furthermore, the lack of perceived control could cause the driver to override the AD system (Borenstein, 2017). The users need to prepare themselves for the transition is important for both the feeling of being in control and to make the situation safe (Pettersson & Karlsson, 2015). According to Pettersson and Ju (2017), the driver may possibly feel unsafe during the transition phase even with given indicators, since the driver wants to be reassured that the car has taken control.

Important aspects to take into consideration during the development of the final steering device would be to enable the driver to take control or give control when desired, as well as to give clear indications of when the car is in control to make the driver feel safe.

### **2.2.3. Universal Design**

Universal design in the international community goes by many names, and can be defined as the design of products, environments, or services to be used by all, without further adaptation or special design (Clarkson & Coleman, 2015; Story, 2001). Universal design enables barriers to be removed to not exclude users, and the concept can empower the population by improving human

performance, social participation, and wellness (Steinfeld & Maisel, 2012). To be able to achieve universal design as well as to clarify how universal design and usability could be pertained to specific designs, some guidelines for the principles are mentioned in the book of Story (2011, chapter 4). Principles such as 1. *Equitable Use*, 3. *Simple and Intuitive Use*, 5. *Tolerance for Error*, 6. *Low Physical Effort*, and 7. *Size and Space for Approach and Use*, have been of importance. Some of the guidelines for these principles are shown below.

**Guideline for principle 1:** Provide the same means of use for all users; identical whenever possible; equivalent when not.

**Guideline for principle 3:** Arrange information consistent with its importance.

**Guideline for principle 5:** Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded.

**Guideline for principle 6:** Minimize sustained physical effort.

**Guideline for principle 7:** Accommodate variations in hand and grip size.

Important aspects to take into consideration during the development of the final steering device would be to include users in the product development process to strive for sustainable use for as many as possible, and to early target and minimize potential misuse or hazards.

### **2.3. Safety**

The safety of cars can be divided into two categories, a passive and active safety system. The active system acts to prevent a collision from happening with sensors, computers and artificial intelligence, and the passive system to protect in case of a collision. Crash and acceleration sensors could be placed and installed in the control unit, as satellites in the front end or side of the vehicle, depending on the placement of airbags (Hella, n.d). One of the most important components of a car's passive safety system is the airbags. Airbags are designed to protect the driver and the passengers in the event of a collision, reducing the risk of serious injury or death.

Important aspects to take into consideration during the development of the final steering device would be that the airbags for the future context need to be chosen to protect the driver passively, and that the car protects the driver actively as well. Both in situations when the car or when the driver is responsible for the drive, and in case of frontal or side collisions.

### 2.3.1. Airbags

An airbag is a safety feature in a car that rapidly inflates following a collision, restraining the occupants, and assisting in lowering the risk of injury (Insurance Institute for Highway Safety, 2022). Sensors in the car that detect the impact of a collision cause the airbags to deploy.

There are several types of airbags that are commonly found in vehicles nowadays (Insurance Institute for Highway Safety, 2022), some of them is described in more detail below. The airbags listed was consider relevant during the product development since they could affect or be affected by the final concept's design when inflated.

**Frontal airbags:** These airbags are designed to deploy in the event of a frontal collision and provide cushioning to the head and upper body of the driver and front passenger. The driver airbag (DAB) is positioned in the steering wheel, and the passenger airbag (PAB) is positioned in the instrument panel. The DAB can have an approximate volume of 65 liters of gas, and a PAB can have a volume between 100-120 liters depending on the car model, with an inflation time between 25-35 milliseconds when fully inflated (Hella, n.d).

**Side airbags:** These airbags are designed to deploy in the event of a side collision and provide cushioning to the torso, chest and head of the driver and passengers. The side airbag (SAB) is located in the door, the far-side airbag (FAB) is located between the driver and the passenger, and the curtain airbag (CAB) is located above the side car windows. In case of impact, a SAB or a FAB can be fully inflated after approximately 12-30 milliseconds (Hella, n.d), depending on the type of airbag and car model, with a volume of 20-40 liters (TraGate, n.d).

**Knee airbags:** These airbags are designed to deploy in the event of a frontal collision and provide cushioning to the legs and lower body of the driver, and to control the movement of the occupant. Knee airbags (KnAB) are located in front of the driver, below the steering wheel and can also be located at the passenger side in the same position.

The airbags protecting the driver in an event of a collision consist of a DAB, a KnAB, a SAB, a CAB and a FAB. The airbags act as a barrier between the driver and the interior of the car during a collision. The steering wheel affects the deployment and performance of the DAB since it is positioned in the steering wheel, and the steering wheel has a significant role in the airbag's ability to provide protection in the event of a crash. Overall factors affecting the DAB concern its position in relation to the driver, the size of the inflated airbag, and the time of the inflation.

## **2.4. Ergonomics**

Ergonomics can be divided into three areas, which are physical ergonomics, cognitive ergonomics, and organizational ergonomics. Ergonomics often handles factors regarding unnecessary attrition of the user in varying contexts. Good physical ergonomics and cognitive ergonomics (or in this case cognitive comfort) for drivers is important since it directly can impact their driving performance. Physical ergonomics can help prevent fatigue, pain, and other discomfort, that can lead to injuries over an extended period. Cognitive comfort, in turn, can help reduce stress and improve focus, allowing drivers to make quick and accurate decisions while driving. Ensuring both physical ergonomics and cognitive comfort can lead to improved safety and reduced risk of accidents on the road.

### **2.4.1. Ergonomics of Steering Devices**

Awareness of the ergonomics of different steering devices can have a significant impact on comfort, safety, and user satisfaction, when designing steering devices for future experiences. The physical stress of five various steering devices, including muscle activity and difficult joint angles, was assessed in the study by Hedegaard et al. (2019). The tested steering devices were a conventional steering wheel, a fast-steering wheel, a miniature steering wheel, a first-order joystick, and a second-order joystick. A second-order joystick has two degrees of freedom, while the first-order joystick has one degree of freedom, which makes the second-order joystick difficult to design since it is more complex. The findings indicate that steering wheels place a greater strain on drivers than joysticks, due to the joysticks' lower levels of muscle activity and fewer joint angles. The findings also showed that utilizing a miniature steering wheel as opposed to a conventional one results in less muscular rest time. When comparing all, the conventional and fast steering wheel were found to have increased workload and caused more deviation from the neutral position of the upper body joints. The performance of the steering devices showed mixed results where the conventional steering wheel were the slowest, the second-order joystick had the greatest angular deviation, and the first-order joystick had the highest rate of steering reversal and the most saturation. All the analyzed steering devices showed some physical strain in terms of joint angles and muscle activity that was outside of the ergonomic recommendations, indicating that all could benefit from ergonomic improvement.

An important aspect to take into consideration during the development of the final steering device would be that its placement, size, and usage needs to be considered to minimize potential physical strains and muscle activity.

### **Anthropometrics**

Anthropometrics is included in physical ergonomics and is the science that handles human measures (Pheasant et al., 2006). While applying anthropometrics in a development process, it ensures that the product is suitable when it comes to physical measures, and that the product

accommodates a certain percentage of the targeted user group, such as the user groups average person, minimum person, and maximum person (HFES 300 Committee, 2004).

When investigating the anthropometrics, measurements to take into consideration were the hand length and the hand breadth, the shoulder breadth, and the length of the forearm. The mean value of female measures is 78.65 mm at the hand breadth, and 179.51 mm at hand length, while for the average male those measures are 86.97 mm and 193.80 mm. The mean value of female shoulder breadth is 424.66 mm, and the average man is 476.43 mm. Additionally the mean length for females' underarms (from elbow to wrist) is 251.73 mm, and for men those measurements are 283.89 mm (Hanson et al., 2009). Further investigations of the 5th and 95th percentile of females and males can be seen in Table 1.

Important aspects to take into consideration during the development of the final steering device would be that the size and shape of the steering device should be suitable and within reach for the average person, the 5<sup>th</sup> %il and the 95<sup>th</sup> %il of the population.

*Table 1 - Anthropometric measurements received from antropometri.se. Authors' own table.*

[mm]	5th %il (female)	5th %il (male)	95th %il (female)	95th %il (male)
Hand length	164.72	178.55	194.30	209.06
Hand breadth	71.29	78.56	86.02	95.37
Shoulder breadth	386.85	432.30	462.47	520.57
Underarm lengths	217.61	250.24	285.85	317.55

## 2.4.2. Cognitive Comfort

This chapter contains aspects of cognitive ergonomics to consider when developing a steering device for an AD car. The section includes cognitive load, ease-of-use, and motion sickness.

### Cognitive Load

By handling driving duties like steering, accelerating, and braking, AVs have the potential to reduce the cognitive strain on drivers and free them to focus on other things. This can make driving less difficult and exhausting by lowering the mental and physical stress involved. By removing the need for constant attention on the road and on other traffic, improved safety features of AV, including collision avoidance and lane departure warnings, can help lessen the cognitive load on drivers. Traditional information is anticipated to continue providing regular updates, particularly when the car alters its route. However, it will take on a more subtle role to accommodate other activities. (Pettersson & Karlsson, 2015). When processing existing knowledge and receiving information from the AD car, it can be seen as a heavy cognitive load for the driver since it requires constant analyzing, although it could contribute to trust (Ekman et al., 2017). As a result of implementing AD cars, the transition phase will add to the cognitive

load. The interaction sequences and timeframe for the takeover should be carefully constructed to not add any unnecessary load to the driver and make the transition safe to handle. Some level of cognitive load when travelling in AD mode might be beneficial to retain since it contributes to the driver's readiness and ability to take over the steering when needed (Johns et al., 2014).

Important aspect to take into consideration during the development of the final steering device would be that the driver should not feel overwhelmed by the given information yet feel ready to take over when needed, as well as to receive necessary information when driving.

### **Ease-of-Use**

Ease-of-use steering and intuitive handling helps decrease the cognitive load when driving since it reduces the amount of mental effort required to operate the vehicle, increasing safety on the road. Important functions should be present (e.g., to communicate with the environment) but not take up too much space. This is important while driving since the driver's cognitive resources are already being divided between several tasks, such as navigating, observing traffic, and making decisions. If the controls of the vehicle are too complex or require excessive attention when driving, it can further increase the driver's cognitive load and reduce the ability to respond effectively to changing road conditions.

When combining feedforward and feedback, they can be used to design easy-to-use and intuitive products. Feedforward is the information a product provides about its function before an action takes place and feedback works as a return of information from a process or action (Wensveen et al., 2004). Feedforward, perceived usefulness, and ease-of-use are crucial since they influence whether users will be eager to utilize a product or not (Davis, 1989). Even though a product would improve their performance, users are less inclined to use the product if they do not think it is easy to use. Providing the user with clear feedback of their actions, such as visual or haptic cues to indicate the results of their actions (Pettersson, 2017) can increase ease-of-use. The study of Schartmüller et al., (2019) shows that it is preferable to have physical buttons with haptic feedback compared to touch since it allows interaction without looking. Additionally, users prefer to have all driving related information located in one place, rather than spread out since it allows them to keep the attention on the road, according to the UX department at Volvo.

Important aspects to take into consideration during the development of the final steering device would be that the steering device should not be too complex, with visual or haptic buttons, and that information and indications should be in one place to enable eyes on the road. Additionally, the feedforward and feedback could help create a clear interaction between the car and driver.

### **Motion Sickness**

Many people experience motion sickness when travelling as passengers today. Implementing automated mode in future cars, motion sickness will possibly influence the driver more than experienced in non-AD cars (Iskander et al., 2019). As drivers attend to NDRTs and become more like passengers, they will have less focus on the road. Management of motion sickness will be a present part of designing AD to create a comfortable and joyful experience for the driver.

Two of many theories explaining the occurrence of motion sickness is the sensory conflict theory, which is when the sense of balance and visual inputs are not matching (Elbanhawi et al., 2015; Kraus et al., 2018), and the posture instability theory, which presents that motion sickness is triggered from the lack of postural control (Iskander et al., 2019). According to Elbanhawi et al., (2015), the driver's method of turning causes lateral acceleration, which is the main contributor to motion sickness in passengers, which could also apply to drivers in the future context.

To counteract the sensory conflict, the car can give a visual cue, mapping up the travelling route ahead, for instance on a display, to match the sensory inputs the driver is given. It is important to give the driver general information about the terrain, route, and speed to create an awareness of the features of the trip (Iskander et al., 2019). Not only visual cues can be used to eliminate sensory conflicts, but other senses can be helpful to include, e.g., auditory cues. Additionally, it is crucial to place the vehicle's information and driving-related features in the driver's focused field of vision (Iskander et al., 2019; Kraus et al., 2018). As a result, the driver can capture motion data of the road with their peripheral vision while simultaneously using their center vision to focus on the information in front of them. Information about "why" (such as a bump ahead) is associated with stronger performance than giving information about "how" (such as how the car is functioning), and when combined, resulting in an even higher performance but with a larger cognitive load. It is argued that keeping information and performing NDRTs at eye level counteracts the effects of motion sickness (Iskander et al., 2019). How motion sickness influences people are highly individual (Iskander et al., 2019).

Important aspect to take into consideration during the development of the final steering device would be that the given information should consist of "why" rather than "how" to minimize sensory conflicts of cognitive load, where the information should be presented near or at eye level.

## **2.5. Sustainability**

This chapter contains two fields within sustainability which are important to take into consideration when developing a steering device for future AD cars, the two fields are societal and safety sustainability. Within the two fields a higher level of AD is discussed.

### **2.5.1. Societal Sustainability**

The societal sustainability of AD is deeply connected to people's acceptance and attitudes (Mora et al., 2020). The sociotechnical aspects are not only dependent on having needs being fulfilled by technique but are also highly connected to cultural, economic, political, and other organizational settings on multiple dimensions. Cultural tendencies are for instance deeply rooted in urban settings, but a change is crucial to foster a new set of desired behaviors and

values that are necessary to support AD technology and enhance the sustainability offered by this transition. The transition of sociotechnical aspects in terms of AD is impacted of organizational settings of society, and it regards management of existing values, attitudes, the infrastructure's settings, services, and peoples' routines. Moreover, the aspects are proposed to be modified due to geographical differences to increase acceptance.

The utilization of AD has the potential to bring substantial alterations in travel behavior due to their potential in reducing congestion (Dingyi et al., 2018; Fagnant & Kockelman, 2015). AVs can lead to increased mobility for individuals who are unable to drive, such as elderly people, and people with functional variations, thereby creating new demands for roadway capacity (Dingyi et al., 2018; Fagnant & Kockelman, 2015; Iskander et al., 2019). Followingly, standards, policies and regulations in the social perspective are yet to be evolved with the same speed as the developed and emerging technology, this could include fields of certifications, liability, technical standards as well as cyber security and insurances, to ensure safe use and development (Dingyi et al., 2018). Moreover, the designer needs to take ethical aspects into consideration to design safer solutions, and in line with Pettersson (2017), Borenstein et al., (2017) also encourages the approach of using autonomy to be able to incorporate value-sensitive design in the future.

Important aspects to take into consideration during the development of the final steering device would be to make the solution somewhat familiar to still create and withhold values and attitudes, as well as to offer a sustainable transition to learn and acquaintance the context that the future might be directed at.

### **2.5.2. Safety Sustainability**

According to predictions, the use of AVs could result in lower crash and injury rates of cars (Fagnant & Kockelman, 2015). This could be a result of the elimination of elements like human mistakes and a decline in legal violations e.g., running red lights. Additionally, pedestrian and bicycle crashes involving motor vehicles are anticipated to reap half of the safety benefits of AVs since one of the two parties engaged in the collision depends on technology. Driver mistake is believed to be responsible for more than 90% of all collisions. Human factors like inattention, distraction, or excessive speed frequently contribute to crashes and the severity of injuries. Designing a vehicle system for AD cars that can safely handle nearly all driving situations presents a significant challenge. One aspect of this challenge is the recognition of humans and other objects on the roadway, which is more complex for AD cars compared to humans. Fagnant and Kockelman (2015) state that even in a perfect setting of AD there might be situations where crashes are unavoidable and need to be handled by a human driver. Therefore, it is crucial to be able to easily take over control of driving in certain situations.

Important aspect to take into consideration during the development of the final steering device would be that the interplay between car and driver could contribute to less accidents if balanced

and advances enough, where the development of systems such as active and passive safety systems should be taken into consideration.

## **2.6. Summary of Framework**

One of the key takeaways from the framework is that the level of automated driving (level four) determines what type of NDRT the driver could attend to while in AD mode and that takeover situations needs to be smooth and easy to understand with clear indications and requests, to make the driver feel safe, in control and trusting the car. The feedback and feedforward need to be relevant for the driver when driving and placed within eyesight, implying that presented information should consist of “what” and “why”. The steering device needs to be designed for sustainable use for as many as possible, to minimize potential misuse or hazards. To further create trust and sustainable use the steering device needs to be attractive and somewhat familiar to the user. The last key takeaway is that the driver must be protected and safe, actively, and passively, through the cars safety systems no matter of the steering devices’ placement or form.

### 3. METHODOLOGY

The project has followed a product development process with a user centered design approach (Interaction design foundation, n.d.), involving participants to express what future steering device is desired to use in AD cars. The project was structured in five phases – pre-study, development loop one, development loop two, evaluation, and development loop three. The development loops functioned as iteration to elaborate with concepts and to refine the final concept of a steering device, based on feedback from potential future users. See Figure 2 for a flow chart of the product development process.

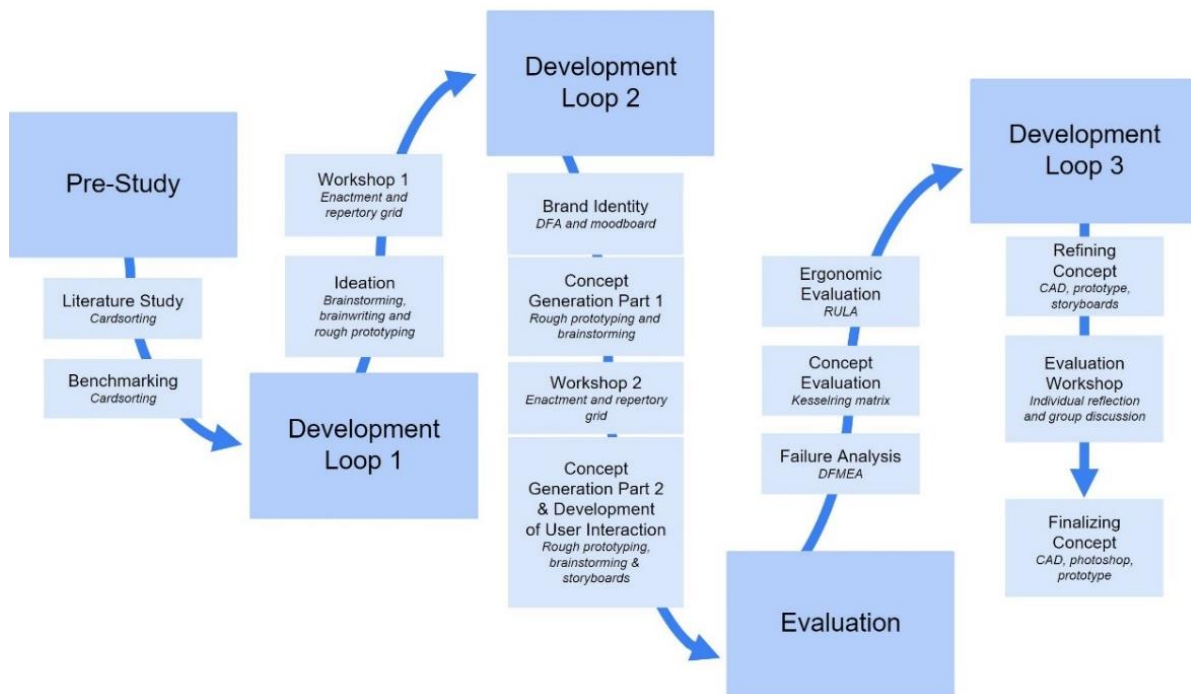


Figure 2 - Flow chart of the project. Authors' own figure.

#### 3.1. Pre-Study

The pre-study was conducted to learn about expectations, requirements and circumstances related to the project's aim, to scope the project and act as a basis for the product development. The flowchart of the project can be directly translated to the product development process with a user centered design approach (Interaction design foundation, n.d.). Each loop has been heavily founded on feedback from each workshop with potential future users to understand how to develop the final concept. See Figure 3 for a user centered design process of the product development.

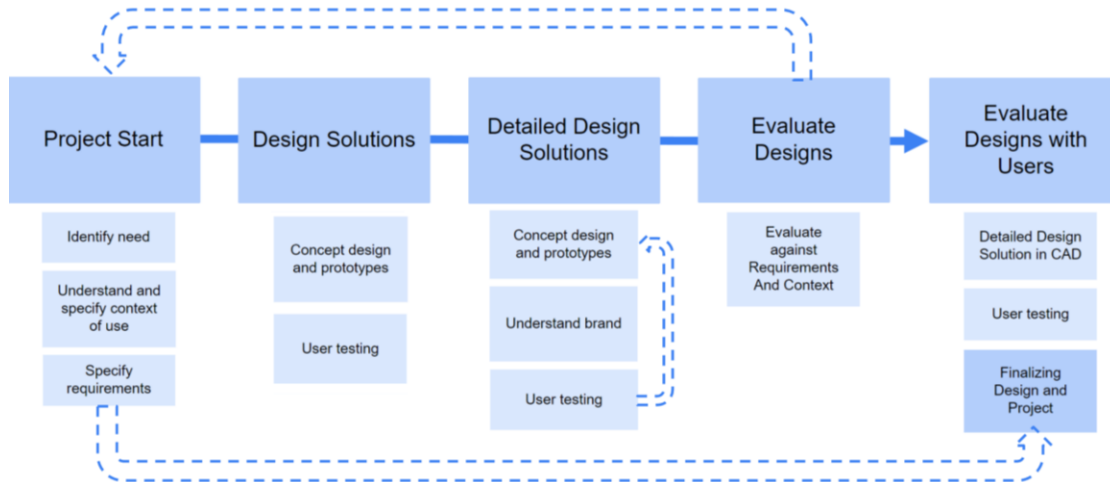


Figure 3 - The development process with a user centered design approach. Authors' own figure.

### 3.1.1. Literature Study

A literature study (Snyder, 2019) was conducted during the pre-study to gain knowledge of what the pre-conditions were for designing a future steering device for AD cars. Relevant books, articles, and research studies were found through keyword searching at Chalmers library and Google scholars. Keywords used for searching sources were automated driving, user experience, airbags, steer-by-wire, automated cars, steering devices, roominess, and anthropometrics. The literature study gave knowledge about automated driving, user's expectations of steering devices and the expected context of use, as well as knowledge within safety and sustainability aspects.

The literature study was a recurrent method along the project to complement the knowledge. It was narrowed down to focus more on details considering ergonomics, safety, and users' experiences. Card sorting (Spencer, 2009) was used during the literature study to sort information, identify gaps, find patterns, and important key factors. It enabled analysis and discussions of what was important to implement in the project and generated discernment of requirements to consider when developing a steering device. The insights from the literature study were summarized in a design brief for the final concept.

### 3.1.2. Benchmarking

Benchmarking (Doumeingts & Browne, 1997) was used in the pre-study to get an understanding of what type of steering devices for cars and other vehicles exist on the market today. It also gave insights on futuristic concepts of steering devices. The gathered data was clustered into different sections depending on their usage principles, shapes, steering and grip with card sorting (Spencer, 2009). Similarities and differences between the steering devices were noted. The method was conducted as a market analysis and the results from the benchmarking were used when defining principle solutions for the design brief.

## **3.2. Development Loop 1**

The purpose of the first development loop was to start the ideation and development of steering devices. The activities in the loop were based on insights and learnings from the pre-study compiled in chapter 4.1. The ideation was evaluated in a workshop with potential users.

### **3.2.1. Ideation**

Brainstorming (Österlin, 2016) was used during the first development loop to start generating rough concepts of steering devices. The focus was to ideate on the overall shape of the steering device, the usage principle of the steering, different grips and to elaborate with the principle solutions in chapter 4.1.4. The brainstorming was done individually through rough sketches and through brainwriting (Österlin, 2016), where the project team elaborated on each other's ideas. The chosen ideas to evaluate in the first workshop were further brainstormed and elaborated through the creation of rough prototypes (Chua et al., 2003). The rough prototypes gave a physical representation of the concepts, to further examine the overall feeling, gripping opportunities, and proportions of the steering devices.

### **3.2.2. Workshop 1**

The purpose of the first workshop (Vavoula & Sharples, 2007) was to test the ideated concepts in terms of what felt intuitive, easy-to-use, and fitting for the future context of use. It was important to gain an overall knowledge of potential users' attitudes and expectations towards AD cars to be able to meet these needs and wishes in the future. The selection of participants took place through a mass mail to employees of the client with less experience in design-related work, where they could register their interest in joining the workshop. The project team strived to include a variety of participants to receive representative insights to the project, but due to dropouts the number of participants decreased to half the intended amount. Four participants were present at the workshop. All were men and their driving behaviors were much alike, frequently driving to and from work, or when running errands.

The workshop consisted of two activities, an enactment scenario, and a repertory grid. Four of the rough prototypes generated from the ideation were evaluated in the workshop. Before starting, a short presentation of the purpose of the project and the future context was given to the participants, to give them an overview of the workshop's purpose. To get detailed input semi-structured interviews (Flick et al., 2004) were used during the workshop. See the questions below:

- How does the steering device feel?
- Do you feel safe when you're using the steering device?
- What do you want to do while you're in AD mode?

- Do you feel that you have control of the vehicle?
- How is the grip?
- Do you feel comfortable?
- What do you think of the placement of the steering device?

Observations functioned as a complement to the interviews, to gather qualitative data and trace latent needs of the participants. The observations ran during both the enactment activity and the repertory grid. See the observation points below:

- What feels intuitive?
- How do the participants use the steering device?
- Does the project team's intended thought on how to use the steering device differ from how the participants use it?
- In case of yes, how?
- How are the participants positioned relative to the steering device?
- Do the participants change position during AD mode?
- What functions do the participants expect to have or wish for?
- How do they expect the transition phase to work?
- How is safety perceived when steering with one or two hands?

The participants were asked to think aloud, to enable discussions about the steering devices, steering functions, future adjustments of the presented concepts, and the participants perception of the context of use.

The enactment (Pettersson & Ju, 2017) activity was designed to be quick to get direct response on what felt intuitive to use when steering future AD cars. The participants were asked to position and use the steering device as they wished, with or without additional provided functions (consisting of an AD button, blinkers buttons or stalks and a horn button). The participants were supposed to engage and act as if they were driving an AD car with the steering device. They were shown a road trip video they had to follow under the scenario as an enabler with additional guidance from one member in the project team. The team member gave them instructions on the car interaction, when they had to switch driver, stop, etc. The enactment scenario was used to get the participants to envision themselves in the context of the future and familiarize themselves with how the concepts would fit in the context.

