Automated car interior layout design based on user activities

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Master thesis
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Summary

The evolution of the automated driving industry liberates users from driving tasks, thus creating more time for Non-Driving-Related activities (NDRAs), thereby transforming the car from a mere mode of transport to a mobile activity platform. This shift presents two main challenges: predicting the type of activities passengers will engage in within the automated cars and adapting the car’s interior design to accommodate these activities