See Figure 4 for the enactment environment, all participants had given consent to be recorded, and to use the material gathered. The participants tested two concepts each, since there was limited time. During the scenario, the participants who were not driving acted as passengers in the car, to make the context of use more realistic.



a) Set environment of one of the two cars. b) Enactment taking place with the participants.

Figure 4 - Enactment activity, workshop 1. Authors' own pictures.

The method repertory grid (Hiort af Ornäs & Persson, 2007) was used in the workshop as a group activity to evaluate the concepts further based on the participants experiences from the enactment. The grid was centered around a few key aspects from the benchmarking, considering the design language, comfort, trust, ease-of-use, and relation to the client's brand. The participants were asked to rank each concept on scales as a group and motivate their rankings while discussing. All participants were invited to give input on all the concepts even though they had not tested all of them in the enactment activity. As enablers for the discussion, the rough prototypes were available to be further tested during the repertory grid.

### 3.3. Development Loop 2

The purpose of the second loop was to elaborate with the concepts' form language and user interaction. The development of the form language was conducted through the methods design format analysis and moodboard. The loop also contained an evaluation of the concepts via a workshop. The results were used when constructing the user interaction with storyboards.

#### 3.3.1. Brand Identity

The second development loop contained a design format analysis (DFA) (Karjalainen, 2007) with the purpose of getting an understanding of the client's form language and brand identity. This knowledge was important to gain to develop a concept in line with the client's product portfolio. Through the DFA, typical form elements of the client and their interior designs of their most recent cars were analyzed. The scope of the project narrowed the method down to only taking the space around the steering wheel and the seating into account during the analysis. For each car, a picture of the surrounding space of the steering wheel and one picture of the seating

were analyzed. The DFA was conducted in four steps, starting with locating valuable design elements for each picture. In the second step, the design elements were placed in matrixes and ranked in comparison to each other according to their importance for the client's design language. The three highest ranked elements from each matrix were then ranked according to the overall occurrence in the product family. The two highest ranked elements were located and used in the final step. The last step ranked how much all of the pictures expressed the design language of the client and what design elements were the most valuable ones. The results of the highest ranked design elements and interior picture from the DFA were used as a base for the moodboard, and as a tool to design a concept in line with the client's identified brand.

A moodboard (Johannesson et al., 2013) was developed during the second development loop to give inspiration to the concept generation with influences from the client's design language. The pictures in the moodboard were chosen based on the results of the DFA and consisted of design elements related to the interior design of the client's current car models. The method gave inspiration and enabled further reflections regarding what form elements the client applies, and how further concepts could be designed to align with it.

### **3.3.2. Concept Generation Part 1**

The two highest ranked principle solutions from the first development loop, were elaborated through brainstorming (Österlin, 2016). The brainstorming was based on input from workshop 1, the DFA and the moodboard. Rough prototyping (Chua et al., 2003) was used to brainstorm, where different variations of the two principle solutions were generated with styrofoam models. The variation between the concepts was on different grips, curvatures, cross sections, buttons, and their placement.

### **3.3.3. Workshop 2**

Four of the generated concepts were tested by participants in a second workshop (Vavoula & Sharples, 2007). The workshop gave additional knowledge of potential users' attitudes and expectations towards AD cars. The selection of participants took place through a mass mail to employees of the client with less experience in design-related work, where they could register their interest in joining the workshop. The project team strived to include a variety of participants in the workshop to receive representative insight from potential users, but due to dropouts decreased the number of participants. Three participants were present at the workshop, one man and two women. Their driving behaviors differed from always driving to and from work, only driving when running errands, and to only driving on special occasions, e.g., on holiday.

The goal of the second workshop was to get feedback on what was preferred in regards of the steering devices' size, placement, curvatures, grip, and usage principle including placement of

buttons. Semi-structured interviews (Flick et al., 2004) were used during the workshop. See questions below:

- How does the steering device feel?
- What do you think of the size of the steering device?
- What do you think of the placement of the steering device?
- What do you think of the placement of the buttons?
- Can you reach everything you need?
- What do you think of the shape?
- Is there any difference in the steering feeling between the first and the second steering device?
- Do you feel safe when you're using the steering device?
- Do you feel that you have control of the vehicle?
- Do you feel comfortable?
- What do you think of the grip?
- What do you want to do while you're in AD mode?

The interview questions were complemented with observations to gather qualitative data and trace latent needs of the participants. The needs of the participants were extracted from reoccurring answers and behaviors from the pre-study, the first workshop, and the second workshop. The observations ran during both the enactment and the repertory grid. See observation points below:

- What do the participants think of the grip and shape of the steering device?
- How do they use the steering device?
- Does the usage principle differ from the project team's idea of how to use it?
- Do the participants change their grip when using the steering device?
- In that case, in what way and how often?
- How are the participants positioned relative to the steering device?
- Do the participants change position during AD mode?
- How do the participants imagine the transition phase to work?
- What functionality related to driving does the participants imagine having?
- Is there some functionality missing?

The participants were asked to think out loud during the activities to easily understand their actions and thoughts on the concepts. The enactment (Pettersson & Ju, 2017) of workshop two was designed similar to workshop one but the participants were more limited in the extent of freedom. The concepts in the second workshop were rough prototypes created in the concept generation. They were fixed in a specific position with set functions for AD, blinkers, and horn, which were pre-installed by the project team. See Figure 5 for the enactment environment, all participants have given consent to be recorded, and to use the material gathered. Otherwise, the

participants were free to choose how they wanted to move the device to steer, how the transition phase worked and other matters.

The method repertory grid (Hiort af Ornäs & Persson, 2007) was used in the workshop as a group activity to evaluate the concepts further based on the participants experiences from the enactment. The method was used in the same way as during the first workshop.



*a) Set environment of one of the two cars of the enactment.*



*b) Enactment taking place with the participants.*



*c) Enactment taking place with the participants.*

*Figure 5 - Enactment activity, workshop 2. Authors' own pictures.*

### **3.3.4. Concept Generation Part 2 & Development of User Interaction**

The highest rated concepts from workshop 2 were elaborated through brainstorming (Österlin, 2016). The brainstorming was based on input from workshop 2 and the moodboard and concerned usage principles, proportions, and comfort. Rough prototyping (Chua et al., 2003) was used to brainstorm variations of the concepts in styrofoam.

Storyboards (Saffer, 2010) were created to analyze and define the interaction of the concepts. They were used to elaborate with the placement of buttons, the user interaction, and the ability to adjust the steering device. They worked as an enabler for further discussions regarding what concept to continue with for evaluation.

## **3.4. Evaluation**

This phase focused on evaluation and narrowing down the concepts to the most suitable concept for further refining as a final concept. The evaluation consisted of the methods design failure modes and effect analysis, Kesselring matrix and an ergonomic evaluation.

### **3.4.1. Failure Analysis**

The concepts from the second development loop were evaluated with a design failure modes and effects analysis (DFMEA) (Sellappan et al., 2015) to identify and evaluate potential errors of functions, requirements, and limitations of the concepts. The method was limited to not include manufacturing processes or material selection but focused on evaluating potential errors within safety and interaction. The requirements from chapter 4.1.3 were used with some adjustments as evaluation criteria in the DFMEA, to identify errors and their potential causes, and were later discussed and applied on the concepts from the second development loop. The output from the method was acknowledging aspects to take into consideration during the refining process of the final concept to counteract risk of failure.

### **3.4.2. Concept Evaluation**

A Kesselring matrix (Johannesson et al., 2013) was used to evaluate the concepts from the second development loop and to decide what concept to proceed with as the final concept. The Kesselring matrix was based on the requirements from chapter 4.1.3 with some adjustments to make them fit as evaluation criteria. The criteria were divided into different categories where some were weighted as more important compared to the others. The DFMEA acted as a support when weighing the criteria.

The matrix was analyzed in three different ways consisting of an analysis of the total ranking of the concepts, an analysis of the ranking for each category and an analysis of the concepts that scored the highest in terms of the highest weighted criteria. The analyses together with input from the client laid as base for the decision of what concept to precede with.

### **3.4.3. Ergonomic Evaluation**

The resulting concept to precede with after the Kesselring matrix needed further evaluation in terms of the usage principle. In other words, how the driver uses the steering device to steer left and right when driving. This was done with a Rapid Upper Limb Assessment (RULA) (Stanton et al., 2004), to investigate which movement was perceived as generating the least physical stress on the upper body. Prototypes with three different usage principles were used during the evaluation of different steering movements. The results of the RULA were analyzed together with the client and laid the basis for the decision of the final concept.

### **3.5. Development Loop 3**

The third development loop focused on refining the concept's form language, the user interaction, and the safety features of the concept. The purpose of the loop was to deliver the final concept.

#### **3.5.1. Refining the Concept**

The chosen concept from the evaluation was refined according to the output from the evaluation methods. Computer aided modelling (Johannesson et al., 2013) was used to further develop the concept that won in the ergonomic evaluation. The computer aided model (CAD) was used to create a 3D-printed prototype to get a physical representation of the concept to later be used in the evaluation workshop. The different parts of the concept were further developed in terms of transforming curvatures, positions, and proportions.

The interaction between the AD car and the driver was defined through storyboards (Saffer, 2010), which represents a scenario to show steering and transitioning from manual mode to AD mode with the steering device, and a scenario to represent the safety in the event of a collision. The purpose of using storyboards and those interactions was to present the context of transitioning with the steering device and to present passive safety systems, as constructed by the project team.

#### **3.5.2. Evaluation Workshop**

Two workshops (Vavoula & Sharples, 2007) were held to further evaluate and refine the final concept together with the client. The workshops revolved around the client's expectations of the project and if the concept was perceived as desired. Eight participants were present in total (2 women and 6 men), four participants at each workshop (1 woman and 3 men). All participants were from the "Airbags and Steering Wheel" department, involving individuals with expertise in safety linked to airbags and steering wheels. During the workshop activities the participants were asked to share their thoughts freely without the project team steering the conversations.

The workshops started with a presentation of the concept and a description of the context and vision. As enablers for the activities the 3D-printed model, renderings, and the storyboards of the user interaction and collision scenario were provided to each participant. After the presentation, the first activity started, which was an individual reflection. Participants were asked to write down their thoughts about the concept without any discussion with the other participants, to not be colored by the opinions of others. The reflection points they were supposed to consider were as following:

- What do you like about this concept?
- What do you dislike about this concept?
- What could be improved?
- Do you have any other thoughts you would like to share?

After the individual reflection, the participants were summoned in a group discussion about the reflection points. All participants were asked to elaborate on their thoughts and discuss them with one another. Both the individual and group activity provided insights on the concept that needed further refinement before finalizing it. The insights were ranked according to their realizability and were divided into what to fix directly or in future work.

### **3.5.3. Finalization of Concept**

The final concept was refined according to the client's feedback from the evaluation workshop. The refining of the concept involved visualization of the concept through renderings, photoshopped pictures, updating the CAD model and presenting the safety features of the concept. The CAD model was updated according to comfort adjustments the client requested at the evaluation workshop. Renderings were made on detailing and adjusting the concepts angles. Photoshop was used on the renderings to apply split lines, materials, and the client's logotype with inspiration from the moodboard, to make the final concept fit into the client's product portfolio.

## 4. RESULTS

In this chapter the result of the project is presented.

### 4.1. Design Brief

The design brief summarizes the valuable insights from the pre-study. It contains the context, vision, and requirements to relate to during the project. Furthermore, the design brief contains a presentation of principle solutions of steering devices, acting as the starting point for the ideation.

#### 4.1.1. Context

The final concept should be used for lateral steering of AD cars at level 4 in the year 2040. In that year, the car's autonomy is assumed to be responsible for 80% of the driving and the driver for the remaining 20%. Since the car is responsible for most of the journey's driving, it opens the possibility for the driver to attend to NDRTs instead of monitoring the driving. The design of the solution should therefore enable more roominess to be able to attend those activities. The interior setup in the future context is similar to the ones in cars nowadays, see the assumptions of the car's condition in chapter 1.1. The driver is, e.g., going to be positioned in the direction of travel with a passenger seat located next to the driver and the seating in the car can be adjusted to personal preferences, but they can't rotate. The driver is going to be responsible for the drive even though the car will handle plenty of the driving-related decisions by itself. Therefore, it is important that the driver has "the final say" and can instantly take control of the driving if needed or desired to ensure safety. The final concept applies principles of universal design to fit as many users as possible to ensure convenience, comfort, and safety. Additionally, the concept's form giving, and design language should fit into the client's product portfolio.

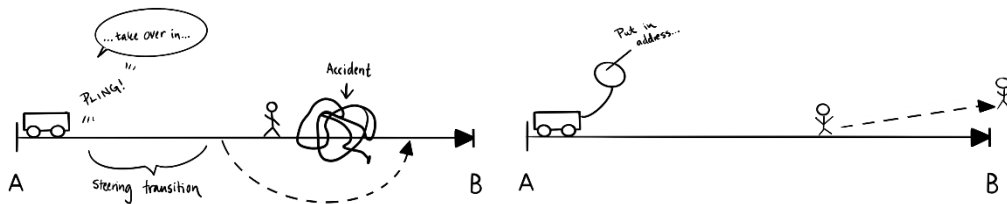
#### Use Cases

The steering device is going to be used for lateral steering, in other words only for turning right and left. Acceleration/braking is done with feet pedals as in today's cars. Driving related functions like blinkers and horn, which are used for communicating with the environment are available when driving. Otherwise, the car is assumed to handle most functionalities automatically, like light settings and windscreen wipers. The steering device has force feedback to enhance the driving experience through giving the driver physical feedback of their steering actions by providing resistance when steering. Additionally, to provide a consistent feeling and response when steering, the steering device is going to be speed dependent. In other words, the force needed to turn the wheels varies with the speed of the car. When driving at low speeds, the steering device needs less effort to turn the wheels. Conversely, when driving at high speeds on a highway, the steering wheel demands more effort to turn the wheels due to the increased aerodynamic forces affecting the vehicle. These feedback elements are expected to enhance the users' experience when they are using the steering device.

The use cases in Figure 6 show situations when the AD car handles the driving and indicates that the driver needs to do a steering takeover. Takeover situations have been investigated during the project, since they can impact the driver's feeling of being in control which in turns can have a large impact on the safety.

The takeover situations can be divided into intended and unintended steering takeovers, depending on if the takeover situation can be predicted by the car in advance or not. During an intended steering takeover, the driver is given enough time to prepare for the takeover, unlike during an unintended steering takeover where the situation requires a more sudden takeover from the driver and hence a shorter preparation time for the transition phase. Drivers will be exposed to both types of takeover situations during travel, thus the interaction between car and driver needs to be adapted according to the type of situation to give the driver an optimal preparedness for the transition. This has an impact on the design of the final concept as it sets expectations on how accessible the steering device should be when traveling in AD mode as well as how the car and driver should communicate to ensure who has the control. How well the transition phases in the takeover situations are constructed will possibly affect the users perceived behavioral control of the steering device.

An unintended steering takeover can for example be when the driver needs to take control when passing a road accident, Figure 6 a), managing an animal crossing, driving in bad weather conditions, or approaching a crowd of people. An intended steering takeover can for example be when the driver prepares to take over control to pick up a friend on the move, Figure 6 b), chooses a parking spot in town, does a spontaneous detour to buy coffee, or when the car predicts that the last bit of the trip has bad road conditions.



a) Unintended steering takeover "driving past a road accident". b) Intended steering takeover "picking up a friend on the move".

Figure 6 - Use cases. Authors' own figures.

### 4.1.2. Vision

The vision of the final concept is:

*“A lateral steering device which is intuitive, easy to access, comfortable, and safe to use for an AD car in the year 2040. It creates user confidence for the driver through its attractive design, that is in line with the client’s design language. The steering device enables roominess, and experiences of attending to NDRTs during the travels with the AD car in a convenient way. The steering device needs to give the driver a feeling of control yet trust.”*

### 4.1.3. Requirements

The following section presents the requirements (Table 2) which have been considered during the development of the final concept. The requirements are arranged according to overall categories.

*Table 2 - Requirement Specification. Authors’ own table.*

<b>Category:</b>	<b>Function:</b>	<b>Requirement:</b>	<b>Source:</b>
Steering Functionality	Provide lateral steering.	The steering device is constructed for lateral steering.	1. Introduction
	Provide opportunity to activate automated mode.	Button for activation/deactivation of AD mode.	1. Introduction
	Provide the ability to communicate with the environment.	Buttons for blinkers and horn.	2.4.2. Cognitive Comfort - Ease-of-use
Feeling of Control	Give clear indications on when the driver has control, to ensure perceived control.	Indications through force feedback and information on screen, to not risk the driver overriding the system.	Borenstein (2017) & 2.2.2. Control

	Give the driver enough preparation time for transition and processing occurring events.	Give indications for when a takeover or handover is about to happen, at least 10 second before transition.	Pettersson & Karlsson (2015) & Melcher et al. (2015) & Kraus et al. (2018) & 2.2.2. Control & 2.1.1. Transition Phase
Safety of the Driver	Airbags should protect the driver.	The safety of the driver should not decrease from today's safety.  The design, position, and time of the airbag should be adapted according to the design of the steering device and the new context of use.	Fagnant and Kockelman (2015) & 2.3. Safety  2.3.1. Airbags
	Provide the ability to instantly take control of the lateral steering.	Constructed sequence of cognitive and physical actions for the transition phase, including timeframe and personal adjustment.  Provide handling “kill switch” to switch to manual mode.  All primary lateral steering functions are available in manual mode.	2.1.1. Transition Phase & 2.4.2. Cognitive Comfort  2.2.2. Control & Pettersson (2017, p.3)  2.2.1. Trust & Acceptance
	Provide low cognitive load.	Few commands to handle during the transition phase.  Functions that are easy to understand.	2.4.2. Cognitive Comfort  2.4.2. Cognitive Comfort - Ease-of-use
	Ensure correct usage.	Connect the feedforward of functions with logical feedback of actions.  Minimize risk of intervening with the driving during AD mode.  No risk of accidentally touching buttons when using the steering device.	Wensveen (2004) & 2.4.2. Cognitive Comfort - Ease-of-use  2.2.3. Universal Design  2.2.3 Universal Design

Eyes on the Road	Have continual presence of traditional driving-related information.	All primary driving-related information should be in one place.	2.4.2. Cognitive Comfort - Motion Sickness
	Provide feedback of actions without looking.	Avoid informational overload.	2.4.2. Cognitive Comfort
		Use physical buttons to let the driver keep the eyes on the road.	2.4.2. Cognitive Comfort - Ease-of Use
		Use haptic/visual feedback for actions.	2.4.2. Cognitive Comfort - Ease-of Use
Offer Comfort	Guarantee a comfortable grip and usage of the steering device for different sizes of hands.	Investigate with anthropometric measurements and the client what is sufficient.	2.4.1. Ergonomics of Steering Devices - Anthropometrics
		Avoid sharp edges in the steering device design that feels uncomfortable.	2.4. Ergonomics
	Provide low effort and minimum strain on the body.	Strive for low muscle activity and few angles/rotations of joints when using the steering device.	2.4. Ergonomics
	Strive for a “Universal design”	Enable more people to use cars through the design of the steering device.	2.2.3. Universal Design
		Provide comfortable reachability for the user’s hands of the steering functions.	2.2.3. Universal Design
	Prevent sensor conflict to avoid motion sickness.	Let the driver sense the steering while in AD mode.	2.4.2. Cognitive Comfort - Motion Sickness
		Give the driver sensory cues of the trip during AD mode.	2.4.2. Cognitive Comfort - Motion Sickness

		Put information in central vision and at eye level so the driver at the same time can keep track of the road with peripheral vision during AD mode to help counteract motion sickness.	2.4.2. Cognitive Comfort - Motion Sickness
	Provide a comfortable steering feeling for the driver.	Implement force feedback in the steering device and speed dependent steering.	2.4.2. Cognitive Comfort - Ease-of-use
Roominess for NDRTs	Provide the opportunity to focus on NDRTs when in AD mode.	The driver should be able to attend to NDRTs within relaxation, working, and socializing.  Adjustable steering device for physical differences and/or preferences.	2.1. Automated Driving & Schartmüller et al. (2019)  2.2.3. Universal Design
	Increase the space for the driver through the design and position of the steering device.	Implement steer-by-wire to gain more design freedom.  Change the design of the airbag and/or the position to make more space for the driver.	2.1.2. Steer-by-Wire  2.3. Safety
Trust Building	The steering device should be intuitive.	A familiar design or interface of the steering device works as an enabler for ease-of-use.  The driver should get a perceived behavioral control through looking at it.	2.2.1. Trust & Acceptance  2.2.2. Control
	Reliability should be expressed through the form language of the steering device.	Soft and friendly shapes are preferred over sharp and aggressive form language.	2.2.1. Trust & Acceptance
	Use attractive design and high quality to increase the user trust of the steering device.	Strong connection to the client's form language to connect with the strong position of the brand.	2.2.1. Trust & Acceptance

#### 4.1.4. Principle Solutions

This section presents the results of the benchmarking, consisting of various gadgets and consoles that are used to operate things during activities or for transportation. See Figure 7 for various unsorted devices.

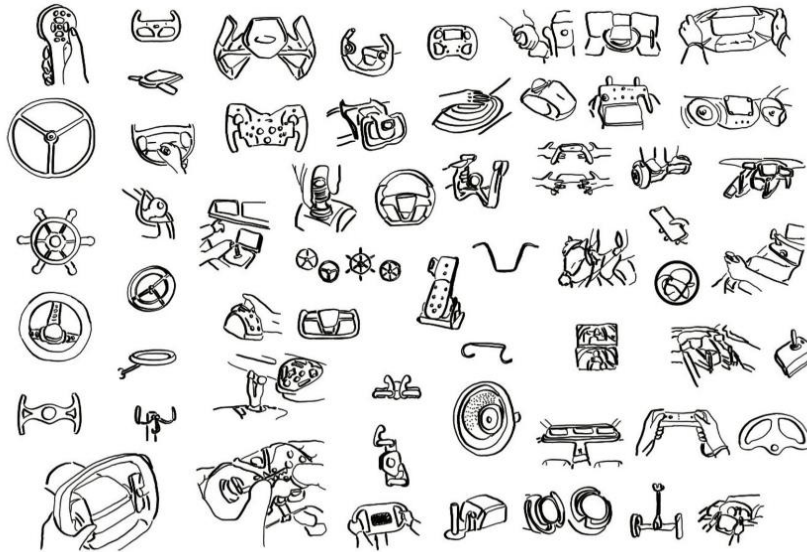
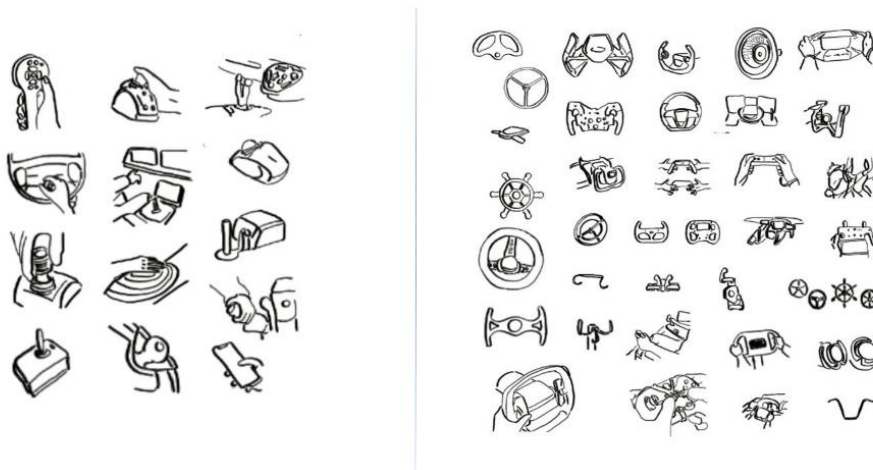


Figure 7 - Investigated steering devices, unsorted. Authors' own figure.

The devices are arranged into different fields of principle solutions for steering, where Figure 8 shows the devices sorted into one-grip steering and two-grip steering, alternatively if the driver can choose to steer with one or two hands.



a) Single handed steering devices.

b) Two-handed steering devices.

Figure 8 - Steering devices. Authors' own figure.

Figure 9 presents other concepts that are relevant steering devices and are categorized according to their shape and function. The figures range from vehicles like trains and bicycles, to gaming controls and steering with one's feet. The different categories identified are listed below, starting from the top, going left to right.

- |                                 |                         |
|---------------------------------|-------------------------|
| a) Levers                       | g) Push and Pull        |
| b) Games                        | h) By foot              |
| c) Yoke / Formula 1             | i) Steering ball        |
| d) One joystick                 | j) Handlebar            |
| e) Others (e.g., voice command) | k) Mini steering device |
| f) Touch                        | l) Round inspired       |



Figure 9 - Steering devices sorted in shape and function. Authors' own figure.

## 4.2. Results of Development Loop 1

The chapter presents the results from the initial development loop, with focus on ideation and potential future users' attitudes. Development loop 1 was based on insights from the design brief. The ideation of principle solutions was targeted on exploring new ideas with focus on use, function, and form. The workshop resulted in a deeper understanding of users' thoughts and attitudes regarding future steering devices.

### 4.2.1. Ideation of Principle Solutions

The ideation of principle solutions resulted in a variety of ideas, mainly focused on exploring the following aspects:

- Form varieties of principle solutions.
- Different positions of the steering device relative to the driver.
- Different rotations axis of the steering device.
- Variants of the steering device grip.
- Types of usage principles, e.g., steering with ‘push and pull’ or on a rotation axis.

The ideation resulted in varying steering devices, in Figure 10 divided into clusters according to the previously mentioned aspects to explore. The steering devices were divided into e.g., if the driver steers with one or two hands, if the steering device is positioned in front of the driver or to the side, and on what axis the steering device was supposed to be functioning. Figure 10 shows 52 rough sketches of steering devices with varying levels of innovation. An overall discussion of the ideation resulted in testing concepts similar to joysticks, steering wheels, handlebars, and balancing boards (e.g., game controls) during the first workshop.

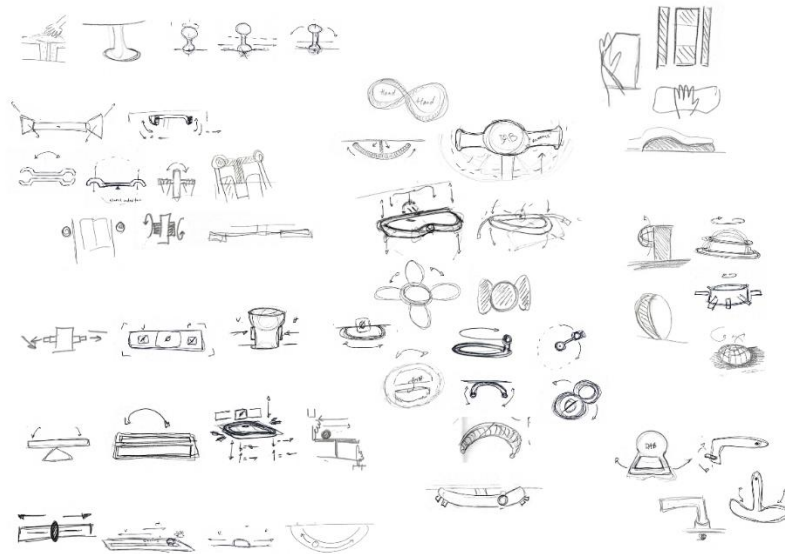


Figure 10 - Brainstormed steering devices with focus on varying functions, sizes, and forms. Authors' own figure.

### 4.2.2. Workshop 1

The principle solution workshop was the first of two workshops with potential future users. Four of the concepts developed from ideation of principle solutions were tested in the workshop. They prototypes were a smaller steering wheel (concept A), a handlebar (concept B), a joystick (concept C) and a brick (concept D) inspired by game controls and balancing boards. The concepts were tested as rough prototypes during the workshop, see Figure 11. These concepts

were chosen based on the clustering's made from the ideation and benchmarking, where similarities could be seen between round inspired concepts, yoke/formula 1, levers and handlebars, se prototypes A, B and C. Prototype D was chosen to test something less familiar. See Appendix 1, for measurements of the prototypes used in the first workshop.

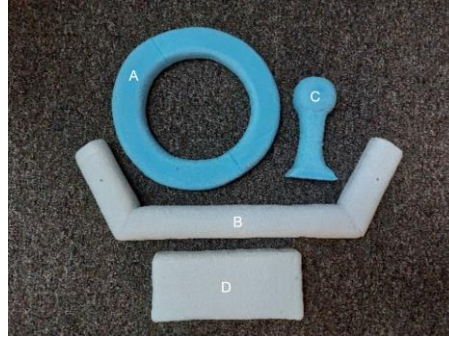






Figure 11 - Prototypes of the tested principle solutions. Authors' own picture.

Each of the participants enacted with two out of the four concepts and since they enacted using varying concepts, it led to different perceptions of the concepts' functionality and placement. The participants tested e.g., concept B differently, some used it as a handlebar and some as a joystick, which resulted in varying opinions of it. The workshop participant's collective scoring of the concepts is shown in Table 3. The participants agreed on the scoring although their hand sizes and shoulder widths differed. The results of the repertory grid showed that concept B (used as a joystick instead of a handle) was the highest ranked concept together with concept D with concept A and C close to it. Concept B used as a handlebar was the lowest ranked concept with the motivation that the handlebar version of concept B was much less appreciated than the joystick version. The overall motivation to the ranking of concept A was that it felt familiar but somewhat boring and that concept C was perceived as unattractive.

Table 3 - Repertory grid with scores from workshop participants from workshop 1. Authors' own table.

	(1)	(2)	(3)	(4)	(5)	
						
Not easy-to-use	5	2	5	4	5	Easy-to-use
Uncomfortable Grip	3.5 - 4	2	5	4	4	Comfortable Grip
Not trustworthy	5	2	5	5	5	Trustworthy
Unattractive Design	3	3	4	3	4	Attractive Design
Not Volvo	Everyone can be perceived as Volvo after alterations					Volvo
Total:	17	9	19	16	18	

Regarding the concepts' intuitiveness and ease-of-use, concept A, B used as a joystick and D were found to be intuitive by the participants, where concept A and D felt the most intuitive. It was motivated by A's similarity to today's conventional steering wheel and that B's (used as a

joystick) cool and futuristic appearance added to its intuitive feeling. Another valuable insight concerned the placement of the steering device. The most natural placement of the steering device was in front of the participants torso or on their right side. The participants expressed appreciation of having their eyes on the road also during AD mode and they discussed the wish to have functions placed on the steering device to add to their ease of usefulness.

Concerning the roominess of the driver, the participants expressed their appreciation of it, which was enabled by using a smaller steering device, though all participants wanted the device to be always within reach if they needed to take over steering. While using concept B as a joystick and concept C, the participants tilted the steering device to the side to indicate activation of AD mode, which added to the roominess. Concept A and D were often tested in fixed positions, similar to today's steering wheel, with the possibility to retract when AD mode was activated. The participants initiated to push the prototypes further away from them, to create more roominess.

The concepts' safety was valued as highly important, yet the participants expressed that the feeling of safety was little affected by using one or two hands when steering. The feeling of stability and sturdiness was instead discussed in regards of safety and were affected by using a one-handed grip or a two-handed grip when steering. This based on potential forces when steering, support when steering or vibrations in the device.

#### **4.2.3. Takeaways from Development Loop 1**

Takeaways from the initial development loop was that the ideated ideas from the ideation resulted in clusters of the overall form, function, and impression of the steering devices, similar to the clusters in the benchmarking. Prototypes that were developed and later tested in workshop 1, based on these clusters, gave insights on potential future users' attitudes and feelings as can be seen above. The concepts chosen for further development were concept B, a handlebar used as a joystick, and concept D, a brick inspired by balancing boards and game controls. Those concepts were ranked the highest by the participants from the perspective of trust and easy-to-use, with additional discussions regarding roominess.

### **4.3. Results of Development Loop 2**

The following chapter presents the results of development loop 2 and includes an overview of the client's brand identity and form language, as well as further discoveries of potential future users' attitudes of the tested steering devices. Further developed versions of the chosen concepts from development loop 1 are presented inspired by these additional findings.

### 4.3.1. Design Format Analysis (DFA)

The DFA result of the client's brand identity (Figure 12) shows that the highest ranked car in terms of how much it expresses the design language of the client was the EX90, the second ranked was the XC90 and the third ranked was the XC90 Recharge. The highest occurrence of a design element related to the client's brand was "visible and evident split lines". See complete DFA in Appendix 2. The ranking of the most important design elements according to the DFA was:

- Visible and evident split lines
- Big curvatures
- Evident safety functions & contrasting materials, colors, and surface finishes
- Visible logotype

These design elements were then used to create a moodboard, and when evaluating the final concept.

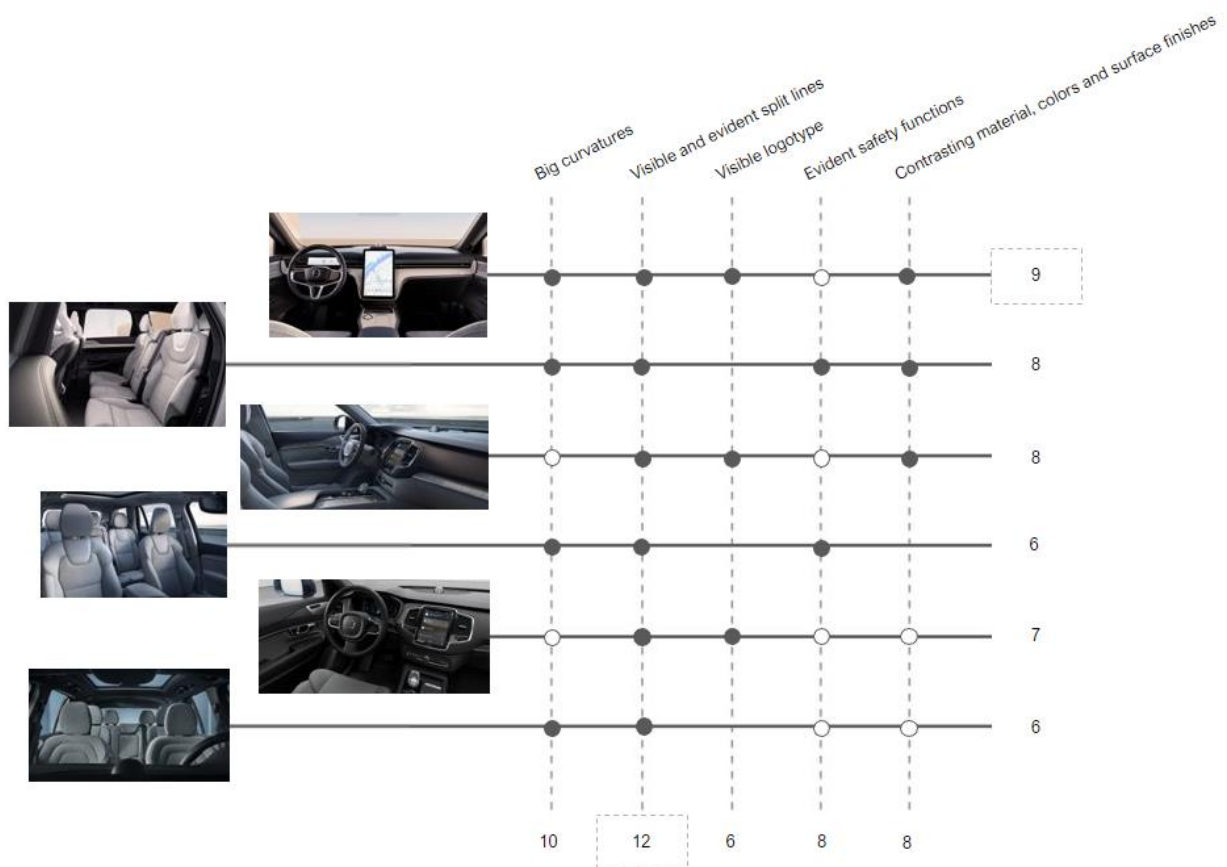


Figure 12 - DFA of the interior and passenger seats of Volvo cars EX90, XC90 and XC90 Recharge. Authors' own figure with product pictures from [www.volvocars.com](http://www.volvocars.com).

### 4.3.2. Moodboard

The moodboard (Figure 13) presents elements of inspiration used as guidance when generating concepts, consisting of a mix of materials, surface finishes, colors, and shapes. The pictures were associated with the most valuable design elements from the DFA expressing the feeling of the client's design language. The design elements were *big curvatures*, *visible and evident split lines*, *visible logotype*, *evident safety functions*, and *contrasting materials, colors, and surface finishes*.

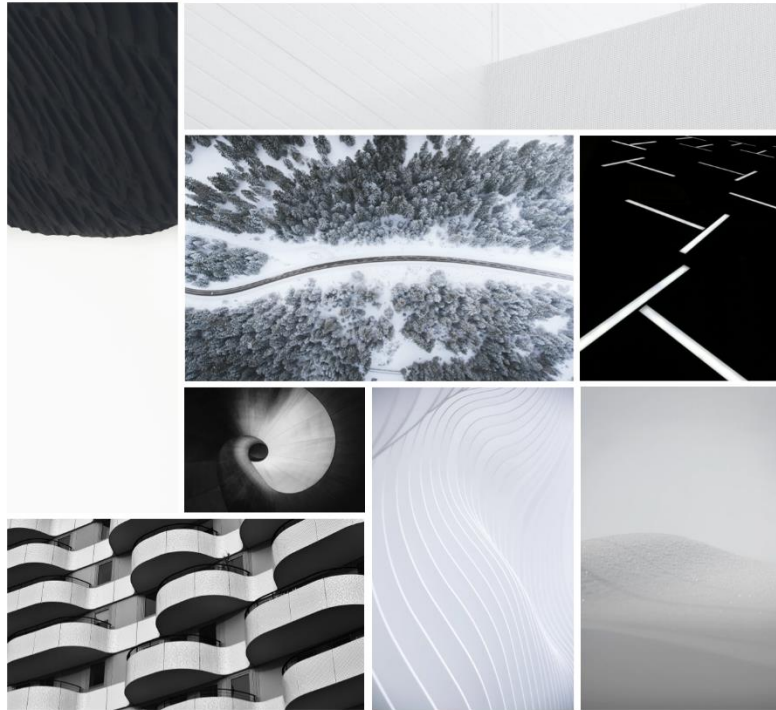


Figure 13 - Moodboard representing Volvos form language. Authors' own figure with pictures from [www.unsplash.com](http://www.unsplash.com).

The design element *big curvatures* were expressed through multiple soft, flowy, and organic shapes and irregular lines which expresses a comfortable and safe atmosphere. Contrasting to the big curvatures, were the design element *visible and evident split lines*, which is presented in the upper right corner of the moodboard with straight lines in different angles connecting to the car interior. The nature landscape picture in the middle of the moodboard represented the design element *visible logotype* since the client strongly connects its brand to the Swedish climate. The design element *evident safety functions* were associated with contrasts since it enables the usage of safety functions, hence the composition of the moodboard's was contrasting pictures. The variety of contrasting pictures in terms of colors, shapes, materials in the moodboard were used to express the design element *contrasting materials, colors, and surface finishes*.

### 4.3.3. Concept Generation Part 1

The generated concepts from the loop were three handlebar joysticks and three rectangular devices named bricks (Figure 14). The design language of the steering devices was inspired by the moodboard and DFA. Main inspiration was the soft and organic shapes, curvatures, and irregular lines. The variety of each brick and joystick was inspired by trying somewhat contrasting shapes of cross sections and curvatures along with the handles, armrests, and edges. The functions that were implemented and tested through different settings on the steering devices were chosen due to their role in communicating with the environment while driving as well as offering AD functionality, see the requirements in 4.1.3. Steering Functionality. These functions were expressed as important to include during manual drive during workshop 1. See Appendix 3, for measurements of the prototypes developed during development loop 2.

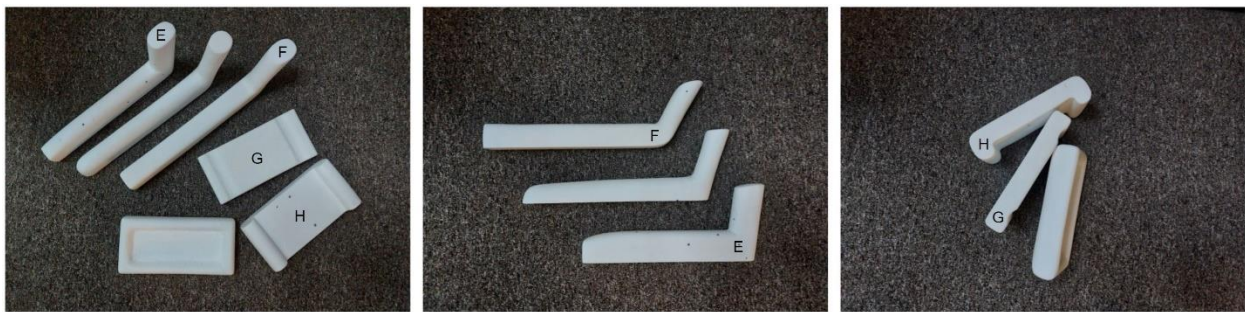


Figure 14 - Prototypes of generated concepts. Authors' own picture.

The joystick concepts differed in terms of their angled handle, the shape of the armrest and the buttons. Concept E had an angled handle of 100 degrees, an oval cross section, and a small blinkers stalk on the side of the handle. Concept F had an angled handle of 120 degrees, a circular cross section, and blinkers buttons on the top of the handle. The third joystick concept had an angled handle of 110 degrees and was otherwise similar to concept F.

The brick concepts differed in terms of their grip, proportions, and buttons. Concept G was a brick with small hollows for grip and a blinkers stalk. Concept H was a brick with more rounded handles on the back with blinkers as buttons on the front. The third brick was a combination of a hollow for grip on the back and the rounded handles.





### 4.3.4. Workshop 2

All the generated concepts were included to some extent in the workshop. However, two joysticks (concept E & F) and two bricks (concept G & H) were tested more throughout since they represented opposite sides of the concept variants. The variants considered grip, curvatures, and proportions. The third variant of both the joysticks and the bricks were assumed to be placed in the middle of the two extremes and was therefore only included as a source of discussion

during the repertory grid. It contributed to further insights on what the participants liked and disliked about concept E, F, G, and H.

The workshop participant’s collective scoring of the concepts is shown in Table 4. The participants agreed on the scoring although their hand sizes and shoulder widths differed. The results of the repertory grid together with input from the enactment activity showed that the highest ranked steering device was concept F, followed by concept H. The two concepts were chosen as basis for further development and to improve their usage, and their designs in terms of making them attractive and in line with the client’s form language.

Table 4 - Repertory grid with scores from workshop 2. Authors’ own table.

(1)					(5)
Not easy-to-use	2	3	4	3	Easy-to-use
Uncomfortable Grip	1	5	2	2	Comfortable Grip
Not trustworthy	2	4	2	4	Trustworthy
Unattractive Design	3	4	2	2	Attractive Design
Not Volvo	1	2	1	1	Volvo
<b>Total:</b>	<b>9</b>	<b>18</b>	<b>11</b>	<b>12</b>	

The workshop gave insight into user needs that needed further development. The needs are listed below:

- There was a need for different grip opportunities when using the steering device. Users do not like to feel forced to have the same grip all the time.
- Users wanted to have the opportunity to adjust the steering device to physical differences and preferences.
- Arm support was essential when using the steering devices to be comfortable as a driver.
- Rounded and organic shapes in the design were regarded as desired since it contributes to a good appearance and increases comfort.
- There was a need to implement force feedback in the steering device and the steering device needed to be speed dependent to give the driver a good sense of steering.
- All of the steering devices’ designs were described as lacking, in terms of expressing the design language of the client.
- The users wanted to get a clear indication from the car if they were in AD or manual mode.

- The users needed to sense where the buttons were placed and what function they held without having to look at them, to keep the driver's eyes on the road.
- Users wanted to have buttons for the blinkers instead of stalks, since it felt old and unattractive with stalks in the future.

### **Development of Handlebar Joysticks**

The workshop results show that concept F was perceived as intuitive and was ranked as the second highest concept (shared with concept G) in terms of easy-to-use. When testing the handlebar joysticks, the users were able to sit relaxed during both manual mode and automated mode. It was expressed by the participants and observed through their changes in sitting positions during the enactment. The participants could during AD mode sit with their legs crossed or slightly directed to the passenger seat without problem. Concept F was most comfortable regarding the grip, with a score of 5 out of 5. The angled handle of 120 degrees was more comfortable compared to the joystick with a smaller angle of 100 degrees (concept E). The wider angle of the handle was also perceived as more attractive. The contact surface of the armrest was more comfortable. The participants expressed a strong need for having a wide, planar, and padded contact surface to rest their arms on, e.g., integrating the joystick with the arm rest. During the workshop, it became clear that the principle of usage for the joysticks needed further investigation, since the users in the first and second workshop did use the joystick differently when steering.

Additional questions regarding misuse situations occurred during the workshop, which were related to safety, which needed further investigation. Questions like, how the steering could be affected in road curves if the driver uses the joystick as support to counteract forces. The size and placement of the joystick's buttons also needed further elaboration to ensure functions within reach, and to prevent accidental use. The participants also discussed that the handle and armrest of the joystick would preferably be adjustable.

### **Development of Bricks**

In comparison, the bricks were questioned in terms of their intuitiveness. In regards of ease-of-use the bricks were discussed on their similarities to the conventional steering wheel, which according to the participants are something deeply rooted in people. Concept H was perceived to have the same usage principle as the conventional steering wheel, excluding the opportunity of varying grips while driving. The participants expressed that they felt forced to have the same grip while using the bricks, which was expressed as a negative and uncomfortable. The small size and lack of support for the arms did put strain in the upper body, mainly noticeable when testing concept G. All participants agreed on this matter even though their shoulder widths differed. The participants also raised concern of crossing one's arms or moving one's arms closer to one's center when making sharp turns, which resulted in discomfort. Size and placement of buttons on the brick needed further testing to provide reachable functions as well as prevention of misuse or accidental usage. The participants often used their thumbs when reaching for functions. In terms of the brick shape, the proportions needed further development, yet the bigger handles presented in concept H gave the participants a feeling of sturdiness and trustworthiness.

### 4.3.5. Concept Generation Part 2

A decision on what type of steering device to continue with, in terms of usage principle and refinement could not be made based merely on the insights from workshop 2. Therefore, the two highest ranked concepts from workshop 2 were elaborated according to the insights.1. The developed storyboards of each concept gave valuable input on the placement of buttons, user interaction, and the ability to adjust the steering device. See Appendix 3, for measurements of the prototypes developed during development loop 2 and see storyboards in Appendix 4.

#### Bricks

One additional version of the brick H was created to elaborate with the width of the steering device. The grip on both versions (H1 & H2) was updated according to the feedback in workshop 2, see Figure 15. Storyboards developed for these concepts were further created to investigate if potential strain in the upper body caused by the brick could be decreased with a broader one. The broader brick could potentially contribute to putting less strain on the upper body when making small turns. The risk of crossing one's arms still existed when steering with both the smaller and broader brick and the concept was therefore in need of further evaluation.



*Figure 15 - Developed prototypes of bricks from workshop 2. The handles of concept H were implemented on these concepts, with differing lengths. Authors' own picture.*

#### Joysticks

The results from workshop 2 showed that further development of the joystick's steering movements on different axis needed to be done. The handlebar joystick F was developed into three versions (F1, F2, F3) with different arm rests, varying handles, and usage principles since it was the highest ranked concept. Inspiration for the form language was gained from the moodboard.

Development of the armrests can be seen in Figure 16. The versions differed in terms of the armrest's height, length, width and radius or curvature of the back of the device for support of the user's underarm.

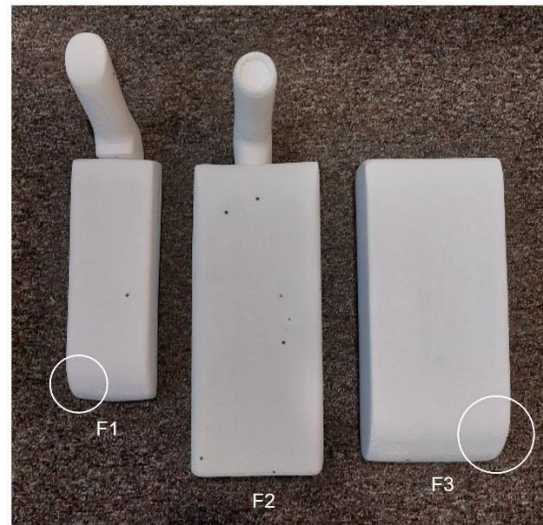
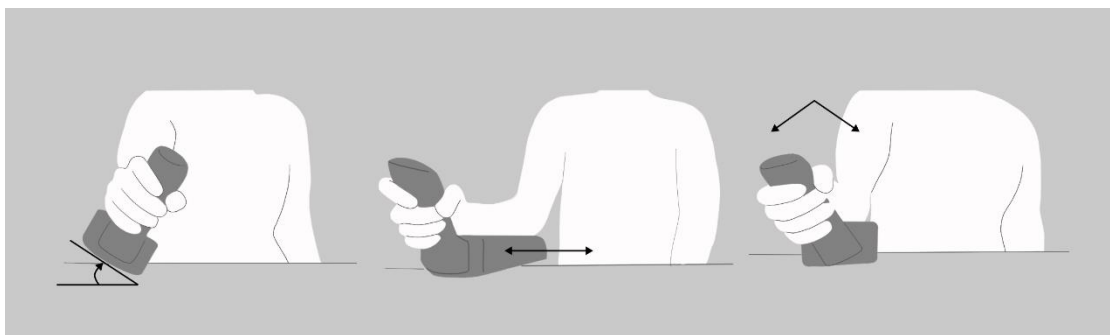


Figure 16 - Developed prototypes of joysticks from workshop 2. The concepts have varying heights, lengths, widths, and radius (marked with red circles). Authors' own picture.

The handle was elaborated to test the comfort and reachability of varying angles and grip opportunities on top of the handle. The different versions of usage principles (Figure 17) were steering by tilting the device left to right 1), steering by sliding the entire device left to right 2), and steering by tilting the handle left to right 3).



1) Steering by tilting. 2) Steering by sliding the steering device. 3) Steering by tilting the handle.

Figure 17 - The different usage principles of the joystick. Authors' own figure.

### **4.3.6. Takeaways from Development Loop 2**

The takeaways from the second development loop were that the DFA and moodboard needed to be involved more in future development of the concepts. The variants from concept generation part 2 needed to be evaluated before deciding what concept to refine as final concept. The feelings, attitudes, and concerns of the participants in workshop 2 did go in line with the attitudes of the participants in workshop 1 and could therefore be further taken into consideration when developing, choosing, and evaluating the final concept.

## **4.4. Evaluation**

The results from the evaluation are presented in this chapter. It includes a risk analysis to understand potential risks of a steering device, further evaluation to narrow down the number of concepts, and an ergonomic evaluation used to choose a final concept.

### **4.4.1. DFMEA**

Several of the current preventative activities that were identified for potential effects and causes of failure in the DFMEA were:

- Further analyzing placement and shape of buttons to minimize the risk of misuse or unintended use, the buttons must still be within reach for the user.
- The form and function of the steering device must feel intuitive when taking control, to minimize the risk of misuse or confusion, hence being a safety hazard.
- Analyze ergonomics for form, usage, and placement of the steering device, to minimize strain on the body of the driver.
- Further decide and analyze how to implement airbags and safety functions for the solution and the user interaction.

Out of 31 potential failure modes, 9 of the potential effects of the failure modes were given high scores of severities, which could in worst case lead to fatality. The current preventative activities for the highest scored failure modes have therefore guided the prioritization of development of the final concept, see Table 5. For the complete DFMEA see Appendix 5.

Table 5 - The most severe effects of failure identified in the DMEA. Authors' own figure.

Potential Effects of the Failure Mode	Potential Causes of the Failure Mode	Current Preventative Activities
The driver is not safe.	The driver does not feel safe, or in control. The driver is not able to drive safely and endangers others.	Consider other safety functions of the car (not just airbags and users' feeling of control).
Airbags do not ensure the safety of the driver.	There is no relevant airbag to implement.	Look up airbags to implement, which are not used to protect the driver in the client's cars nowadays.
	Today's airbags performances are affected by the design of the steering device.	Check if the concepts affect today's airbags.
The transition phase goes wrong.	The driver does not copy with the actions and sequence of transition, hence cannot take control, or will not use the function, which could endanger others.	Analyze how the transition phase should be designed to benefit most people, regarding preparation time, actions, and takeover indications.
The driver cannot control the vehicle correctly and ensure safety.	The steering device has no space for all essential functions or has not included these functions.	Analyze if the primary driving-related functions are available with the design of the steering device.
The transition phase leads to misuse.	The design has not taken "less-is-more" into consideration when balancing the transition load.	Understand how to balance the sensory stimuli, actions, and information with the most necessary steps.
AD is activated during manual mode without knowing.	The AD button is too much within reach.	Consider placing the AD function in an area away from where the hands frequently are moving or in a zone where the driver might touch during AD mode.
The steering device cannot be implemented; hence it is not realizable.	The adaptation and technology do not match the innovation.	Investigate what can be assumed with steer-by-wire.
The steering device is not realizable since it does not fit in the client's product portfolio.	Incorrect choice of material, surface finishes, split line positions, curvatures, contrasts, logotype and evident safety functions.	Analyze the client's needs and preferences further.

#### 4.4.2. Kesselring Matrix

The evaluated concepts in the Kesselring matrix can be seen in Figure 18, where concept F1 is the joystick with fixed armrest, concept H2 is the brick, and concept F2 is the joystick where the armrest is moving with the handle. The ranking in the Kesselring matrix resulted with small margins in between the concepts, both as a whole and in the rankings of each category. The concept choice was based on a thorough analysis of each category together with the client's expectations. Not all criteria from the requirement list were added in the evaluation since they constituted to be the very basis for developing a steering device according to conditions specified in the aim. They were therefore found to be ranked the same for all concepts, not affecting the outcome of the evaluation. The evaluated categories were *Safety*, *Eyes on the road*, *Comfort*, *Roominess*, and *Trust*. See the Kesselring matrix in Table 6.

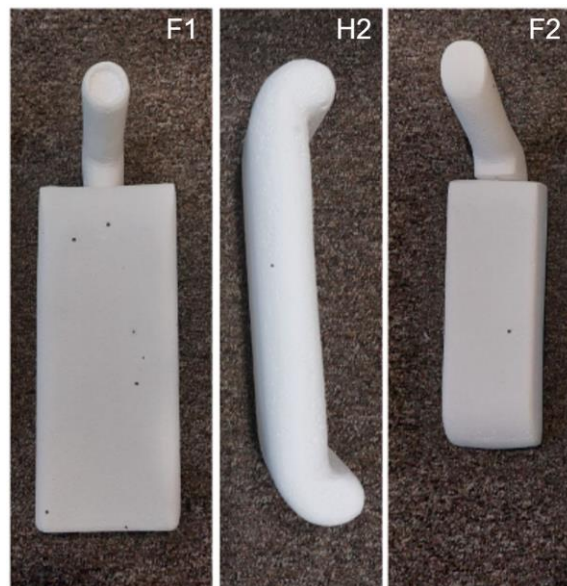


Figure 18 - Evaluated concepts in the Kesselring Matrix. From left to right; Concept F1 (left), Concept H2 (middle), Concept F2 (Right). Authors' own figure.

Concept H2 was ranked with the highest score in the Kesselring matrix with 24 points more than concept F2, and concept F1 was ranked 34 points lower than concept F2. Concept H2 won in 3 out of 5 categories with small variations in the scores, concept F2 won in one of the categories and concept F1 won one of the categories.

Table 6 - Kesselring matrix with evaluation criteria based on the requirement list. Authors' own table.

Category:	Criteria:	Solution Alternative								
		Weight	IDEAL		F1		H2		F2	
			Value	Total (WxV)	V	T	V	T	V	T
Name										
Safety of the Driver	The safety of the driver should not decrease from today's safety.	10	10	100	9	90	9	90	9	90
	Airbags should protect the driver.	10	10	100	9	90	8	80	9	90
	Ability to instantly take control of the lateral steering.	9	10	90	6	54	8	72	7	63
	All primary lateral steering functions are available in manual mode.	10	10	100	8	80	9	90	9	90
	Provides low cognitive strain	8	10	80	8	64	8	64	8	64
	Few commands to handle during the transition phase.	7	10	70	8	56	7	49	8	56
	Functions/buttons are easy to understand.	7	10	70	9	63	8	56	8	56
	Ensure correct usage.	9	10	90	8	72	9	81	8	72
	Low risk of intervening with the driving during AD mode.	9	10	90	9	81	8	72	8	72
No risk of accidentally touching buttons when using the steering device.	7	10	70	6	42	7	49	6	42	
Eyes on the road	All primary driving-related information is placed in one place.	6	10	60	9	54	9	54	9	54
	Physical buttons to keep the eyes on the road.	5	10	50	7	35	8	40	7	35
	Haptic/visual/audio feedback for actions.	7	10	70	8	56	8	56	8	56
Offer comfort	Offers a comfortable grip and usage of the steering device for different sizes of hands.	7	10	70	6	42	7	49	7	49
	Inline with "Universal design"	5	10	50	6	30	7	35	6	30
	Low effort and minimum strain on the body.	8	10	80	7	56	8	64	6	42
	Provides comfortable reachability.	7	10	70	7	49	7	49	7	49
	Gives the driver sensory cues of the trip during AD mode.	7	10	70	7	49	8	56	7	49
	Information in central vision and at eye level.	6	10	60	8	48	7	35	8	48
Roominess	Adjustable steering device	8	10	80	8	64	8	64	7	56
	Increased space/roominess for the driver when in AD.	8	10	80	8	64	6	48	8	64
Trust Building	A familiar design/interface of the steering device.	7	10	70	8	56	9	63	8	56
	Perceived behavioral control through looking at the steering device.	7	10	70	7	49	9	63	8	56
	Has soft and friendly shapes (no hard edges)	7	10	70	5	35	7	49	8	56
	Cohesive with the client's form language	9	10	90	6	54	7	63	8	72
Total:			250	1900	187	1433	196	1491	192	1467
Rank:						3		1		2

From a safety perspective, H2 was ranked the highest, closely followed by F1 and F2. Considering the criteria with a weighting of 10, concept F2 was ranked the highest, including criteria related to safety and airbags. Concept H2 was ranked the highest considering safety aspects with a weight of 9, with a small margin to concept F2, these criteria considered control and correct use. The other safety criteria with a lower weighting consisted of cognitive strain, the transition phase, and buttons, where concept H2 and F2 were ranked the same or with small differences. These aspects were assumed to not have a bigger impact on the final choice since they can be adapted and optimized to fit their purpose equally, not depending on the specific concept.

Considering Eyes on the road, concept H2 was ranked the highest with a margin of 5 points to both concept F1 and F2. In terms of comfort, concept H2 scored highest with concept F1 as second, and concept F2 in third place. From a roominess perspective, concept F1 scores the highest points, with concept F2 second and concept H2 third. In terms of trust, concept F2 scored highest, concept H2 close second and concept F1 last.

Based on the similarities of concept F1 and F2, and the ranking within the criteria of Trust and Roominess, concept F2 (a joystick with more evident curvatures) was chosen to work further with as the final concept. Additionally, concept F2 was considered to go most in line with the clients form language (see Appendix 2 and chapter 4.3.2), when considering big curvatures which was one of the key takeaways from the moodboard and symmetry. Concept H2 was not chosen for further development based on the uncertainty of cognitive strain when turning, and lack of creating roominess. Further analysis on the chosen joystick has to be done in regards of buttons from a safety perspective, the user's ability to instantly take control, and potential strain when using the joystick.

#### **4.4.3. Ergonomic Evaluation**

The RULA evaluations were done on the usage principles when simulating an extreme position during a turn, to understand which concept caused the least physical strain on the body. The pictures in Figure 17 were further used when evaluating the usage principles. From previous activities it was noted that the principle of a regular joystick, similar to usage principle 3), was ranked low during workshop one, that the usage principle 1) was perceived as intuitive during workshop one and that the usage principle 2) was perceived as intuitive during workshop two. The final wrist and arm score of usage principle 1) scored higher than 2) and 3) when executing the RULA, although the final score of all usage principles resulted in the same action level, "to investigate further". See complete RULA in Appendix 7.

The RULA score of the usage principles differed with little variations, thus further discussions took place with the client's department of ergonomics to receive an outer point of view. Usage principle 1) was not further developed after the discussion with the motivation that it potentially could bring a larger load to the user and be easy to unintentionally reach or access. Usage principle 2) was considered to interfere with the passenger or could be seen as less inclusive of people with limited range or bigger body types and was therefore not chosen for further development. Usage principle 3) was perceived as less stressful to use, and as the most familiar and intuitive one. It was considered as the least interfering way of using a joystick in a car's environment and may therefore contribute to safer driving, in relation to the other principles of use. Therefore, usage principle 3) was chosen for further development.

#### **4.4.4. Decision from Evaluation**

The decision made based on the evaluation was to continue to develop a joystick with a fixed armrest and a moving handle which steers on one axis, sideways. The joystick needed further development in regards of safety, misuse, placement of functions such as buttons, and form language to go in line with the client's design language.

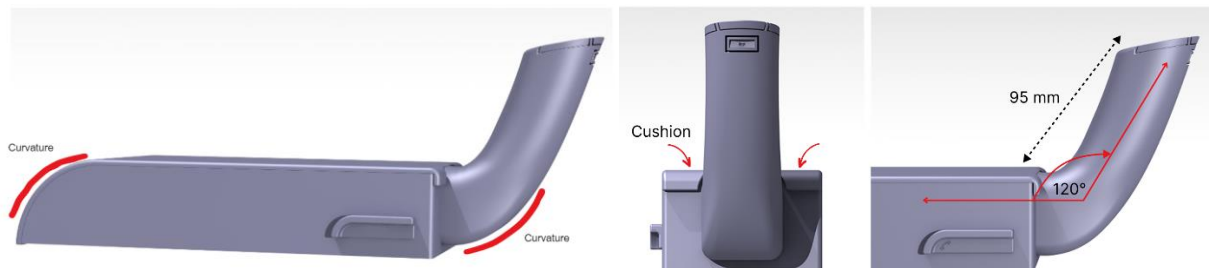
## 4.5. Results of Development Loop 3

This chapter presents the results of the final development loop which completed the final concept. It introduces the development of the shape and the buttons, and the feedback from the evaluation workshop. The final concept is presented in chapter 4.6.

### 4.5.1. Development of Concept Shape

The inspiration for the profile of the concept, see Figure 19 a), was taken from the balcony image in the moodboard, where a similar curvature was desired. The curve of the handle at the front of the armrest was created to have an equivalent appearance in curvature to the rear curvature of the armrest. The accompanying cushion of the armrest with a padding of 5 mm, see Figure 19 b), was implemented to increase the comfort of the steering device, since it was expressed as desirable by users. The handle of the joystick, see Figure 19 c), was constructed with an angle of 120 degrees in relation to the horizontal line of the armrest as a default setting, since it was perceived to be the most comfortable angle in workshop 2. The concept was developed to have an adjustability for physical differences and preferences; allowing the driver to adjust it in the x- and z-direction, and additionally to adjust the angle of the handle.

The joystick is placed in the tunnel console between the driver and the passenger, to offer support for the lower arm of the driver. The width of the armrest is 95 mm, and the length is 290 mm to suit the need expressed by the users during workshop 2 and to go in line with the client's existing armrests which is approximately 100-150 mm. The length of the handle is approximately 95 mm, to suit varying user's hands based on anthropometrics in 2.4.1. The height of the armrest is 59 mm and enables space for the electronic control unit for SbW.



a) The concept in profile.

b) The cushion of the concept's armrest.

c) The angle and length of the concept's handle.

Figure 19 - Rendering of the final concept. Authors' own figure.

## 4.5.2. Development of Buttons

Variations of the joysticks' buttons were further developed with CAD modeling. Their appearances were designed to go in line with the client's form language and to be suitable for varying users. The varying buttons of size, form, and function can be seen in Figure 20. Each button was designed and placed with reachability to the driver and without causing strain or discomfort. The functions of the horn and blinker buttons were included in the concept since they play an essential role in communicating to the surroundings when driving, see requirements 4.1.3 Steering Functionality.

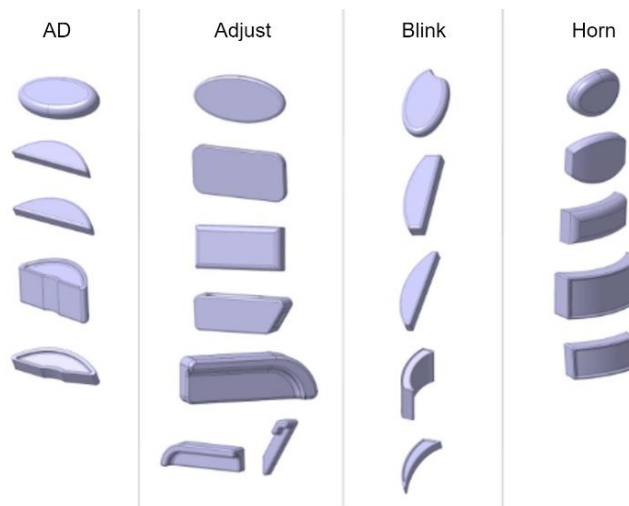


Figure 20 - Varying forms and sizes of buttons for activating AD, adjusting the armrest, blink (left) and the horn function. Authors' own figure.

The position of the buttons was compromised between offering good reachability and to have them enough out of reach to not risk of intervening with them easily. The position of the blinkers, AD button, the horn button and the adjustment button are shown in Figure 21.

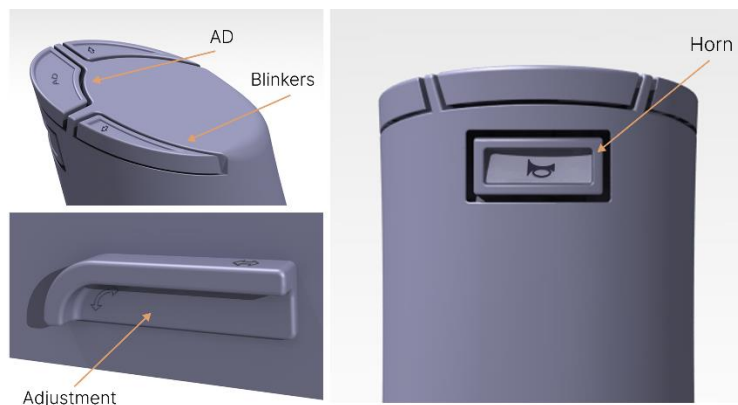


Figure 21 - Placement of blinkers and AD button. Authors' own figure.

### 4.5.3. Evaluation Workshop & Takeaways

In the evaluation workshops were the participants able to test a 3D printed prototype of the CAD model, see Figure 22.



Figure 22 - The 3D printed joystick concept shown in use that were evaluated during the workshop. Authors' own figure.

The points that were discussed during the evaluation workshop needing refinement can be seen in the list below. Some of the points led to further refinement of the final concept and others were left for future work.

- Develop the form language to make it fit into the client's product portfolio. Implications to use the moodboard and how to implement the client's logotype.
- Optimize the steering mobility to increase the comfort of the driver by developing adjustments of the joystick handle and the curvatures where the driver's hand rests.
- Further development of safety related to the concept, considering misuse and passenger interaction, the concept's interaction with airbags and indications of actions through force feedback and driving related indications.
- Further development of the interaction with display(s), including general placement of the display(s) and their function, to minimize potential constraints or safety hazards when feeling forced to reach for the center display with the steering hand.

Although the concept needed further development, the participants perceived the joystick to be easy to use, that it enabled roominess, was intuitive, had a clean design, was easy to understand, comfortable, accessible, had varying grip opportunities, and had the right functions accessible on the steering device. Furthermore, misuse was frequently discussed during the workshop, specifically intended and unintended usage by the passenger next to the driver. This was due to the placement of the joystick between the driver and the passenger. Further aspects concerning misuse are referred to in Misuse 5.5.4. Integration of the concept in the interior, further development of the grip and other limitations of the concept are left for future work, presented in chapter 5.5.

## 4.6. The Final Concept

The final concept is a lateral steering device with foot pedals to accelerate and brake. Figure 23 shows the final concept in the car interior of EX90, during manual mode, to visualize its placement in one of the client's newest car models. The point of origin of the handle when steering is vertical. When making a turn, the handle is tilted left or right with a slight spring back to the vertical point of origin. The steering function of the joystick is limited to a steering ratio of 90 degrees in total, 45 degrees to the right and 45 degrees to the left, to not put stress on the driver's wrist while making sharp turns. The joystick has force feedback and is speed dependent to create a realistic and comfortable steering feeling, which also contributes to a robust and reliable feeling. Furthermore, the joystick has some resistance when applying force feedback when steering to minimize the risk of making harsh or accidental turns, a risk that was discussed in the workshops. When steering and while in AD mode, the driver is offered support by the armrest and can position their lower arm how they feel the most comfortable.



Figure 23 – The interior during manual mode. Authors' own figure with product pictures from [www.volvocars.com](http://www.volvocars.com).

In automated mode (Figure 24), the handle of the final concept is folded forward to minimize the risk of intervening with the steering when in AD mode, to give a clear indication that the car is responsible for the driving and to increase the roominess even more. The driver can use the armrest as usual during AD mode and does not risk intervening with the steering since the takeover is two commanded – the handle of the final concept must be put vertically simultaneously as the driver needs to press the AD button for 3 seconds to activate manual mode. More information about the transition phase is presented in chapter 4.6.3.



Figure 24 – The interior during automated (AD) mode. Authors' own figure with product pictures from [www.volvocars.com](http://www.volvocars.com).

The final concept can be seen more in detail in Figure 25, in profile and from the front. From the evaluation workshop it became obvious that the concept's form language needed improvements to be in line with the client's product portfolio. The driver's mobility while steering was additionally pointed out to be limited. Therefore, the final concept has been refined according to these aspects. The driving comfort has been increased by adding a bigger radius to the armrest's edge at the wrist space, and by increasing the radius and tilt where the driver can relax their thumb.

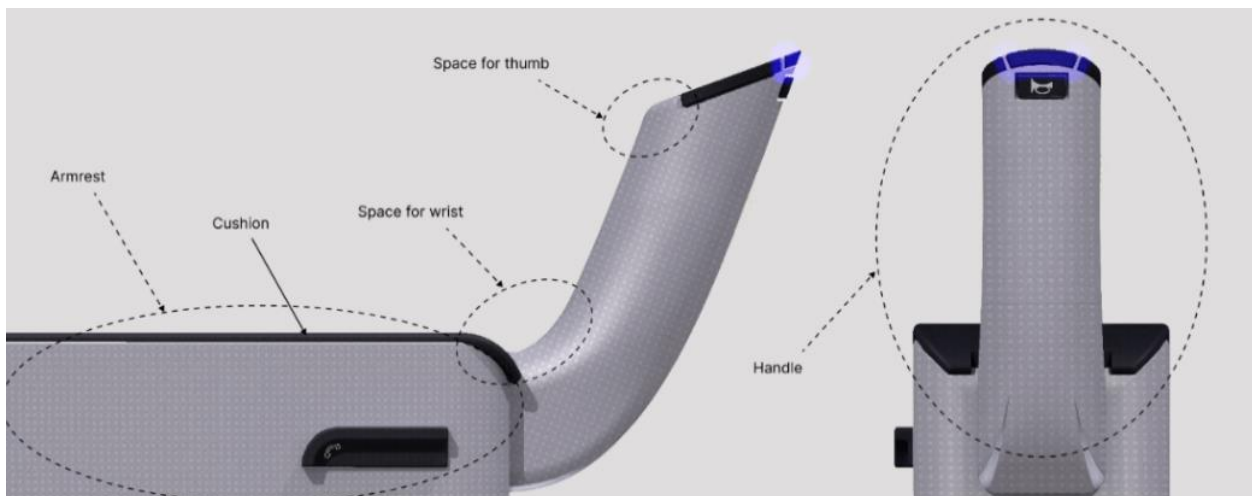


Figure 25 - Different views of the final concept with callouts. Authors' own figure.

The added driving related functions of the final concept (Figure 26) were considered as the most important functions to include in the design, see chapter 4.1.3. Requirements, since they are used to communicate with the environment and to make the activation of AD mode safe. The functions are blinkers, horn, and AD activation/deactivation. The functions are activated easily through pressing on them with some force. The AD button indicates through light that AD mode is available for activation.



Figure 26 - Detailed view of the buttons. Authors' own figure.

Split lines and the client's logotype were added in the design, to make the final concept visibly more in line with the moodboard, and therefore more in line with the client's form language. The split lines are evident at the lower part of the handle (Figure 27).



Figure 27 - Detailed view of the split lines at the lower part of the handle. Authors' own figure.

A driver display has been added in front of the driver (Figure 28), in addition to the center stack display. The center stack display is available and within reach for the driver and passenger as nowadays, and the driver display only presents information and functions important for the driver. The intention of an additional display is to make it easier for the driver to use functions such as handling TORs, taking calls or changing music without having to use the center stack display during manual mode. Using the center stack display during manual mode might otherwise lead to the driver letting go of the steering device (if the driver wants to use his/her right hand) or to an awkward and uncomfortable body position when the left hand crosses the

body to use the display when in right-hand traffic. The additional driver display can therefore counteract potential misuse scenarios.



Figure 28 - Intended placement of displays in the future interior of AD cars. Authors' own figure with product pictures from [www.volvocars.com](http://www.volvocars.com).

#### 4.6.1. Colors & Materials

The final concept is presented with three different color schemes and materials in Figure 29. The color and material choices are based on the moodboard and the interior of EX90. The color schemes are a) *a cooler design with a stripy pattern*, b) *a warmer design with a wavy pattern*, and c) *a grey design with a dotted pattern*. They differ in terms of the presence of the warmth in the EX90 interior or the cooler tones of the moodboard. Materials are not specified (according to 1.1 Demarcations) but used for visualization only. The handle and armrest are made of plastic material with a surface structure (different for each color scheme). The buttons are in a contrasting color to easily recognize where to press for activation. The armrest's cushion is made of textile in the same color as the buttons, adding to the contrasts of the final concept. The different colors of the AD light indication add as well to the contrasts.



a) A cooler design with a stripy pattern. b) A warmer design with a wavy pattern. c) A grey design with a dotted pattern.

Figure 29 - The final concept, with varying cool and warmth in pattern, colors, and lights. Authors' own figure.

To understand how the chosen colors and materials go in line with the moodboard and the client's brand identity, the final concept has been evaluated with the DFA (Figure 31). The grey design with dotted pattern shown in Figure 29 c) was found matching the interior of EX90 and the moodboard the best and was therefore analyzed in the DFA. Figure 30 shows callouts of design elements in the interior with the final concept.

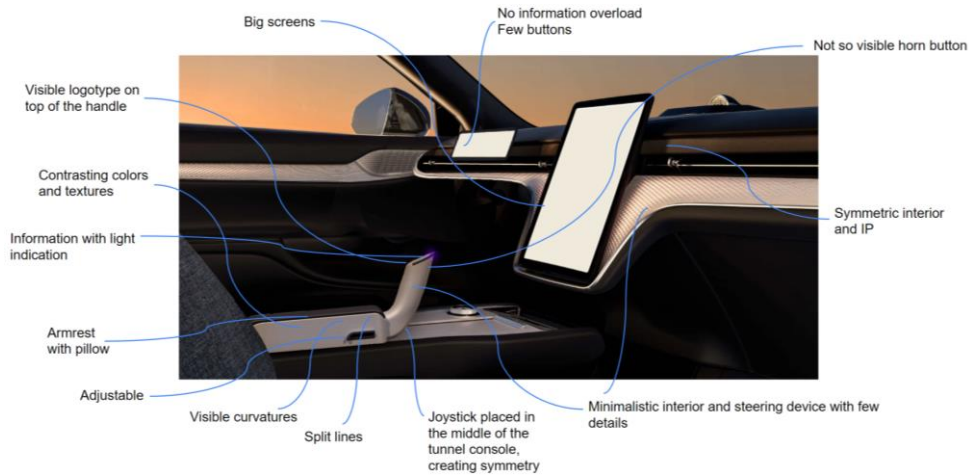


Figure 30 – The final concept with callouts as preparation for the DFA. Authors' own figure.

The results of the DFA (Figure 31) shows that the final concept was ranked with a score of 8, meaning that the design might be in line with the identified design elements of the client's product portfolio. Though, there could be improvements to make it more in line with the product portfolio, such as more visible and evident split lines and evident safety functions.

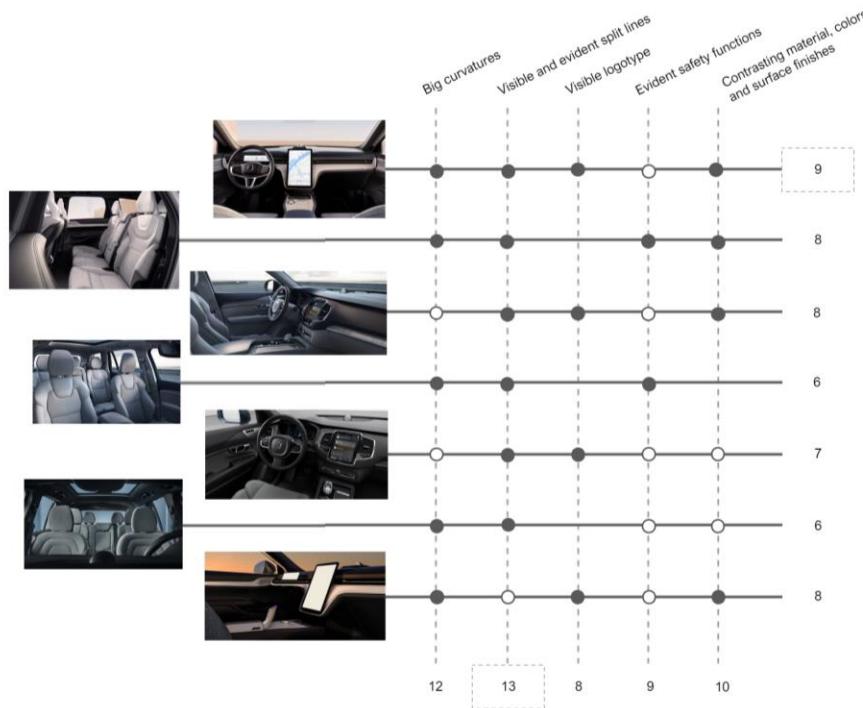


Figure 31 – The final concept evaluated with the DFA. Authors' own figure.

The final concept has a lot of elements that relates to the moodboard (Figure 32). The overall form and placement of buttons on top of the handle was inspired by the spiral picture in the moodboard. The contrasting colors as a design element (from the DFA) was considered when deciding on the button's materials and colors. The shape of the AD light indication and split lines at the top of the handle was inspired by the illuminated white T-shapes in the moodboard. The client's logotype is visible, and the Scandinavian nature inspired the color of the light indication and the certain curvatures. Furthermore, the balcony picture was the main inspiration source of the curvatures in the final concept, e.g., the curvature of the handle and back of the armrest.

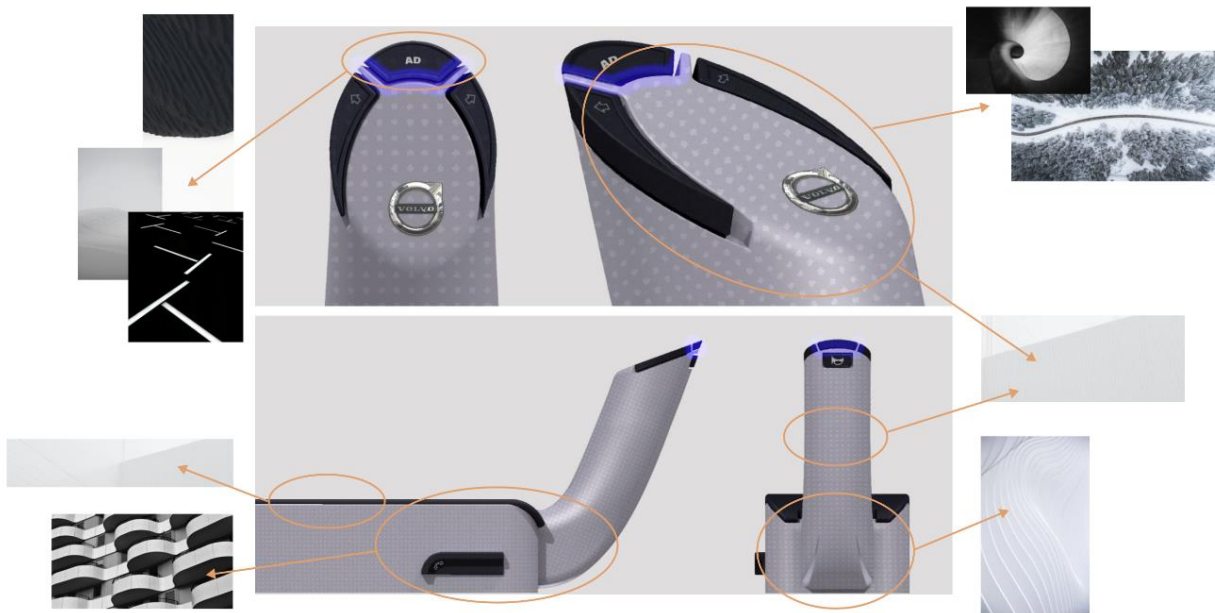


Figure 32 – The final design of the joysticks including colors and textures with the moodboard as reinforcement. Authors' own figure.

#### 4.6.2. User Interaction

The storyboard (Figure 33) shows a user scenario with the final concept. It represents the following scenario with step-by-step actions:

*“The driver has been in her summer cottage during the weekend, which is out in the countryside. The driver is now going back home to the city and has just gotten into her AD car”.*

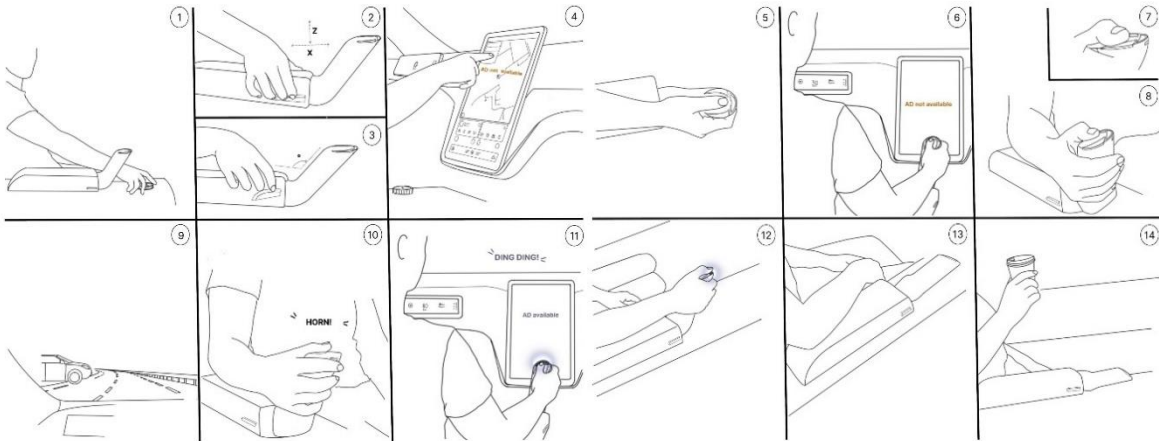


Figure 33 - Storyboard of user interaction. Authors' own figure.

1. The driver starts the car.
2. The driver adjusts the armrest on the z and x axis by lifting the button on the side of the armrest upwards/downwards and forwards/backwards.
3. The angle of the handle is adjusted by lifting/pushing down the front part of the adjust button on the armrest.
4. The driver puts in the address on the GPS (at the center stack display). The car tells the driver that AD mode is not available for the first part of the trip due to bad road conditions and tells the driver to drive manually until reaching the highway.
5. The driver grips the steering device.
6. The driver starts to drive manually.
7. When reaching the highway, the driver signals to other road users that she is about to enter the highway. She activates the right blinkers on the top of the joystick.
8. When the timing is right, the driver turns onto the highway by angling the joystick to the right.
9. The driver spots a car that is oblivious to her approaching.
10. The driver uses the horn to get the attention of the other car.
11. After a while the car indicates that the AD mode can be activated by displaying a message on the center stack display and the AD button lights up.
12. The driver activates AD through holding in the AD button 3 seconds and simultaneously pushing the handle of the joystick forward.
13. Once the handle of the joystick is tilted all the way forward, the driver lets go of the handle, and the car is in AD mode.
14. During AD mode, the driver attends to NDRTs, such as drinking coffee.

## Grip Opportunities

Along the development of the final concept, it has been of importance for users to be able to change their grip when steering. During the second workshop, the participants expressed a need to be able to change grip, to not feel forced to have just one grip. Furthermore, participants in the evaluation workshop perceived that the concept offered varying grip opportunities, which additionally accommodates variations in hand and grip size, (see 2.4.1) of the participants in the evaluation workshop. See Figure 34.

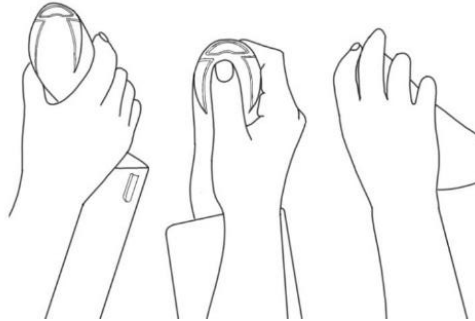


Figure 34 - Varying grip opportunities. Authors' own figure.

### 4.6.3. Transition Phase

The driver is on all occasions responsible for the safety of the car, which can be seen in Figure 33. When taking control or giving control of the steering the driver must press the AD button at least 3 seconds and simultaneously pull the joystick back to “normal” position (meaning the driver is responsible) or push it forward to AD mode (meaning the car is responsible). see Figure 33, step 12 and 13, for transition phase from manual mode to automated mode, and Figure 35, step two and three, for transition phase from automated mode to manual mode. The overall transition time between the driver initiating taking or giving control, and when the car has given or taken over the control should be close to 10 seconds. The transition needs to be further tested and evaluated in a realistic setting, to understand what feels trustworthy, safe and gives the driver a feeling of control. When the driver is taking control or giving control to the car, the car system indicates what is happening by making a request (TOR) or indication, informing the driver of what is about to happen. The driver can then confirm the command to take or give control or dismiss the command if it was not intended or accidental, e.g., if the driver accidentally initiate activation of AD mode, the car confirms the drivers act before putting in action. The transition needs to be done in a clear and smooth way to make the driver feel safe and certain of what is happening. The requests and indications need to have clear feedforward and give clear feedback to perceive the AD function as easy to use.

#### 4.6.4. Safety Features

When developing the final concept, both active and passive safety functions of the car have been considered. For more information about safety functions, see chapter 2.3. The car's active safety system is assumed to have been adapted during this timeframe based on the new expectations that are created for a car in AD level 4, to be able to:

- Sense the driver's state when driving manually e.g., if the driver is tired or no longer has their eyes on the road or their hand on the joystick.
- Act if the driver cannot act on their own, by indicating or informing the driver, or by taking control to stop the ride in a safe manner e.g., by stopping on the side of the road or at a safe spot.
- Indicate when there are obstacles or danger on the road or close by (danger could be accidents, unauthorized on the road, roadwork, heavy traffic, etc.).

The passive safety system of the car has been developed to protect the driver in the new context the joystick creates. It is important that the joystick does not interfere or intervene with the frontal airbag or the side airbags. Since the joystick is placed on the right side of the driver when driving in right-hand traffic, there is no need to apply a driver airbag as today (DAB), and new airbag similar to today's passenger airbag (PAB) can instead be installed to protect the driver in case of a frontal collision.

The storyboard (Figure 35) shows a collision scenario of the user interaction with the steering device. It represents the following scenario with step-by-step actions:

*“The driver has been involved in a frontal collision. The frontal airbags have been inflated and effectively decrease the severity of potential injuries”.*

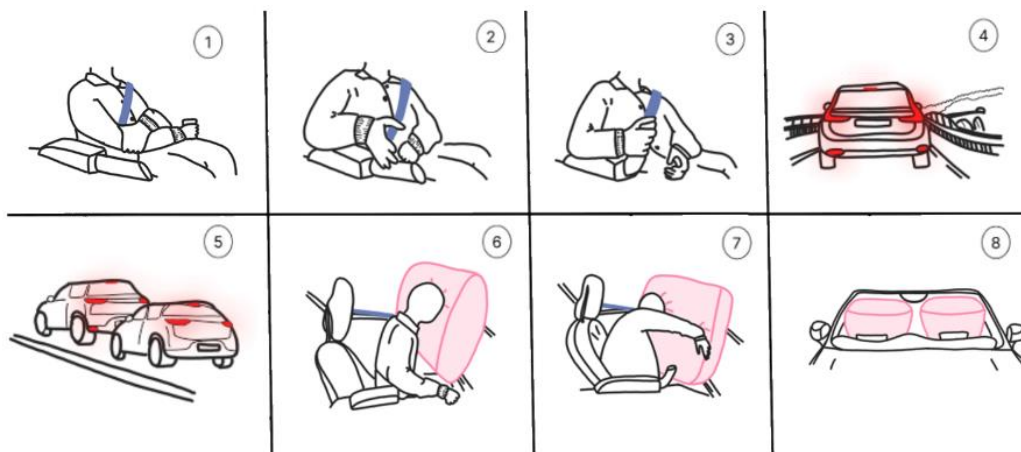


Figure 35 - Storyboard in the event of frontal collision. Authors' own figure.

1. The driver is sitting relaxed in the driver's seat with a cup of coffee, while the car drives in activated AD mode.
2. The driver reaches after the joystick to deactivate the AD mode, and to take back control of the drive. The driver pushes down the AD button for at least 3 seconds, and simultaneously pulls the joystick back to manual mode again.
3. The driver is now in control of the car.
4. Suddenly, a car in front of the driver brakes rapidly.
5. The driver, nor the car, does not have time to slow down enough, and collides with the car in front of them.
6. The driver airbag (shape and size as today's passenger airbag) is triggered and catches the driver during the collision.
7. The airbag cushions impact the driver as they are being forced to the front by the collision violence.
8. Different view of the deployed airbags. Both the driver's airbag and the passenger's airbag have deployed.

#### 4.6.5. Fulfillment of Vision

This chapter presents how the final concept fulfills the vision of the design brief. Each sentence of the vision is presented below with belonging motivations for how the concept fulfills the key words.

*A lateral steering device which is **intuitive**, **easy to access**, **comfortable**, and **safe to use** for an AD car in the year 2040.*

**Intuitive:** It has been a recurring point during the workshops that the concept is expressed to be intuitive by the participants and the usage principle comes naturally for many. The steering device's functionality is considered to be easy to understand – the driver steers by angling the device right or left and the design does not include too many driving-related functions which keeps the complexity down on low levels.

**Easy to access:** The design and position of the steering device enables good accessibility so the driver in all situations instantly can take control of the driving. The device is not hidden away during AD mode but always close at hand if needed. The design of the grip and opportunity to switch gripping position invites the driver to a proper and comfortable grip, thus enabling safe driving.

**Comfortable:** The steering device offers a comfortable grip for a large percentage of users, both for smaller and larger hands. It offers additional adjustment options for its positioning in the z-direction, x-direction, and angle adjustment of the handle, to offer comfort according to individual preferences. Low cognitive load is provided through a carefully selected transition

phase, with clear and smooth indications and by providing the driver with enough time to do a safe takeover or handover.

**Safe to use in the context:** The steering device is safe to use in the context, with its straightforward usage principle and few functionalities to handle. The buttons are placed within reach to keep the eyes on the road during activation, but not too much within reach to risk activating them. Clear communication between the car and the driver takes place during takeover situations which enables safe transition phases. The design and placement of the steering device does not decisively interfere with the safety of the intended implementation of airbags.

*It creates user confidence for the driver through its **attractive design**, that is in line with the client's design language.*

**Creates user confidence:** The final concept creates user confidence through its attractive design. The participants attending the evaluation workshop, expressed their willingness to cruise around steering with the final concept rather than with a big, round steering wheel since it felt cooler. The slim design contributes to a futuristic feeling where roominess is taken into consideration for the entire interior. The steering device is fitting in this new context of use where driving-related functionality takes a more subtle role when travelling compared to nowadays.

**Attractive design:** The attractive design of the steering device complies with the design language of the client with its big curvatures, logotype, and usage of functional elements like split lines as design detailing.

*The steering device **enables roominess**, and experiences of **attending to NDRTs** during the travels with the AD car in a **convenient** way.*

**Enables roominess:** The design and position of the steering device enables roominess in front of the driver. It gives more space for the legs and in front of the torso as well as more increased forward view. The space created in front of the driver gives an airier atmosphere to the interior and freedom when travelling.

**Enables NDRTs:** The increased roominess in front of the driver enables the driver to attend to other activities rather than driving. The driver can sit more relaxed, read a book, or look out the window without having to monitor the driving, when in active AD mode. Since the car is supposed to communicate when a takeover is needed the driver can relax for most of the trip.

**Convenient:** In this new convenient way of travelling, the driver can be more of a passenger. It is considered to lessen the burden on drivers and to effectively help them facilitate their lives through giving them more time for everyday tasks. The time during AD mode can as mentioned be used for other tasks that make peoples' everyday life easier. More comfortable journeys could lead to less stressful journeys and less accidents on the road.

*The steering device needs to give the driver a **feeling of control** yet **trust**.*

**Feeling of control:** The steering device provides the driver with a good feeling of steering through speed dependency and force feedback. Through sensing the steering, the driver can maneuver the car during manual mode without any difficulties. Feedforward and feedback are used to give the drivers certainty of their actions and add to the feeling of control.

**Feeling of trust:** The steering device gives the driver a feeling of trust through good communication with the car, great comfort, as well as through the easy-to-use and easy to access steering device. All these aspects invite the driver to trust the AD technology and to use the steering device.

## 5. DISCUSSION

In this chapter, the project is discussed in terms of what it can add to existing research, and how the project's aim and the client's expectations have been met.

### 5.1. Answering the Research Questions

The project's research questions are answered in the following section.

- *What steering device will be relevant to use when steering AD cars in the future?*

The driver will not be required to steer as much when travelling in AD cars and a steering wheel might therefore not be relevant for level 4 AD cars (SAE International, 2021). Previous findings from Hedegaard et al. (2019) state that a joystick offers less physical stress than a steering wheel. Additionally, Schartmüller et al. (2019) suggests that automated cars will lessen the cognitive load on the drivers, even when the driver still must be able to take over the steering when needed (Johns et al., 2014). Since the burden on the driver will be lowered in the future context the driver may attend other activities, which require more roominess in the car than nowadays. The implementation of steer-by-wire makes the joystick design possible and enables more space in the car. According to the project's workshops, the participants perceived the joystick as intuitive, comfortable, minimalistic and attractive in its design, contributing to more space, ease-of-use, and acceptance (4.2.2; 4.3.4; 4.5.3). The final concept is perceived as a relevant steering device for future AD cars but needs further development to ensure the safety. It regards the safety in hand-over and take-over situations, as well as the impact on airbags when implemented in cars and misuse situations. The final concept has a design of a joystick to offer less physical stress, which is to be used in new driving conditions (level 4 AD cars) based on new potential expectations and is developed with existing technology (SbW).

- *What type of steering experience is desired and relevant when steering AD cars in the future?*

A lateral steering device in the set context could affect how comfort and safety for the driver is perceived, and the user's experience can be elevated if the driving feels trustworthy and joyful (chapter 2.2). When creating trust in the steering device, the driver may be more willing to use the steering device and doing so in a correct manner (Ekman et al., 2017). Also, an attractive design might increase the trust (Pettersson & Karlsson, 2015). Furthermore, functions and information during manual mode and AD mode is provided with feedback, without the need to look at the steering device which enables the driver to keep their eyes on the road (4.1.3 - Eyes on the road). The final concept has enabled roominess in front of the driver and is perceived as intuitive and easy to use during the workshops. The final concept needs to be further evaluated and developed to be perceived as trustworthy, by as many users as possible. Although, the final concept enables the driver to keep their eyes on the road based on frequent feedback from the car, the driver needs to be able to trust the car of taking control or giving back control, which is a big leap from today's cars and the well-known, conventional steering wheel.

- *What type of steering device is desired or needed to preserve the safety of today?*

To preserve the safety of today the steering device must not interfere with airbags on all occasions, to keep the driver safe when driving. The steering device should therefore be designed and placed accordingly. Furthermore, implementing AD that feels safe to use could lower crash and injury rates since manual driving and human mistakes can be lowered (Fagnant & Kockelman, 2015). The final concept differs from the conventional steering wheel and could therefore put strain on the driver during the learning period until using it feels familiar. The strain on the driver is based on the need of learning how to maneuver a new device, in an already stressful environment such as driving or riding a car in the new context of higher AD levels. A steering device like this could potentially bring new regulations, such as taking a new driver's license, based on the big leap from a steering wheel to the final concept. The final concept requires the driver to act, drive, and direct their focus differently than today, which encounters uncertainty for safe use and acceptance within set timeframe, if not the transition is made smoothly.

## **5.2. Reflection on Findings**

The project contributes to research in terms of investigating an alternative steering device to a steering wheel for AD cars. The usage principles differ from the most common joysticks, which are typically movable in more than one axis. The final concept is working on two dimensions. The implementation of steer-by-wire with a joystick in AD cars is also a rather unexplored area. One of the benefits of implementing this solution could be that manufacturing for right-handed and left-handed traffic, could be simplified since only the pedals needs to be moved.

The final concept show how other steering devices can be as intuitive or easy-to-use as the conventional steering wheel in set context, and that the way of steering with a steering wheel can be questioned. Is it mainly regarded as easy-to-use and reliable since the design of the steering wheel has not been changed for a long period of time? The results of the study show that users are more or less willing to hand over the responsibility of the steering and to use other types of steering devices. Younger people could be more openminded in this regard and considering the timeframe of 20 years from now, the mindset of the younger generation should be important to consider more, since they are the future of society where AD cars will be more present than today. Replacing a conventional solution such as the steering wheel can be considered strange in many cases, when e.g., the driver's safety has been developed specifically according to the design of the steering wheel. Therefore, it may be questioned if it is a good choice to change a safety system that works well and has been thoroughly developed for about 40 years. Switching to the final concept, a joystick, may not be able to surpass the conventional steering wheel with respect to e.g., the previously mentioned aspects but can create other possibilities, such as increased space and convenience. It should rather be seen as an opportunity rather than a need to replace the steering wheel, an opportunity to create space for other activities when the car is so developed that the driver does not need to have the same steering control as today. Just as in

today's situation, the passive safety system must ensure the safety when the driver cannot. The timeframe of the final concept might need to be extended to make a gradual shift from the conventional steering wheel to the final concept as smooth as possible. It is also possible that another redesign might be better to shift to, e.g., a redesign that has more in common with the conventional steering wheel and therefore be easier accepted by users.

### **5.3. Achievement of Client Expectations**

The expected deliverables (chapter 1.1) requested by the client have somewhat been met considering development of a steering device suitable for the future, which is realizable and innovative. The client expected a prototyped final concept (chapter 4.6) with belonging requirements (4.1.3), which has been delivered. The concept has been developed with an open mind and it enables more room since the driver is expected to pay less attention to actual driving. The final concept is expected to be realizable since it implements existing technology in a new context. Yet, the final concept is not perceived as fully realizable based on the big leap from today's cars, within the set timeframe. Since the final concept is developed in a context where both the driving conditions and the steering device is changed, the timeframe could be too close to enable a smooth and safe transitioning from today's steering.

### **5.4. Limitations**

The following chapter describes limitations related to the choice of research methodology, addresses experimental uncertainty, and their causes.

#### **5.4.1. Choice of Research Methodology**

As research methodology, the project followed a product development process with a user centered design approach. The most valuable methods were:

- The workshops which gave valuable and qualitative input to the project.
- Creation of physical prototypes, that helped a lot to brainstorm ideas and variations of steering devices and were valuable as enablers in the workshops.
- The storyboards to gain insight into the user interaction and the future context.
- The moodboard to understand the client's design language.

After conducting the project, the project team reflected upon what methodology could have been improved by the following aspects:

- While researching and analyzing data to understand the context during the pre-study, it later became evident that the scope of the project was too broad, leading to making several assumptions. The requirements from the design brief have more or less been involved in the development. When specifying the requirements and defining the interaction much focus has been on how the transition between AD mode and manual mode, and the condition of the steering device has been perceived. Less focus has been on investigating the optimal time of transition, hand-over situations, the type of indications or requests.
- The workshops' enactment scenarios were structured to test a transition and driving scenario when in use. Adding other aspects could have added valuable input on safety related matters. Aspects like how the steering devices placement and function would have been affected with an unruly passenger, or different transition scenarios with varying time to takeover. Furthermore, the concepts could be tested in a more realistic environment in future work to get more valuable input on users' expectations, e.g., in a car interior using Wizard of Oz or through virtual reality (VR). Additionally, it could be interesting to incorporate more co-creating workshops involving potential future users, to learn more about their needs, expectations, and desires. This might then add to a higher user acceptance of the steering device when testing.
- The DFMEA contributed with understanding of the requirements but could have contributed even more, if more detailed and realistic prototypes were developed, to understand failures and to construct preventative activities.

### **Assumptions**

Some assumptions have been made along the project work to enable the development of the final concept, since "exploring future steering devices for automated cars" is a broad subject. These assumptions relate to the context, the demarcations, the timeline, the car's interior, and future technology. Some of the assumptions might be lacking and needs to be updated in future work if predictions of the future change. See assumptions listed below:

- A lateral steering device for autonomous cars level 4, where the car handles 80% of the driving and the driver 20%. The driver can drive the car fully manual if desired.
- The driver must be able to take control of the driving situation when desired or needed.
- The joystick has speed dependent steering.
- Cars with this steering device will be launched in the year 2040.
- No collective use, the driver is the owner of the car.
- The driver is positioned in the direction of travel.
- The driver has a passenger seat side beside them as in today's cars.
- Safety functions and systems, such as sensors, have been developed within the timeline to better interact with the driver.

- Two informational and interactional screens are available in the car, one center stack display and one in front of the driver within eyesight, where information and functions are available.
- The steering device is implemented with SbW, to enable a realizable concept.

The assumptions are reasonable but must be reevaluated for future work, to ensure safe use in the new context. The assumptions of the passenger seat beside the driver, and the car's ability to manage the driving will need reconsideration. The passenger beside the driver could possibly interfere with the driving, hence the final concept needs to be more hidden, or the passenger seat needs to be removed to lower the risk. This could make the implementation in cars difficult and delay the year of launch. Also, the final concept is heavily dependent on the active and passive safety systems within the car to ensure correct use. To not risk overriding the system, and to ensure smooth transition from today's cars to future AD cars, the development of safety systems needs to be thoroughly developed and evaluated for implementation, which could affect and delay the timeframe.

Furthermore, when driving in higher AD levels (SAE level 4 and 5) in the future, there may not be a need to install pedals or a steering wheel (SAE International, 2021). Based on set assumptions and demarcations during the project, the ideation and refinement of the final concept is perceived to have been enabling as well as limiting. The demarcations have enabled the opportunity to redesign a lateral steering device but has also limited the scope in what way this could be done. With less demarcations the final concept could have been something completely different, e.g., voice commands or a steering mouse, and the context could have been harder to design for when considering safety. This would have affected the outcome as well as relevant research and methodology during the project. The demarcations have worked as enables to set the context and to start generating ideas, and without those it would have been difficult to initially start and develop the final concept.

#### **5.4.2. Experimental Uncertainty**

This project has had a product development process with a user centered design approach. The project and development of the final concept has been heavily dependent on the feedback of potential future users, represented by the client's employees. Since the project has been focusing on making a steering device suitable and acceptable for future users, the participants experience while using and testing concepts during workshops has been of great value. The scope of the project concerns future use, and the project has been focusing on analyzing and developing in the broad context of future use. The process chosen for this project is regarded as suitable, since giving the participants to much freedom or no freedom at all could have limited or made the development more difficult, based on the unknown predictions of the future and future users' wishes or needs.

Experimental uncertainty might be present in the workshop results. A cause of the uncertainty is related to the small number of people included in the workshops. The total number of participants was 15 (4 females and 11 males) of varying ages. The participants might not be representative of all users since the group was less broad, since all were employed by the client and the results might therefore be a bit lacking. The concepts were not evaluated in a realistic scenario in the workshops, which might have affected the results, e.g., in a real car with force feedback implemented in the steering device concepts. The participants might have expressed other opinions or likings if the concepts had given them a more realistic steering feeling or if they thought they steered the car with the devices and not only pretended to. Some people are better to act than others which might have affected the workshops' output. Yet, all participants attending the workshops have shown interest in the developed concept even if their age, size, and driving habits differed. Further development of the final concept needs to be tested with a broader user group. This includes varying cultural backgrounds and countries, since the need to communicate with one's environment differs depending on how many vehicles are on the road or in the city, and what type of road the driver is driving on. Also, a broader age ratio needs to be included when further testing, since different generations is more or less used to automated features today, which can affect how acceptable the concept is perceived. Additionally, the drivers' interest and habit of driving manually needs to be taken into consideration, since the purpose of commuting from one point to another and the purpose of cruising during a summer day also can affect how acceptable or desirable the final concept is perceived. From an ergonomic perspective, the concept needs to be further tested in regards of comfort and grip.

## **5.5. Future Work**

To improve the final concept, further development should regard how the steering device interacts with the cars active and passive safety systems, in both intended and unintended steering takeovers. The concept should be further developed to fit individuals with different preferences, how the steering device is implemented in the car, as well as how to counteract potential misuse.

The project has not taken material or manufacturing into consideration and could therefore be further developed and decided on after the concept has fully been developed to fit the future context in regards of safety and the drivers' experience.

### **5.5.1. Safety Improvements**

The conditions for implementation of the final concept depend on how laws and regulations related to safety will be formulated for future AD cars. Since they have not been set yet, their impact is currently uncertain. Both active and passive safety regarding usage and implementation of the steering device need further improvements. In case of collisions from the side, where FAB and SAB could inflate, the steering device should not interfere. To further adapt the joystick

similar to how a steering wheel is adapted in case of collision today, the joystick could be a bit flexible to not risk intervening with the airbag. Further, the active safety system of the car and the joystick must be developed and tested to make sure that the driver do not feel the need to override the active safety system based on the feeling of not being in control, or not being the one making the decision of the driving experience. Then the interaction between the car and the driver with feedback and feedforward indications and requests needs to be evaluated to ensure safe use, without risking mental overload or potential overriding of the system. Adding to this, force feedback in the joystick could indicate what is happening during manual mode and needs to be further implemented and evaluated. Another safety-related improvement is that unintended takeover situations need to be taken into consideration for safe use. Since those situations is hard to predict and instantly act on by the car and the driver, the needed resistance in the joystick and the transition time needs to be evaluated further to feel safe and not forced for the driver, and to minimize mental stress and load on the driver.

### **5.5.2. Usage**

The usage related to comfort needs further improvements as well. The radius and length of the joystick handle needs to be further evaluated and determined relating to ergonomics, to best fit different users' needs and to have a comfortable grip while steering. The comfort for the driver related to grip and hand placement should also be further improved for both left and right-handed drivers to fit varying users and to minimize potential misuse. With the steering device places in the tunnel console, a left-handed driver in right-hand traffic could possibly find it not as intuitive as right-handed drivers. On the other hand, left-handed people learn to use gear shifts and right-handed computer mice without problem which shows that the problem might not be so big after all. The car will be responsible for 80% of the driving and the driver will not need to drive as frequently, which will make the steering less strenuous no matter if the drivers are left or right-handed. Interaction with the cars system when in manual mode also needs further improvements, where placement of functions and activating functions in e.g., a display in front of the driver only for driving related functions and information with or without touch, needs to be tested in a realistic environment.

### **5.5.3. Implementation in Car Interior**

In future work, implementation of the steering device in the car interior needs to be considered. In this study, it has been assumed that the steering device is positioned in the tunnel console. Generally, car manufacturers are moving towards a future with slimmer interiors with more roominess also between the seats. By the year 2040 the interior may not look the same as today. There might not even exist a tunnel console as a base for the implementation of the steering device and therefore it needs to be investigated whether the position is the most optimal one.

The position of the steering device might also have a possible effect on the side airbags as mentioned previously in chapter 5.5.1, which is another factor to take into consideration for the implementation and positioning of the steering device. The position of the joystick also affects where the electronic control unit of the SbW can be placed or not.

#### **5.5.4. Misuse**

Future work is recommended to handle situations of misuse to ensure correct usage, performance, and safety. The risk of intervening with the steering device unintentionally was put forward as an important matter to consider in future work, during the evaluation workshop. The following sections address both misuse caused by the driver and misuse related to passengers interacting with the steering device. There may be other misuse situations which are not touched upon in this project but can have a decisive impact on the usage, performance, and safety, therefore tests must be carried out that deal with misuse scenarios.

##### **Driver Misuse**

The steering device needs further refinement concerning the risk of activating buttons or intervening with the driving when pressing on buttons (e.g., accidentally making a turn when pressing one of the blinkers buttons). The refinement concerns balancing the buttons' sizes and placements on the steering device to have them within reach but not too much within reach, to not accidental activation.

Some drivers might feel limited to only using their right hand for the lateral steering without being able to shift the grip between the hands. There is a risk of misuse related to this aspect which concerns the driver letting go of the steering device during manual mode when they want to use their right hand for another task, e.g., when interacting with the center stack display or reaching for something from the backseat of the car.

##### **Passenger Interaction**

The placement of the steering device in the tunnel console between the driver and the passenger can lead to misuse since it will be more accessible for the passenger. Both conscious and unconscious interactions with the steering device may be present. Passenger interactions can for instance be a child in a car seat kicking the steering device, a passenger who leans on the armrest and at the same time accidentally activates buttons or a driver and a passenger who shares the responsibility of the lateral steering during a trip.

Investigations regarding how to make the steering device less accessible for the passenger must be made, e.g., a different placement of the steering device or to hide it in a reasonable way for the passenger. Additional investigations could potentially touch upon implementing more or other commands and systems, removing the passenger seat, adding sensors on the steering device that feels contact when in manual mode, or implementing artificial intelligence to identify who is driving the car.

## 6. CONCLUSION

The purpose of the thesis was to explore future steering devices for automated cars and include what users would like to use when steering a high-level automated car. It can be concluded that creating a realizable steering device for high-level automated cars in a future setting is challenging, since future circumstances rely on various external factors such as technological advancements, user expectations, laws, and regulations. These factors may alter over time and impact the implementation success of the steering device. Hence, it is critical to persist in researching and developing future steering devices suitable for high-level autonomous cars and the future driving context.

A gradual shift of steering devices from steering with a conventional steering wheel to steering with the final concept is needed, to make the transition as smooth as possible and to ensure user acceptance and safety. Additionally, it is imperative to thoroughly test the final concept with a larger number of users with different preferences in a realizable setting of a future context to ensure its success.

In conclusion, for future work technological advancements need to be considered, safety related matters, and to continue involving users in the development to ensure acceptance. Also, further investigations and predictions regarding the circumstances of the future needs to be done, to be able to make the shift to the future context of AD cars as smooth as possible.

## REFERENCES

- Borenstein, J., Herkert, J., & Miller, K. (2017). Self-driving cars: Ethical responsibilities of design engineers. *IEEE Technology and Society Magazine*, 36(2), 67-75.
- Chua, C. K., Leong, K. F., & Lim, C. S. (2003). *Rapid Prototyping: Principles and Applications*. (2nd ed.). World Scientific Publishing Co.
- Clarkson, P. J., & Coleman, R. (2015). History of inclusive design in the UK. *Applied ergonomics*, 46, 235-247.
- Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, 13(3), 319-340
- Dingyi, Y., Haiyan, W., & Kaiming, Y. (2018). State-of-the-art and trends of autonomous driving technology. In *2018 IEEE international Symposium on Innovation and entrepreneurship (TEMS-ISIE)*, 1-8.
- Doumeingts, G., & Browne, J. (1997). *Modelling Techniques for Business Process Re-engineering and Benchmarking*. (1st ed.). Springer publishing.
- Ekman, F., Johansson, M., & Sochor, J. (2017). Creating appropriate trust in automated vehicle systems: A framework for HMI design. *IEEE Transactions on Human-Machine Systems*, 48 (1), 95-101.
- Elbanhawi, M., Simic, M., & Jazar, R. (2015). In the Passenger Seat: Investigating Ride Comfort Measures in Autonomous Cars. *IEEE Intelligent transportation systems magazine*, (Fall 2015), 4-17.
- Fagnant, J. D., & Kockelman, K. (2015). Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation Research Part A* 77, (2015), 167–181.
- Flick, U., von Kardoff, E., & Steinke, I. (Eds.). (2004). *A companion to qualitative research*. Sage.
- Hanson, L., Sperling, L., Gard, G., Ipsen, S., & Vergara, C.O. (2009). Swedish anthropometrics for product and workplace design. *Applied Ergonomics*, 40, 797-806.
- Hedegaard, M., Støttrup, N., Sørensen, F. F., Langer, H. T., & Samani, A. (2019). Evaluation of five steering input devices in terms of muscle activity, upper body kinematics and steering performance during heavy machine simulator driving. *International Journal of Industrial Ergonomics*, 72 (2019) 137–145.

Hella. (n.d). CAR AIRBAG SYSTEM. <https://www.hella.com/techworld/au/Technical/Car-electronics-and-electrics/Car-airbag-system-3083/>

HFES 300 Committee, 2004, Guidelines for Using Anthropometric Data in Product Design, Human Factors and Ergonomics Society, Santa Monica, CA. [Received 10.02.2023].

Hiort af Ornäs, V., & Persson, S. (2007). Things, constructs and meanings.

Insurance Institute for Highway Safety. (2022). Airbags. <https://www.iihs.org/topics/airbags>

Interaction design foundation. (n.d.) *User centered design*. [What is User Centered Design? | IxDF \(interaction-design.org\)](https://www.interaction-design.org/)

Iskander, J., Attia, M., Saleh, K., Nahavandi, D., Abobakr, A., Mohamed, S., Asadi, H., Khosravi, A., Lim, C.-P., & Hossny, M. (2019). From car sickness to autonomous car sickness: A review. *Transportation Research, Part F* 62 (2019), 716-726.

Johns, M., Sibi, S., & Ju, W. (2014). Effect of cognitive load in autonomous vehicles on driver performance during transfer of control. *Automotive UI '14: Adjunct Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive*. 1–4. <https://doi.org/10.1145/2667239.2667296>

Karjalainen, T. M. (2007). It looks like a Toyota: Educational approaches to designing for visual brand recognition. *International Journal of design*, 1(1).

Kraus, J., Babel, F., Walch, M., Rukzio, E., & Baumann, M. (2018). How to design valid simulator studies for investigating user experience in automated driving: review and hands-on considerations. In *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 105-117.

Melcher, V., Rauh, S., Diederichs, F., Widlroither, H., & Bauer, W. (2015). Take-over requests for automated driving. *Procedia Manufacturing*, 3, 2867-2873.

Mora, L., Wu, X., & Panori, A. (2020). Mind the gap: Developments in autonomous driving research and the sustainability challenge. *Journal of Cleaner Production* 275, (2020).

Mortazavizadeh, S.-A., Ghaderi, A., Ebrahimi, M., & Hajian, M. (2020). Recent Developments in the Vehicle Steer-by-Wire System. *IEEE Transaction on Transportation Electrification*, 6 (3), 1226-1235.

Pettersson, I., & Ju, W. (2017). Design techniques for exploring automotive interaction in the drive towards automation. In *Proceedings of the 2017 conference on designing interactive systems*. 147-160.

Pettersson, I., & Karlsson, I. C. M. (2015). Setting the stage for autonomous cars: a pilot study of future autonomous driving experiences. *IET Intelligent Transport Systems*, 9 (7), 694-701.

Pheasant, S., & Haslegrave, C.M. (2006). *Bodyspace: Anthropometry, Ergonomics and the Design of Work*, (3rd ed.), Taylor & Francis, Boca Raton. ISBN 0415285208.

Rödel, C., Stadler, S., Meschtscherjakov, A., & Tscheligi, M. (2014). Towards autonomous cars: The effect of autonomy levels on acceptance and user experience. In *Proceedings of the 6th international conference on automotive user interfaces and interactive vehicular applications*. 1-8.

SAE International. (2021, 03 May). SAE Levels of Driving Automation [Table]. <https://www.sae.org/blog/sae-j3016-update>

Schartmüller, C., Wintersberger, P., Frison, A. K., Riener, A. (2019). Type-o-Steer: Reimagining the Steering Wheel for Productive Non-Driving Related Tasks in Conditionally Automated Vehicles. *2019 IEEE Intelligent Vehicles Symposium*, (IV).

Saffer, D. (2010). *Designing for Interaction: Creating Innovative Applications and Devices*. (2nd ed.). Berkeley Calif. New Riders Pub.

Sellappan, N., Nagarajan, D., & Palanikumar, K. (2015). Evaluation of risk priority number (RPN) in design failure modes and effects analysis (DFMEA) using factor analysis. *International Journal of Applied Engineering Research*, 10 (14), 34194-34198.

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104 (November 2019). 333-339. <https://doi.org/10.1016/j.jbusres.2019.07.039>

Spencer, D. (2009). *Card Sorting: Designing Usable Categories*. Rosenfeld Media.

Steinfeld, E., & Maisel, J. (2012). *Universal design: Creating inclusive environments*. John Wiley & Sons.

Stanton, N. A., Hedge, A., Brookhuis, K., Salas, E., & Hendrick, H. W. (Eds.). (2004). *Handbook of human factors and ergonomics methods*. CRC press.

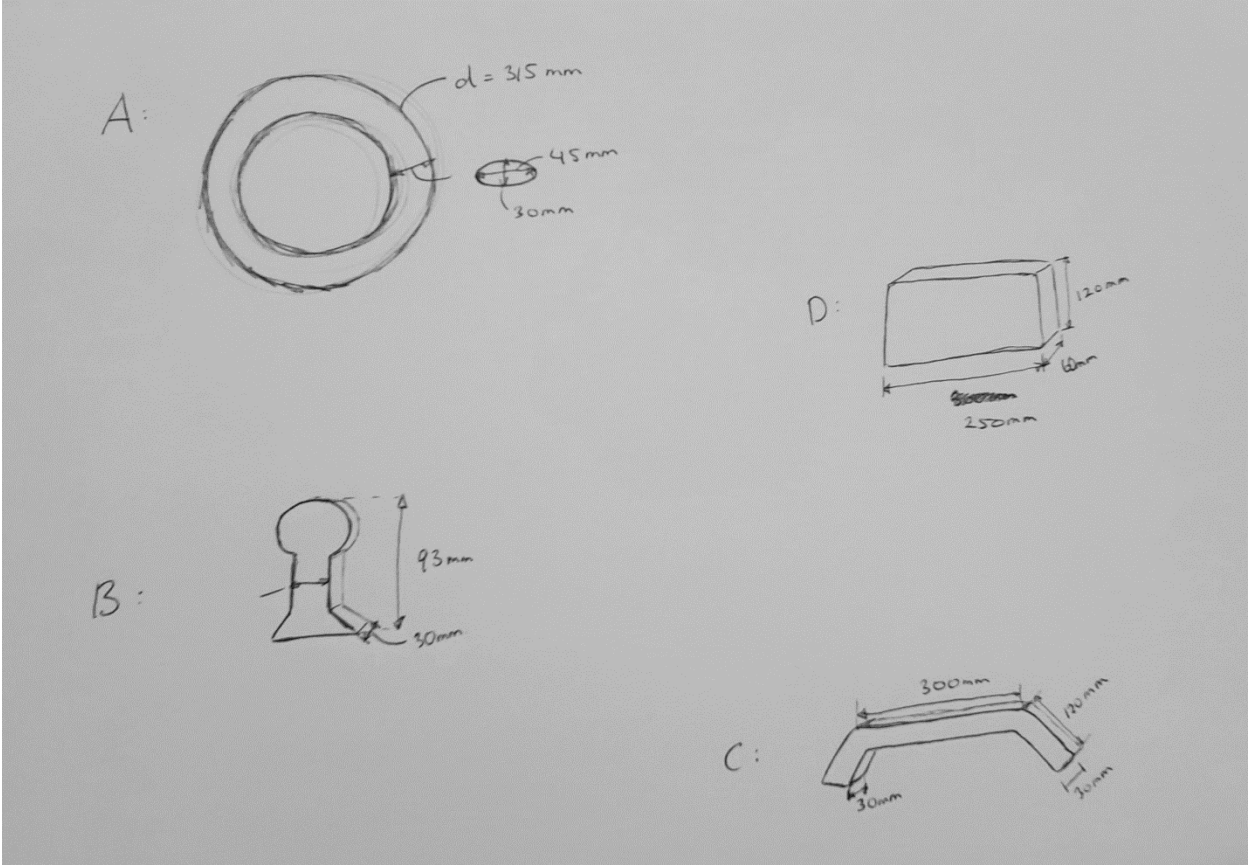
Story, M. F. (2001). Principles of universal design. *Universal design handbook*, 2.

TraGate. (n.d). Side Airbags. <https://tragate.com/side-airbags-130436/product>

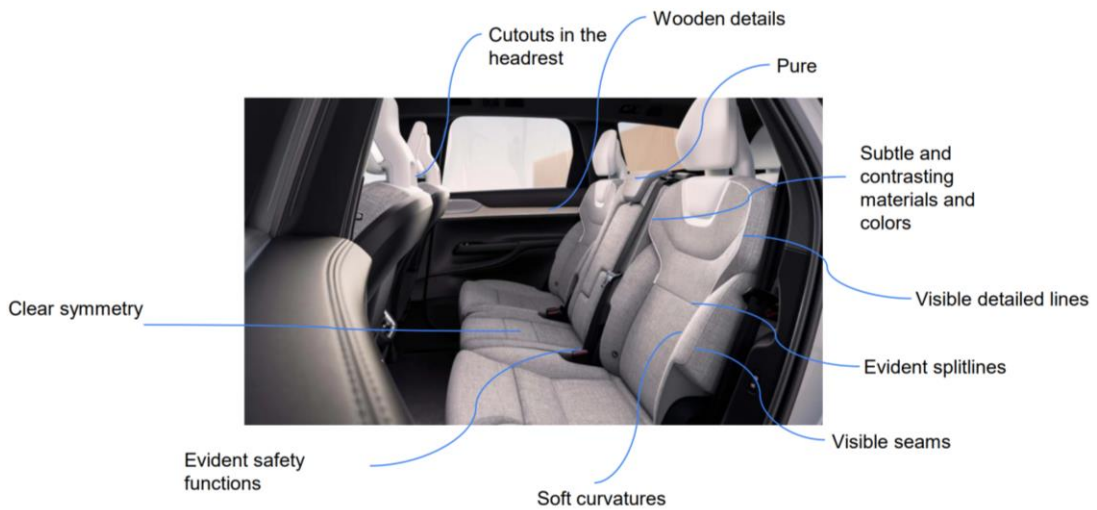
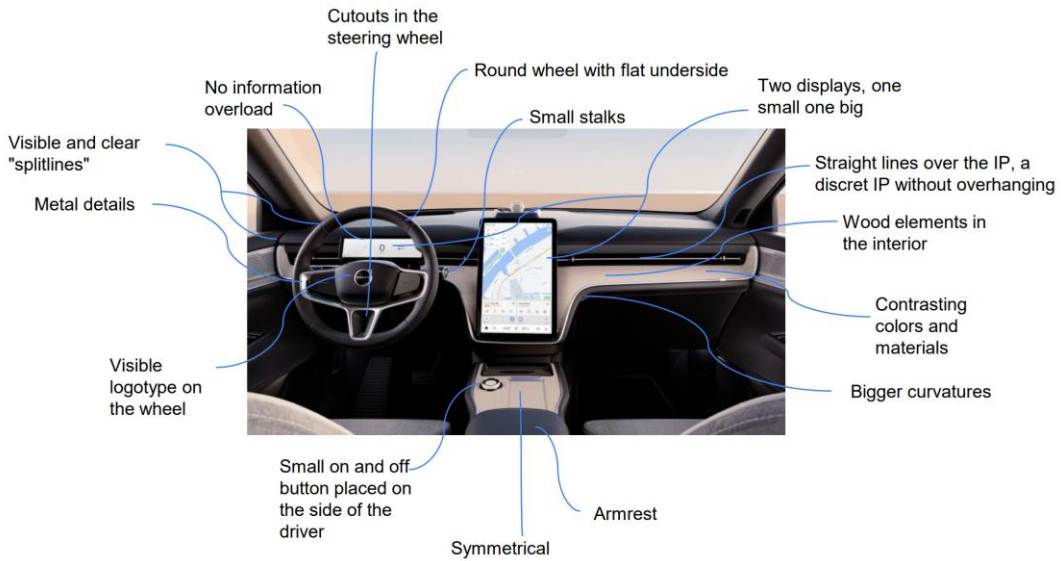
Vavoula, G, N., & Sharples, M. (2007). Future technology workshop: A collaborative method for the design of new learning technologies and activities. *Computer-Supported Collaborative Learning*, 2. 393–419. <https://dx.doi.org/10.1007/s11412-007-9026-0>

Österlin, K. (2016). Design i fokus (4th ed.). Liber AB.

# APPENDIX



Appendix 1- Prototype measurements of development loop 1.



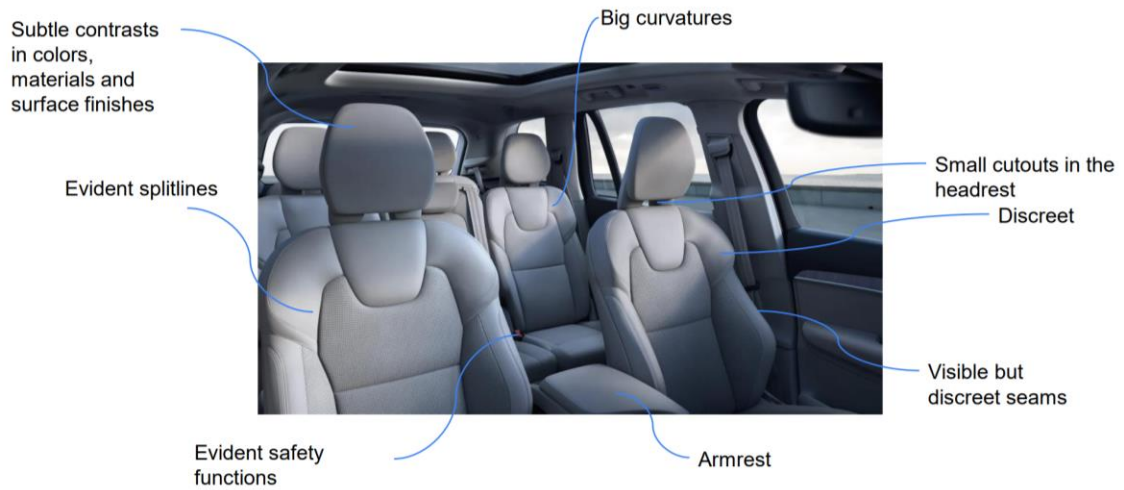
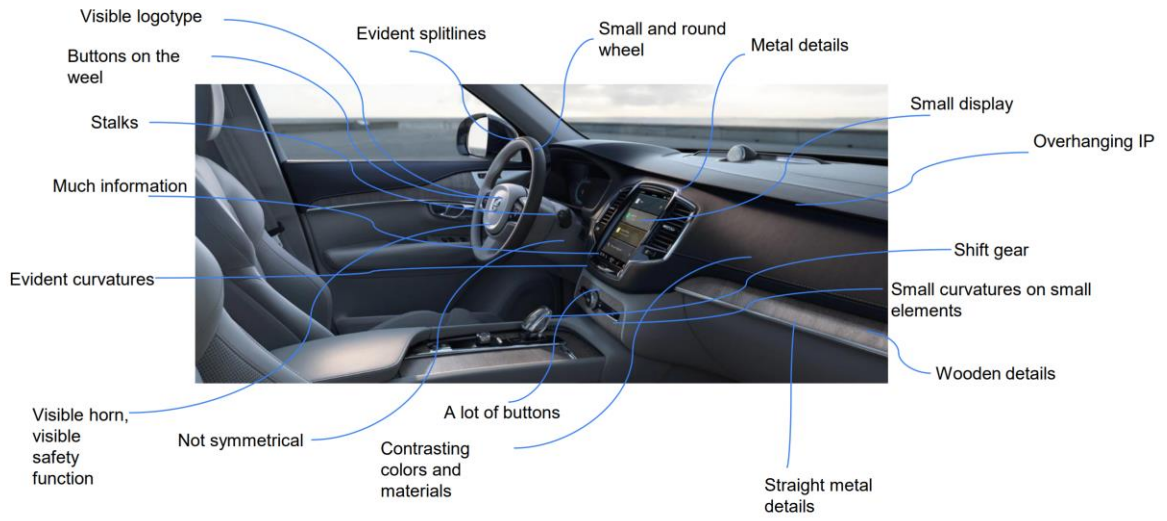


	Cutouts in Stw	Splittines	Round wheel with flat underside	Two displays	Visible logo	Discreet IP	Metal details	Small on and off button	Wooden details	Contrasting materials and colors	Big curvature	No information overload	Symmetry	Armrest	Little stalks
Cutouts in Stw	1	-1	-1	1	1	0	-1	1	0	1	1	1	0	1	1
Splittines	-1	1	-1	-1	0	-1	0	-1	1	1	1	0	0	1	1
Round wheel with flat underside	1	1	1	0	1	1	1	-1	1	1	1	1	0	0	0
Two displays	1	1	0	1	1	0	0	-1	-1	0	1	1	0	0	0
Visible logo	-1	0	-1	-1	1	0	0	-1	-1	0	-1	0	-1	-1	-1
Discreet IP	-1	1	-1	0	0	1	0	-1	-1	0	0	0	0	-1	-1
Metal details	0	0	-1	0	0	0	1	-1	0	1	0	1	0	1	-1
Small on and off button	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0
Wooden details	-1	-1	-1	1	1	1	0	0	1	1	1	1	0	1	0
Contrasting materials and colors	0	-1	-1	0	0	0	-1	-1	-1	1	0	0	-1	0	-1
Big curvature	-1	-1	-1	-1	1	0	0	-1	-1	0	0	0	-1	0	-1
No information overload	-1	0	-1	-1	0	0	-1	-1	-1	0	0	1	-1	0	-1
Symmetry	-1	0	0	0	1	0	0	0	0	1	1	1	1	1	0
Armrest	0	-1	0	0	1	1	-1	0	-1	0	0	0	-1	1	-1
Small stalks	-1	-1	0	0	1	1	1	0	0	1	1	1	0	1	1
Sum	-5	0	-8	-3	9	5	0	-10	-4	7	7	8	-4	3	-5
Relative sum	9	14	6	11	23	19	14	4	10	21	21	22	10	17	9
Weight	0.322	0.5	0.214	0.393	0.822	0.678	0.5	0.143	0.357	0.75	0.75	0.786	0.357	0.607	0.322
Rank					1					3	3	2			
Typicality value					0.137					0.25	0.5	0.0219			



	Clear symmetry	Evident safety functions	Cutouts in headrest	Wooden details	Soft curvatures	Visible seams	Pure	Subtle and contrasting materials and colors	Visible detailed lines	Evident splittines
Clear symmetry	1	0	0	1	0	1	1	1	1	1
Evident safety functions	-1	1	-1	-1	-1	-1	-1	-1	-1	-1
Cutouts in headrest	0	1	1	0	1	1	1	1	1	1
Wooden details	0	-1	0	1	0	1	1	1	-1	1
Soft curvatures	-1	1	-1	-1	1	-1	1	0	0	0
Visible seams	0	1	-1	0	1	1	1	1	1	1
Pure	-1	1	-1	-1	-1	-1	1	-1	-1	-1
Subtle and contrasting materials and colors	-1	-1	-1	-1	0	-1	1	1	-1	-1
Visible detailed lines	-1	1	-1	-1	0	-1	1	1	1	-1
Evident splittines	-1	1	-1	-1	0	-1	1	1	1	1
Sum	-6	9	-7	-6	2	-5	7	4	2	0
Relative sum	3	18	2	3	11	4	16	13	11	9
Weight	0.167	1	0.111	0.167	0.611	0.222	0.889	0.722	0.611	0.5
Rank		1					2	3		
Typicality value		0.017					0.0494	0.241		

XC90



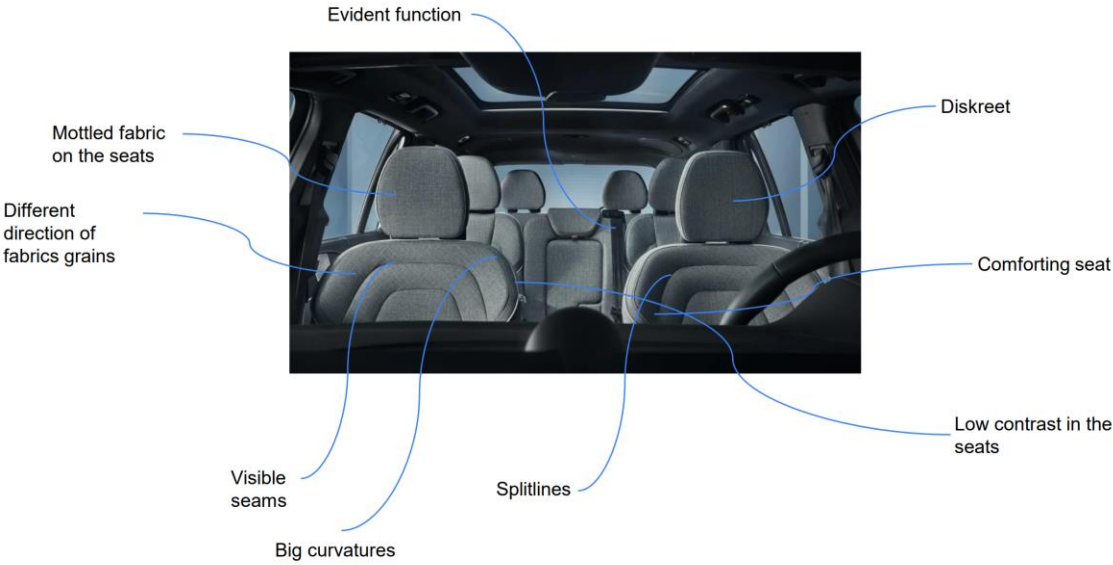
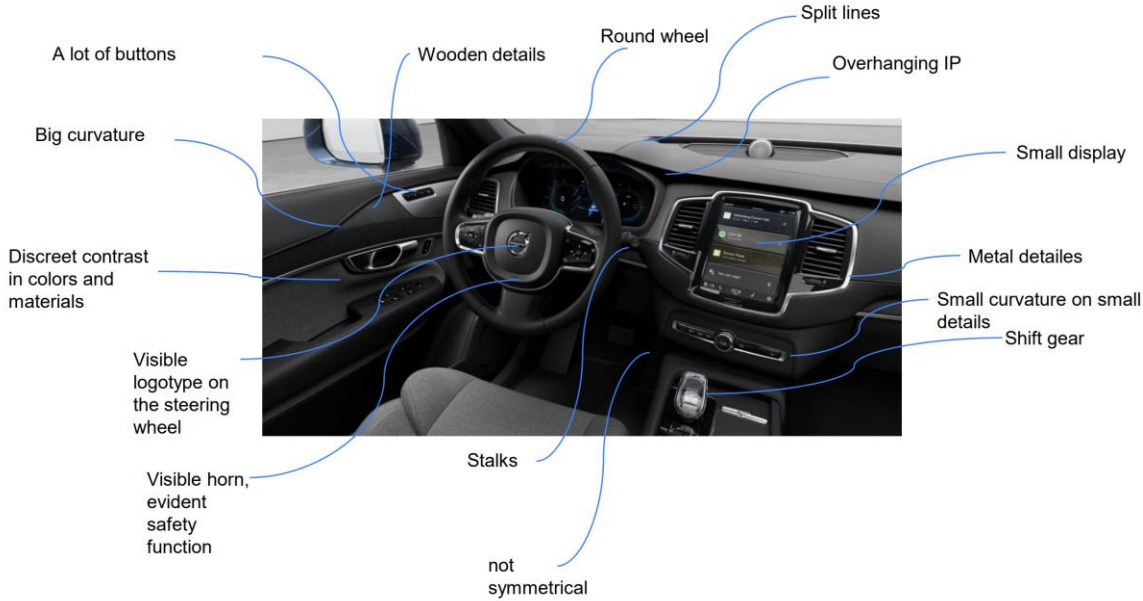



	Visible logo	Buttons on wheel	Evident splittines	Stalks	Information overload	Evident curvatures	Visible safety functions	Not symmetrical	Contrasting materials and colors	A lot of buttons	Straight metal lines	Wooden details	Small curvatures	Shift gear	Overhanging IP	Small display	Metal details	Small, round stw
Visible logo	0	0	-1	-1	0	1	-1	0	-1	-1	0	0	0	-1	0	-1	0	0
Buttons on wheel	0	1	0	0	1	1	0	1	0	1	0	1	0	0	0	0	1	1
Evident splittines	0	-1	-1	-1	0	1	-1	0	-1	-1	-1	0	-1	0	0	-1	0	-1
Stalks	1	0	1	-1	1	1	0	1	-1	0	0	1	0	1	0	1	0	0
Information overload	1	0	1	1	1	1	0	1	0	1	1	1	0	1	0	1	0	1
Evident curvatures	0	-1	0	-1	-1	1	-1	0	-1	-1	-1	-1	-1	-1	0	-1	-1	-1
Visible safety functions	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Not symmetrical	1	0	1	0	0	1	1	1	0	1	0	0	0	0	0	0	0	1
Contrasting materials and colors	0	-1	0	-1	-1	0	1	-1	-1	-1	-1	-1	-1	-1	0	-1	0	-1
A lot of buttons	1	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1
Straight metal lines	1	-1	1	0	-1	1	1	-1	1	-1	0	0	1	-1	0	-1	1	0
Wooden details	0	0	1	0	-1	1	1	0	1	-1	0	1	-1	0	0	0	1	-1
Small curvatures	0	-1	0	-1	-1	1	1	0	1	-1	-1	-1	-1	-1	0	-1	0	0
Shift gear	1	0	1	0	0	1	1	0	1	0	1	1	1	0	0	0	1	0
Overhanging IP	0	0	0	-1	-1	0	1	0	0	0	0	0	0	0	0	0	1	0
Small display	1	0	1	0	0	1	1	0	1	0	1	0	1	0	0	0	1	0
Metal details	0	-1	0	-1	-1	1	1	-1	0	-1	-1	-1	0	-1	-1	-1	-1	-1
Small, round stw	0	-1	1	0	-1	1	1	-1	1	-1	0	1	0	0	0	0	0	1
Sum	6	-8	8	-6	-12	11	17	-8	9	-11	-1	-2	6	-9	0	-8	9	-2
Relative sum	23	9	24	11	5	28	34	9	26	6	16	15	23	8	17	9	26	15
Weight	0.676	0.265	0.706	0.326	0.147	0.824	1	0.265	0.765	0.176	0.471	0.441	0.676	0.235	0.5	0.265	0.765	0.441
Rank						2	1		3								3	
Typicality value						0,938	0,417		0,255								0,064	



	Subtle contrasts in colors and materials	Evident splittines	Big curvatures	Small cutouts in headrest	Discreet	Visible but discreet seams	Armrest	Evident safety functions
Subtle contrasts in colors and materials	1	1	0	1	0	1	1	
Evident splittines	-1	0	-1	0	-1	0	1	
Big curvatures	-1	0	-1	0	-1	0	1	
Small cutouts in headrest	0	1	1	1	0	1	1	
Discreet	-1	0	0	-1	0	1	1	
Visible but discreet seams	0	1	1	0	0	1	1	
Armrest	-1	0	0	-1	-1	-1	1	
Evident safety functions	-1	-1	-1	-1	-1	-1	-1	
Sum	-5	2	2	-5	0	-4	7	
Relative sum	2	9	9	2	7	3	14	
Weight	0.143	0.643	0.643	0.143	0.5	0.214	0.714	
Rank		3	3				2	
Typicality value		0,214	0,498			0,0595	0,417	

XC90 recharge



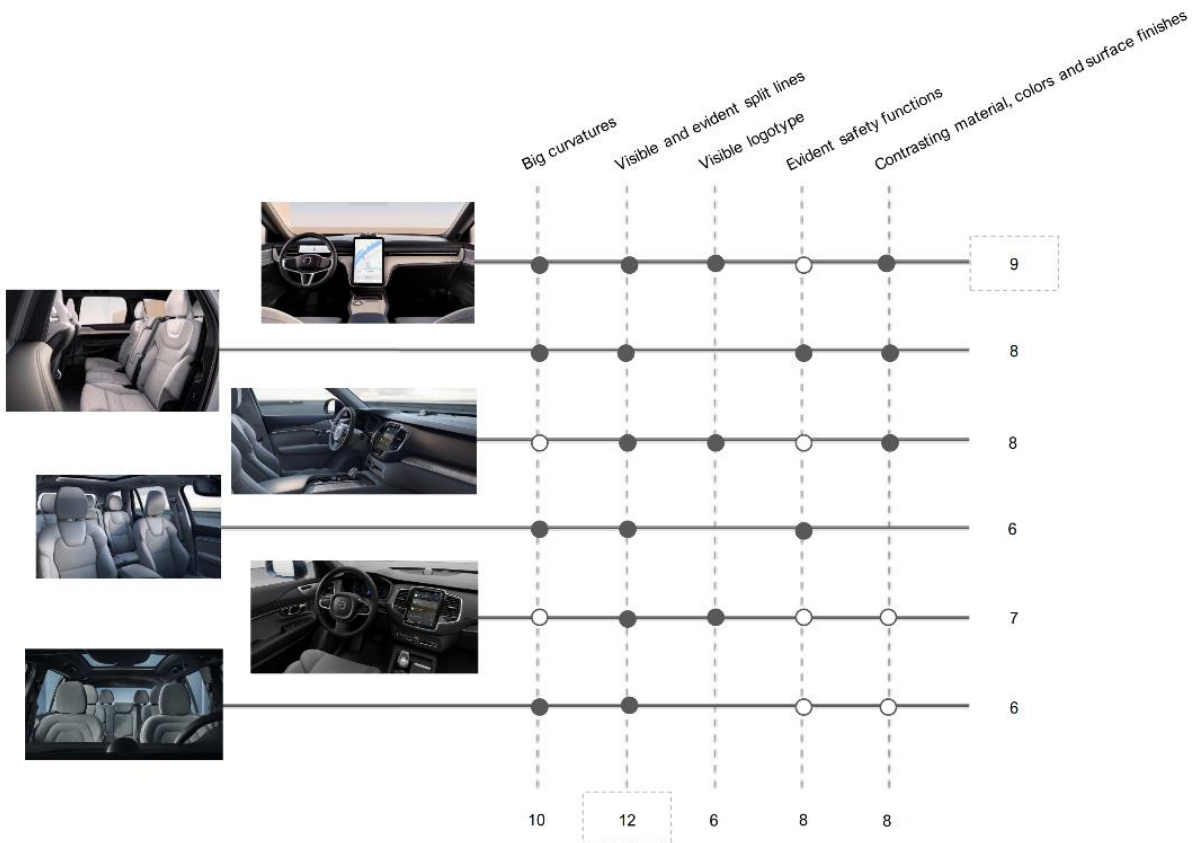
	A lot of buttons	Wooden details	Round stw	Split lines	Overhanging IP	Small display	Metal details	Small curvatures	Shift gear	Not symmetrical	Stalks	Evident safety functions	Visible logo	Discreet, contrasting materials and colors	Big curvatures
A lot of buttons	1	1	1	0	0	1	0	0	0	0	0	1	1	1	1
Wooden details	-1	1	1	1	0	1	1	1	0	1	1	1	1	-1	1
Round stw	-1	-1	1	-1	-1	-1	0	-1	-1	-1	-1	1	-1	-1	0
Split lines	-1	-1	1	0	0	0	0	-1	-1	-1	-1	0	1	0	0
Overhanging IP	0	-1	1	0	0	0	0	-1	-1	0	-1	1	1	-1	0
Small display	0	0	1	0	0	0	1	0	-1	0	0	0	1	-1	1
Metal details	-1	-1	0	0	0	-1	0	-1	-1	-1	0	0	1	0	0
Small curvatures	0	-1	1	1	1	0	1	0	1	0	1	1	1	0	1
Shift gear	0	-1	1	1	1	1	1	-1	0	-1	0	1	1	0	0
Not symmetrical	0	0	1	1	0	0	1	0	1	0	1	1	1	0	1
Stalks	0	-1	1	1	1	0	0	-1	0	-1	0	1	1	-1	0
Evident safety functions	-1	-1	-1	0	-1	0	0	-1	-1	-1	-1	0	0	-1	0
Visible logo	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1
Discreet, contrasting materials and colors	-1	1	1	0	1	1	0	0	0	0	1	1	1	0	1
Big curvatures	-1	-1	0	0	0	-1	0	-1	0	-1	0	0	1	-1	0
Sum	-8	-7	8	4	2	-2	5	-8	0	-8	-1	9	11	-7	5
Relative sum	6	7	22	18	16	12	19	6	14	6	13	23	25	7	19
Weight	0,214	0,25	0,786	0,643	0,571	0,429	0,679	0,214	0,5	0,214	0,464	0,821	0,893	0,25	0,679
Rank			3									2	1		
Typicality value			0,065									0,092	0,149		



	Evident function	Mottled fabric	Different direction of fabrics grains	Visible seams	Big curvatures	Splitlines	Low contrast in seats	Comforting seat	Discreet
Evident function	1	-1	-1	-1	0	0	-1	0	0
Mottled fabric	1	1	0	1	1	1	0	1	1
Different direction of fabrics grains	1	0	1	1	1	1	0	1	1
Visible seams	1	-1	-1	1	0	0	-1	1	0
Big curvatures	0	-1	-1	-1	0	0	-1	0	-1
Splitlines	0	-1	-1	0	0	1	-1	0	-1
Low contrast in seats	1	0	0	1	1	1	1	1	1
Comforting seat	0	-1	-1	-1	0	0	-1	1	-1
Discreet	0	-1	-1	0	1	1	-1	1	0
Sum	4	-6	-6	0	5	4	-6	5	0
Relative sum	12	2	2	8	13	12	2	13	8
Weight	0,75	0,125	0,125	0,5	0,813	0,75	0,125	0,813	0,5
Rank	2			3	1	2		1	3
Typicality value	0,104				0,271	0,25		0,068	

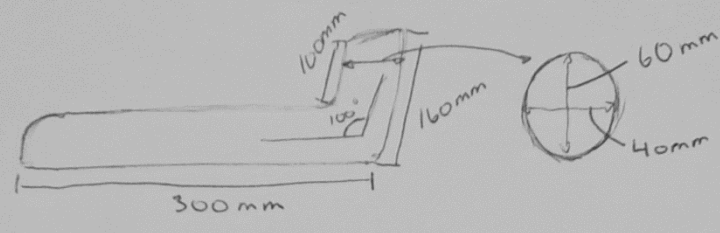


Form element	Occurance value	Frequency	Normalized occurrence value
Visible logotype on the wheel	2/6	3*(2/6)	3*(2/6)/6
No information overload	1/6	1*(1/6)	1*(1/6)/6
Subtle but contasting colors, materials and surface finishes	3/6	4*(3/6)	4*(3/6)/6
Big curvatures	4/6	6*(4/6)	6*(4/6)/6
Evident safety functions	3/6	5*(3/6)	5*(3/6)/6
Pure	1/6	2*(1/6)	2*(1/6)/6
Visible and evident splitlines	2/6	6*(2/6)	6*(2/6)/6
Clear functionality	1/6	5*(1/6)	5*(1/6)/6
Round steering wheel	1/6	3*(1/6)	3*(1/6)/6
Metal detailing	1/6	3*(1/6)	3*(1/6)/6
Armrest	1/6	3*(1/6)	3*(1/6)/6
Comforting seat	1/6	3*(1/6)	3*(1/6)/6

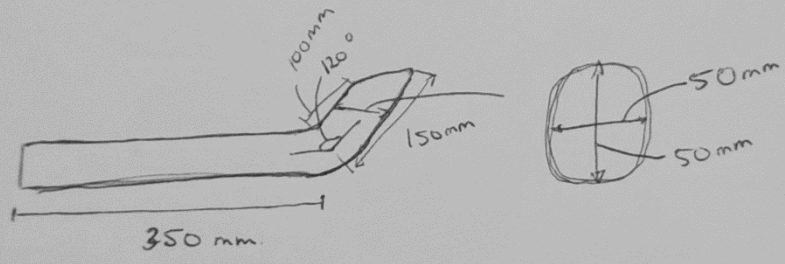


Appendix 2 - Design format analysis.

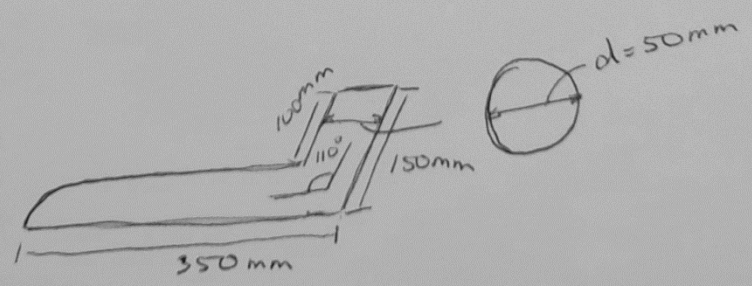
E:



F:

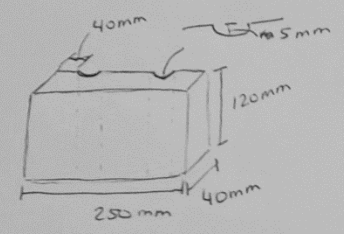


Additional joystick :

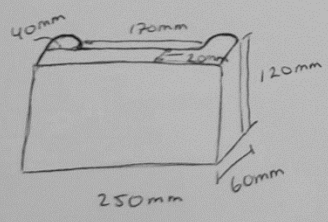


Bricks

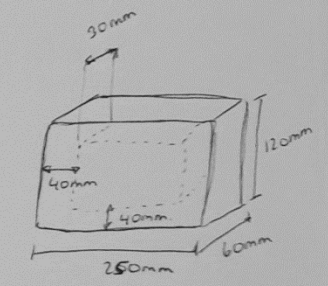
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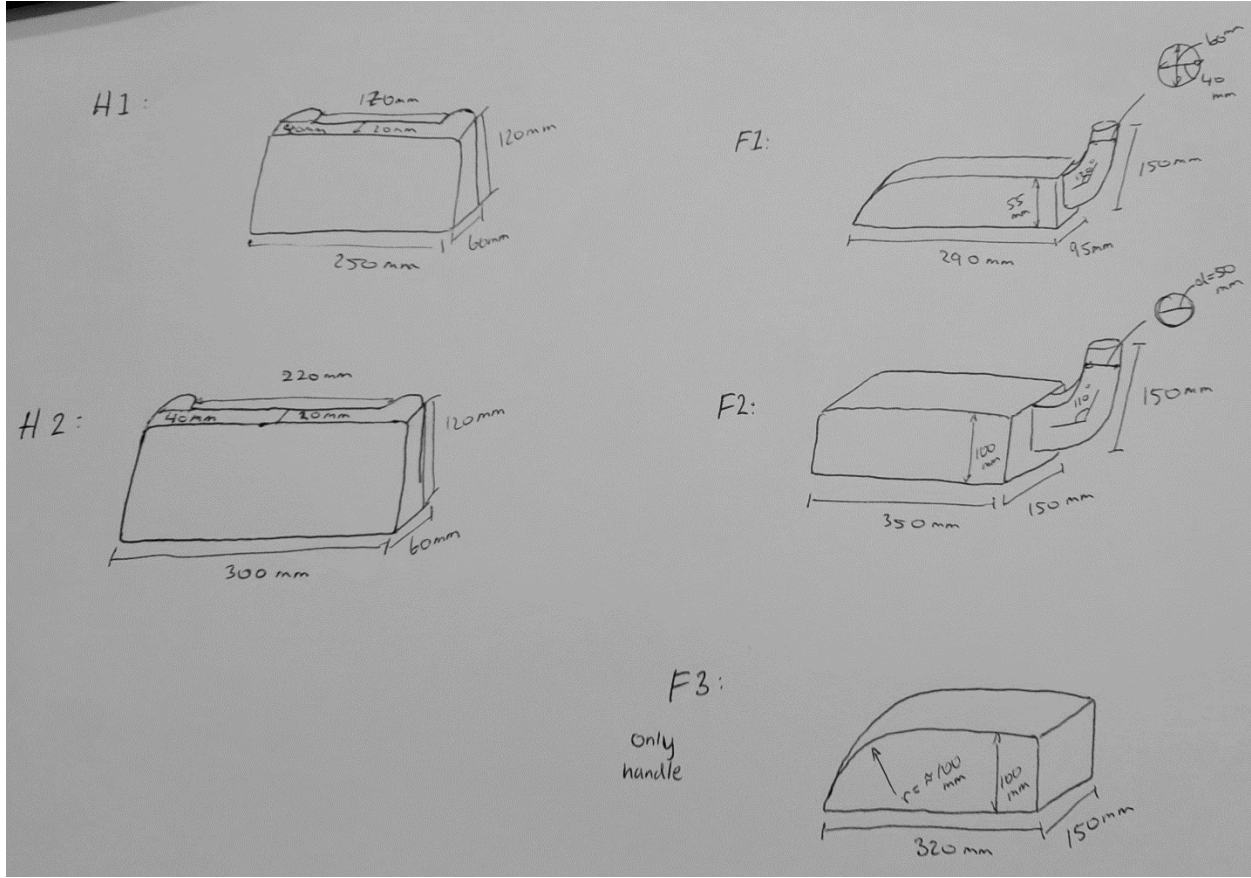


H:

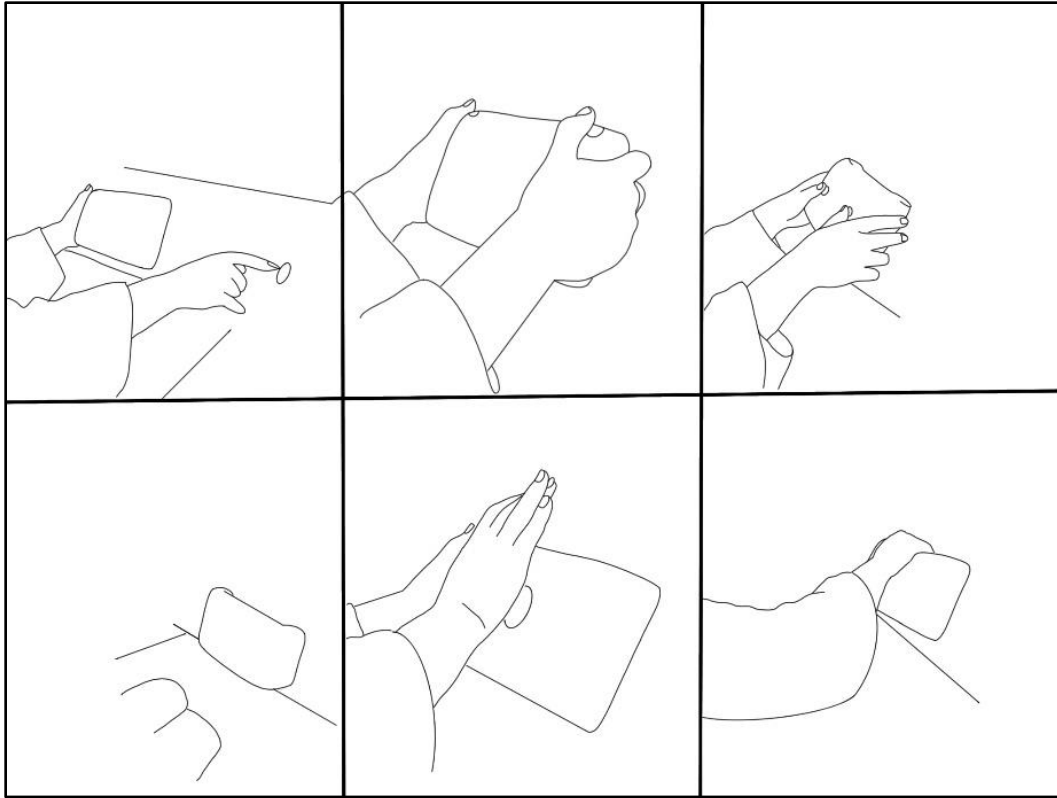


Additional Brick :





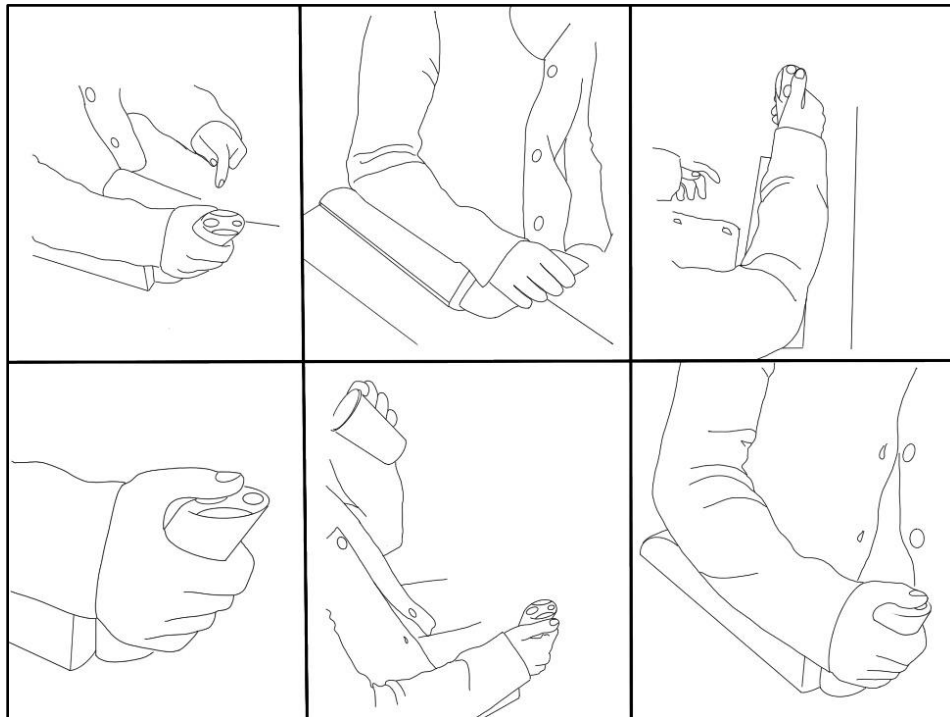
Appendix 3 - Prototype measurements of development loop 2.



a) Initial storyboard of brick after workshop two.



b) Initial storyboard of broad brick after workshop two.



c) Initial storyboard of joystick with tiltable armrest after workshop two.



d) Initial storyboard of joystick with tiltable handle after workshop two.

Design Failure Mode and Effect Analysis (DFMEA)							
Category	Requirements	System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities
	Airbags should protect the driver.	The safety of the driver should not decrease from today's safety.	The safety of the driver has decreased from today.	The driver is not safe.	9	The driver does not feel safe, or in control. Are not able to drive safely, and endangers others.	Consider other safety functions of the car (not just airbags and user's feeling of control).
		The design, position, and time of the airbag should be adapted according to the design of the steering device and the new context of use.	The design, position or time of the airbags are not adapted according to the new steering device.	The airbags is not ensuring the safety of the driver.	10	No relevant airbag to implement. Today's airbags' performances are affected by the design of the steering device.	Look up alternatives of airbags to implement, which is not used to protect the driver in the client's cars nowadays. Check if the concepts affect today's airbags.
		Constructed sequence of cognitive and physical actions for the transition phase. Including timeframe and personal adaptation.	The transition sequence of actions is tricky to understand/ to get right.	The transition phase goes wrong.	9	The driver does not copy with the actions and sequence of transition, hence can not take control, will not use the function, or could endangers others.	Analyze how the transition phase should be designed to benefit most people, regarding preparation time, actions, and stimuli.
	Provides the ability to instantly take control of the lateral steering.	Provides handling "kill switch" to switch to manual mode.	There is no feature to instantly go into manual mode.	The driver can not instantly take control of the vehicle.	8	Control can not be taken instantly, hence could endanger others and the driver's safety.	Check if the driver physically can take over the control in short time.
<b>Safety of the Driver</b>		All primary lateral steering functions are available in manual mode.	The steering device lacks important steering functions, correctly and ensure the safety.	The driver can not control the vehicle correctly and ensure the safety.	9	The steering device has no space or has not included these functions.	Analyze if the primary driving-related functions is available with design of the steering device.
	Provide low cognitive load.	Few commands to handle during the transition phase.	Too many commands to handle during transition phase.	The transition phase leads to misuse.	9	The design has not taken "less-is-more" into consideration when balancing the transition load.	Understand how to balance the sensory stimuli, actions and information with the most necessary steps.
		Functions that are easy to understand.	Physical buttons that are not easy to understand or in an odd position.	The driver misuses the buttons or does not use them.	8	The design is not easy-to-use in regards of reachability.	Analyze with regards to ergonomics what is enough reachability.
		Connect the feedforward of functions with logical feedback of actions.	The feedforward of actions is not logically connected to the feedback.	The driver gets confused of his/her actions.	8	The design of the buttons lack understanding of logical feedforward and feedback.	Analyze logical connections between feedforward and feedback.
	Ensure correct usage.	Minimize risk of interfering with the driving during AD mode.	There is a risk of activating AD without being aware of it.	AD is activated during manual mode without knowing.	9	The AD button is too much within reach.	Consider placing the AD function in an area away from where the driver is likely to be touching or in a zone where the driver might touch during AD mode.
		No risk of accidentally touching buttons when using the steering device.	It is possible to accidentally click on buttons during usage.	Functions are activated without knowledge.	8	The buttons placement is within reach and within the area of hand placement.	Analyze with regards to ergonomics what is enough reachability, frequency of use and risk of misuse.
	Have continual presence of traditional driving-related information.	All primary driving-related information should be in one place.	The driving-related information is spread out with little logic.	The driver need to search/look for information, hence no eyes on the road.	7	Implementation of the idea of information overload wrongly.	Sort and select what driving-related information and functions are necessary, and implement carefully.
		Avoid informational overload.	There are too much information present at the same time.	The driver gets information overload.	6	Too much information presented or functions available.	Minimize the amount of not necessary information unless specifically asked by the driver.
<b>Eyes on the Road</b>	Provide feedback of actions without loading.	Use physical buttons to keep the eyes on the road.	The physical buttons do not provide enough feedback to keep the eyes on the road.	The driver can not activate functions without looking at the buttons.	7	The buttons are too small or too "invisible".	Analyze placement of functions, sizes and physical feedback of buttons and how to cluster correctly.
		Use haptic/visual feedback for actions.	The haptic/visual feedback is not logical.	The driver gets confused of the information and gets information overload.	6	The button responds in some way, not reflecting on what reaction it triggers.	Investigate what reaction should be triggered when implementing haptic/visual feedback.

Category	Requirements	System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities
Offer Comfort	Guarantees a comfortable grip and range of the steering wheel for different sizes of hands.	Consider anthropometric measurements. Avoid sharp edges in the design that feels uncomfortable.	The grip is not comfortable for different sizes of hands. There are uncomfortable edges in the design.	The driver is uncomfortable. The driver is uncomfortable.	6	The shape of the design has overwhelmed the comfortability and usability of the steering device.	Take measurements of the majority of potential human users. Round all uncomfortable edges.
	Low effort and minimum strain on the body.	Stive for low muscle activity and low angles/torques of joints when using the steering device.	The usage of the steering device involves high muscle activity and/or many repetitions of joints. The weights on the steering device is not comfortable.	The steering device puts strain to the body of the driver over a period of time. The driver can not reach torques and/or is uncomfortable when reaching.	5	Low understanding of ergonomics.	Check ergonomics and reachability with the client. Understand their expectations and framework.
	Stive for a "universal design"	Provide comfortable reachability for the hands of the steering limitations.	Less people are able to use cars due to the design of the steering device.	The design is not universal or fitting for a broad user group.	6	The design is limited in use and function (cognitive and sensory).	Understand usage limitations and translate that to the design of the steering device.
	Prevent sensor contact to avoid motion sickness.	Let the driver sense the steering while in AD mode.	The driver is not able to sense the steering during AD mode.	The driver gets motion sick.	6	The car does not communicate its actions with the driver.	Investigate how to make the driver feel the cars forces and actions in a pleasant way.
Roominess for NDRTs	Provides the opportunity to focus on NDRTs when in AD mode.	Give the driver sensory cues of the tip during AD mode. Put information in central vision and at eye level so the driver can keep track of the road when perceived vision during AD mode to help connect sensor feedback while driving.	The sensory cues of the tip is not logical and/or conflicting. The position of the information is not counteracting the presence of motion sickness while driving.	The driver gets motion sick.	6	Low understanding of sensory stimuli or sensory overload.	Understand how to implement sensory cues. Further understand how to counteract motor sickness and sensory overload.
	Increase the space for the driver through the design and position of the steering device.	The driver should be able to attend to relaxation, working, and socializing activities.	The driver is not able to attend to relaxation, working and socializing activities.	The driver do not want to use the AD function.	6	The driver does not feel able to let go of the control.	Check on how to strengthen the communication between car and driver, and how to increase the feeling of control.
		Be able to adjust the steering device for physical differences and/or preferences.	The steering device can not be adjusted to physical differences and/or preferences.	The driver is uncomfortable or has little control.	7	The Steer by Wire handles inclusive and adaptive design features.	Investigate what we can do and account with Steer-by-Wire.
		Implement steer by wire to gain more design freedom.	The design freedom is restricted by steer by wire.	The steering device can not be implemented, hence is not realisable.	9	The adaptation and technology does not match the innovation.	Do not compromise on safety, initial estimate and assume how the thing could be allowed or implemented for future use.
Trust building	The steering device should be intuitive.	Change the design of the wiring and/or the position to make more space.	The design and/or the position of the wiring decreases the space.	The driver is uncomfortable, and/or the steering device can not be implemented in a convenient and comfortable way.	7	Not able to compromise between technology and design due to safety hazards.	
		A familiar design or interface of the steering device works as an enabler for user-focus.	The steering device is not familiar enough.	The driver has problems with using the steering device.	8	What is familiar to them might not be perceived as familiar in the future.	Find future familiarity with future potential users, and understand and implement future trends.
	Reliability should be expressed through the form and/or shape of the steering device.	The driver should perceive behavioral control through haptic all.	The driver does not trust the steering device to provide control of the vehicle.	The driver does not want to use the steering device and relinquish the car.	8	Defective delivered or presented information and functions.	Analyze how the product are creating trust and control, as well as what to further develop.
	Use attractive design and high quality to increase the user trust of the steering device.	Soft and friendly shapes are preferred over sharp and aggressive form language.	There are too many sharp edges and comes in the design.	The steering device is not perceived as reliable or comfortable.	8	Could be grounded in misunderstanding of the clients design language or a misunderstanding regarding construction.	Analyze potential structure limitations, and sync with the client.
		Strong connection to the client's form language to connect with the strong position of the brand.	The steering device is not perceived as an extension and is not associated with the client's design language.	The steering device is not making sense if does not fit in the client's product portfolio.	9	Insistent choices of material, surface finishes, etc. are positive, but contrast, shape and overall safety features.	Analyze the client's mood further and check with them regarding their future material choice and preferences of manufacturing.

Category:	Criteria:	Solution Alternative									
		Weight	IDEAL			A		B		C	
			Value	Total (WxV)	V	T	V	T	V	T	
Name											
Safety of the Driver	The safety of the driver should not decrease from today's safety.	10	10	100	9	90	9	90	9	90	
	Airbags should protect the driver.	10	10	100	9	90	8	80	9	90	
	Ability to instantly take control of the lateral steering.	9	10	90	6	54	8	72	7	63	
	All primary lateral steering functions are available in manual mode.	10	10	100	8	80	9	90	9	90	
	Provides low cognitive strain	8	10	80	8	64	8	64	8	64	
	Few commands to handle during the transition phase.	7	10	70	8	56	7	49	8	56	
	Functions/buttons are easy to understand.	7	10	70	9	63	8	56	8	56	
	Ensure correct usage.	9	10	90	8	72	9	81	8	72	
	Low risk of intervening with the driving during AD mode.	9	10	90	9	81	8	72	8	72	
No risk of accidentally touching buttons when using the steering device.	7	10	70	6	42	7	49	6	42		
Eyes on the road	All primary driving-related information is placed in one place.	6	10	60	9	54	9	54	9	54	
	Physical buttons to keep the eyes on the road.	5	10	50	7	35	8	40	7	35	
	Haptic/visual/audio feedback for actions.	7	10	70	8	56	8	56	8	56	
Offer comfort	Offers a comfortable grip and usage of the steering device for different sizes of hands.	7	10	70	6	42	7	49	7	49	
	Inline with "Universal design"	5	10	50	6	30	7	35	6	30	
	Low effort and minimum strain on the body.	8	10	80	7	56	8	64	6	42	
	Provides comfortable reachability.	7	10	70	7	49	7	49	7	49	
	Gives the driver sensory cues of the trip during AD mode.	7	10	70	7	49	8	56	7	49	
	Information in central vision and at eye level.	6	10	60	8	48	7	35	8	48	
Roominess	Adjustable steering device	8	10	80	8	64	8	64	7	56	
	Increased space/roominess for the driver when in AD.	8	10	80	8	64	6	48	8	64	
Trust Building	A familiar design/interface of the steering device.	7	10	70	8	56	9	63	8	56	
	Perceived behavioral control through looking at the steering device.	7	10	70	7	49	9	63	8	56	
	Has soft and friendly shapes (no hard edges)	7	10	70	5	35	7	49	8	56	
	Cohesive with the client's form language	9	10	90	6	54	7	63	8	72	
Total:			250	1900	187	1433	196	1491	192	1467	
Rank:					3		1		2		

Category:	Criteria:	Solution Alternative								
		Weight	Value	Total (WxV)	A		B		C	
					V	T	V	T	V	T
Name										
Safety of the Driver	The safety of the driver should not decrease from today's safety.	10	10	100	9	90	9	90	9	90
	Airbags should protect the driver.	10	10	100	9	90	8	80	9	90
	Ability to instantly take control of the lateral steering.	9	10	90	6	54	8	72	7	63
	All primary lateral steering functions are available in manual mode.	10	10	100	8	80	9	90	9	90
	Provides low cognitive strain	8	10	80	8	64	8	64	8	64
	Few commands to handle during the transition phase.	7	10	70	8	56	7	49	8	56
	Functions/buttons are easy to understand.	7	10	70	9	63	8	56	8	56
	Ensure correct usage.	9	10	90	8	72	9	81	8	72
	Low risk of intervening with the driving during AD mode.	9	10	90	9	81	8	72	8	72
	No risk of accidentally touching buttons when using the steering device.	7	10	70	6	42	7	49	6	42
Total:				80	692	81	703	80	695	
Rank:					3		1		2	
Decision:		From a safety perspective, B wins, with A and C nearby.								

Category:	Criteria:	Solution Alternative								
		IDEAL			A		B		C	
		Weight	Value	Total (WxV)	V	T	V	T	V	T
Eyes on the road	All primary driving-related information is placed in one place.	6	10	60	9	54	9	54	9	54
	Physical buttons to keep the eyes on the road.	5	10	50	7	35	8	40	7	35
	Haptic/visual/audio feedback for actions.	7	10	70	8	56	8	56	8	56
Total:					24	145	25	150	24	145
Rank:						2		1		2
Decision:		With regard to eyes on the road, B ranks highest, five points lower for A and C.								

Category:	Criteria:	Solution Alternative								
		IDEAL			A		B		C	
		Weight	Value	Total (WxV)	V	T	V	T	V	T
Offer comfort	Offers a comfortable grip and usage of the steering device for different sizes of hands.	7	10	70	6	42	7	49	7	49
	Inline with "Universal design"	5	10	50	6	30	7	35	6	30
	Low effort and minimum strain on the body.	8	10	80	7	56	8	64	6	42
	Provides comfortable reachability.	7	10	70	7	49	7	49	7	49
	Gives the driver sensory cues of the trip during AD mode.	7	10	70	7	49	8	56	7	49
	Information in central vision and at eye level.	6	10	60	8	48	7	35	8	48
Total:					41	274	44	288	41	267
Rank:						2		1		3
Decision:		With regards to comfort, B wins by about 14 points over A, and C by a further 7 points less.								

Category:	Criteria:	Solution Alternative								
		IDEAL			A		B		C	
		Weight	Value	Total (WxV)	V	T	V	T	V	T
Roominess	Adjustable steering device	8	10	80	8	64	8	64	7	56
	Increased space/roominess for the driver when in AD.	8	10	80	8	64	6	48	8	64
Total:			20	160	16	128	14	112	15	120
Rank:						1		3		2
Decision:		In terms of roominess, A wins, 8 points lower for C and 8 points between C and B.								

Category:	Criteria:	Solution Alternative								
		IDEAL			A		B		C	
		Weight	Value	Total (WxV)	V	T	V	T	V	T
Trust Building	A familiar design/interface of the steering device.	7	10	70	8	56	9	63	8	56
	Perceived behavioral control through looking at the steering device.	7	10	70	7	49	9	63	8	56
	Has soft and friendly shapes (no hard edges)	7	10	70	5	35	7	49	8	56
	Cohesive with the client's form language	9	10	90	6	54	7	63	8	72
Total:			40	300	26	194	32	238	32	240
Rank:						3		2		1
Decision:		Regarding trust, C is winning with 2 points over B, and A behind with 34 points.								

Appendix 6 – Kesselring matrix.

## RULA Employee Assessment Worksheet

Complete this worksheet following the step-by-step procedure below. Keep a copy in the employee's personnel folder for future reference.

### A. Arm & Wrist Analysis

**Step 1: Locate Upper Arm Position**

**Step 1a: Adjust...**

If shoulder is raised: +1  
If upper arm is above head: +1  
If arm is supported or person is leaning: 0  
Final Upper Arm Score = 3

**Step 2: Locate Lower Arm Position**

**Step 2a: Adjust...**

If arm is working across middle of the body: +1  
If arm out to side of body: 0  
Final Lower Arm Score = 2

**Step 3: Locate Wrist Position**

**Step 3a: Adjust...**

If wrist is bent from the midline: +1  
Final Wrist Score = 1

**Step 4: Wrist Twist**

If wrist is twisted in mid-range = 1  
If twist at or near end of range = 2  
Wrist Twist Score = 2

**Step 5: Look-up Posture Score in Table A**

Use values from steps 1, 2, 3 & 4 to locate Posture Score in Table A

Posture Score A = 3

**Step 6: Add Muscle Use Score**

If posture mainly static (i.e. held for longer than 1 minute) or:  
if action repeatedly occurs 4 times per minute or more: +1  
Muscle Use Score = 1

**Step 7: Add Force/load Score**

If load less than 2 kg (intermittent): 0  
If 2 kg to 10 kg (intermittent): +1  
If 2 kg to 10 kg (static or repeated): +2  
If more than 10 kg load or repeated or shocks: +3  
Force/load Score = 0

**Step 8: Find Row in Table C**

The combined score from the Neck, Trunk & Leg analysis is used to find the row on Table C

Final Wrist & Arm Score = 4

### SCORES

**Table A**

Upper Arm	Lower Arm	Wrist	1	2	3	4
1	1	1	1	2	3	4
1	2	1	2	3	4	5
1	3	1	3	4	5	6
2	1	1	2	3	4	5
2	2	1	3	4	5	6
2	3	1	4	5	6	7
3	1	1	3	4	5	6
3	2	1	4	5	6	7
3	3	1	5	6	7	8
4	1	1	4	5	6	7
4	2	1	5	6	7	8
4	3	1	6	7	8	9
5	1	1	5	6	7	8
5	2	1	6	7	8	9
5	3	1	7	8	9	10
6	1	1	6	7	8	9
6	2	1	7	8	9	10
6	3	1	8	9	10	11

**Table B**

Neck	1	2	3	4	5	6
1	1	2	3	4	5	6
2	2	3	4	5	6	7
3	3	4	5	6	7	8
4	4	5	6	7	8	9
5	5	6	7	8	9	10
6	6	7	8	9	10	11

**Table C**

1	2	3	4	5	6	7
1	1	2	3	4	5	6
2	2	3	4	5	6	7
3	3	4	5	6	7	8
4	4	5	6	7	8	9
5	5	6	7	8	9	10
6	6	7	8	9	10	11

### B. Neck, Trunk & Leg Analysis

**Step 9: Locate Neck Position**

**Step 9a: Adjust...**

If neck is tilted: +1  
If neck is side-bending: +1  
Final Neck Score = 1

**Step 10: Locate Trunk Position**

**Step 10a: Adjust...**

If trunk is tilted: +1  
If trunk is side-bending: +1  
Final Trunk Score = 2

**Step 11: Legs**

If legs & feet supported and balanced: +1  
If not: +2  
Final Leg Score = 1

**Step 12: Look-up Posture Score in Table B**

Use values from steps 9, 10 & 11 to locate Posture Score in Table B

Posture B Score = 2

**Step 13: Add Muscle Use Score**

If posture mainly static or:  
if action 4 times or more: +1  
Muscle Use Score = 1

**Step 14: Add Force/load Score**

If load less than 2 kg (intermittent): 0  
If 2 kg to 10 kg (intermittent): +1  
If 2 kg to 10 kg (static or repeated): +2  
If more than 10 kg load or repeated or shocks: +3  
Force/load Score = 0

**Step 15: Find Column in Table C**

The combined score from the Neck, Trunk & Leg analysis is used to find the column on Chart C

Final Neck, Trunk & Leg Score = 3

Subject: \_\_\_\_\_ Date: 11 / 4 / 23  
Company: \_\_\_\_\_ Department: \_\_\_\_\_ Scorer: \_\_\_\_\_

**FINAL SCORE: 1 or 2 = Acceptable; 3 or 4 investigate further; 5 or 6 investigate further and change soon; 7 investigate and change immediately**

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a) Fixed joystick, tilting (A).

## RULA Employee Assessment Worksheet

Complete this worksheet following the step-by-step procedure below. Keep a copy in the employee's personnel folder for future reference.

### A. Arm & Wrist Analysis

**Step 1: Locate Upper Arm Position**

**Step 1a: Adjust...**

If shoulder is raised: +1  
If upper arm is above head: +1  
If arm is supported or person is leaning: 0  
Final Upper Arm Score = 2

**Step 2: Locate Lower Arm Position**

**Step 2a: Adjust...**

If arm is working across middle of the body: +1  
If arm out to side of body: 0  
Final Lower Arm Score = 3

**Step 3: Locate Wrist Position**

**Step 3a: Adjust...**

If wrist is bent from the midline: +1  
Final Wrist Score = 1

**Step 4: Wrist Twist**

If wrist is twisted in mid-range = 1  
If twist at or near end of range = 2  
Wrist Twist Score = 0

**Step 5: Look-up Posture Score in Table A**

Use values from steps 1, 2, 3 & 4 to locate Posture Score in Table A

Posture Score A = 2

**Step 6: Add Muscle Use Score**

If posture mainly static (i.e. held for longer than 1 minute) or:  
if action repeatedly occurs 4 times per minute or more: +1  
Muscle Use Score = 1

**Step 7: Add Force/load Score**

If load less than 2 kg (intermittent): 0  
If 2 kg to 10 kg (intermittent): +1  
If 2 kg to 10 kg (static or repeated): +2  
If more than 10 kg load or repeated or shocks: +3  
Force/load Score = 0

**Step 8: Find Row in Table C**

The combined score from the Neck, Trunk & Leg analysis is used to find the row on Table C

Final Wrist & Arm Score = 3

### SCORES

**Table A**

Upper Arm	Lower Arm	Wrist	1	2	3	4
1	1	1	1	2	3	4
1	2	1	2	3	4	5
1	3	1	3	4	5	6
2	1	1	2	3	4	5
2	2	1	3	4	5	6
2	3	1	4	5	6	7
3	1	1	3	4	5	6
3	2	1	4	5	6	7
3	3	1	5	6	7	8
4	1	1	4	5	6	7
4	2	1	5	6	7	8
4	3	1	6	7	8	9
5	1	1	5	6	7	8
5	2	1	6	7	8	9
5	3	1	7	8	9	10
6	1	1	6	7	8	9
6	2	1	7	8	9	10
6	3	1	8	9	10	11

**Table B**

Neck	1	2	3	4	5	6
1	1	2	3	4	5	6
2	2	3	4	5	6	7
3	3	4	5	6	7	8
4	4	5	6	7	8	9
5	5	6	7	8	9	10
6	6	7	8	9	10	11

**Table C**

1	2	3	4	5	6	7
1	1	2	3	4	5	6
2	2	3	4	5	6	7
3	3	4	5	6	7	8
4	4	5	6	7	8	9
5	5	6	7	8	9	10
6	6	7	8	9	10	11

### B. Neck, Trunk & Leg Analysis

**Step 9: Locate Neck Position**

**Step 9a: Adjust...**

If neck is tilted: +1  
If neck is side-bending: +1  
Final Neck Score = 1

**Step 10: Locate Trunk Position**

**Step 10a: Adjust...**

If trunk is tilted: +1  
If trunk is side-bending: +1  
Final Trunk Score = 2

**Step 11: Legs**

If legs & feet supported and balanced: +1  
If not: +2  
Final Leg Score = 1

**Step 12: Look-up Posture Score in Table B**

Use values from steps 9, 10 & 11 to locate Posture Score in Table B

Posture B Score = 2

**Step 13: Add Muscle Use Score**

If posture mainly static or:  
if action 4 times or more: +1  
Muscle Use Score = 1

**Step 14: Add Force/load Score**

If load less than 2 kg (intermittent): 0  
If 2 kg to 10 kg (intermittent): +1  
If 2 kg to 10 kg (static or repeated): +2  
If more than 10 kg load or repeated or shocks: +3  
Force/load Score = 0

**Step 15: Find Column in Table C**

The combined score from the Neck, Trunk & Leg analysis is used to find the column on Chart C

Final Neck, Trunk & Leg Score = 3

Subject: \_\_\_\_\_ Date: 11 / 4 / 23  
Company: \_\_\_\_\_ Department: \_\_\_\_\_ Scorer: \_\_\_\_\_

**FINAL SCORE: 1 or 2 = Acceptable; 3 or 4 investigate further; 5 or 6 investigate further and change soon; 7 investigate and change immediately**

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b) Fixed joystick, sliding (B).

# RULA Employee Assessment Worksheet

Complete this worksheet following the step-by-step procedure below. Keep a copy in the employee's personnel folder for future reference.

### A. Arm & Wrist Analysis

**Step 1: Locate Upper Arm Position**

**Step 1a: Adjust...**  
If shoulder is raised: +1  
If upper arm is abducted: +1  
If arm is supported or person is leaning: 0

**Final Upper Arm Score = 1**

**Step 2: Locate Lower Arm Position**

**Step 2a: Adjust...**  
If arm is working across the middle of the body: +1  
If arm not to side of body: 0

**Final Lower Arm Score = 2**

**Step 3: Locate Wrist Position**

**Step 3a: Adjust...**  
If wrist is bent from the middle: +1

**Final Wrist Score = 1**

**Step 4: Wrist Twist**  
If wrist is twisted in mid-range: 1  
If wrist is twisted at or near end of range: 2

**Wrist Twist Score = 2**

**Step 5: Look-up Posture Score in Table A**  
Use values from steps 1, 2, 3, & 4 to locate Posture Score in Table A

**Posture Score A = 2**

**Step 6: Add Muscle Use Score**  
If posture mainly static (i.e. held for longer than 1 minute) at: 0  
If action repeatedly occurs 4 times per minute or more: +1

**Muscle Use Score = 1**

**Step 7: Add Force/load Score**  
If load less than 2 kg (intermittent): +0  
If 2 kg to 10 kg (intermittent): +1  
If 2 kg to 10 kg (static or repeated): +2  
If more than 10 kg load or repeated or shocks: +3

**Force/load Score = 0**

**Step 8: Find Row in Table C**  
The completed score from the Arm/Wrist analysis is used to find the row on Table C

**Final Wrist & Arm Score = 3**

### SCORES

**Table A**

Upper Arm	Lower Arm	Wrist	Wrist Twist	Posture Score
1	1	1	1	1
1	1	1	2	2
1	1	2	1	3
1	1	2	2	4
1	2	1	1	5
1	2	1	2	6
1	2	2	1	7
1	2	2	2	8
2	1	1	1	9
2	1	1	2	10
2	1	2	1	11
2	1	2	2	12
2	2	1	1	13
2	2	1	2	14
2	2	2	1	15
2	2	2	2	16

**Table B**

Neck	Trunk	Legs	Posture Score B
1	1	1	1
1	1	2	2
1	1	3	3
1	2	1	4
1	2	2	5
1	2	3	6
1	3	1	7
1	3	2	8
1	3	3	9
2	1	1	10
2	1	2	11
2	1	3	12
2	2	1	13
2	2	2	14
2	2	3	15
2	3	1	16
2	3	2	17
2	3	3	18

**Table C**

Final Wrist & Arm Score	Final Neck, Trunk & Leg Score	Final Score
1	1	1
1	2	2
1	3	3
2	1	4
2	2	5
2	3	6
3	1	7
3	2	8
3	3	9

### B. Neck, Trunk & Leg Analysis

**Step 9: Locate Neck Position**

**Step 9a: Adjust...**  
If neck is bent: +1  
If neck is side-bending: +1

**Final Neck Score = 1**

**Step 10: Locate Trunk Position**

**Step 10a: Adjust...**  
If trunk is bent: +1  
If trunk is side-bending: +1

**Final Trunk Score = 1**

**Step 11: Legs**

**Step 11a: Adjust...**  
If legs & feet supported and balanced: +1  
If not: +2

**Final Leg Score = 1**

**Step 12: Look-up Posture Score in Table B**  
Use values from steps 9, 10 & 11 to locate Posture Score in Table B

**Posture Score B = 2**

**Step 13: Add Muscle Use Score**  
If posture mainly static or: 0  
If action 4 minutes or more: +1

**Muscle Use Score = 1**

**Step 14: Add Force/load Score**  
If load less than 2 kg (intermittent): +0  
If 2 kg to 10 kg (intermittent): +1  
If 2 kg to 10 kg (static or repeated): +2  
If more than 10 kg load or repeated or shocks: +3

**Force/load Score = 0**

**Step 15: Find Column in Table C**  
The completed score from the Neck/Trunk & Leg analysis is used to find the column on Chart C

**Final Neck, Trunk & Leg Score = 2**

**Final Score = 3**

Subject: \_\_\_\_\_ Date: 11 / 4 / 23  
 Company: \_\_\_\_\_ Department: \_\_\_\_\_ Scorer: \_\_\_\_\_

FINAL SCORE: 1 or 2 = Acceptable; 3 or 4 investigate further; 5 or 6 investigate further and change soon; 7 investigate and change immediately  
 © Professor Alan Hedge, Cornell University, Nov. 2000

c) Moveable handle joystick (C).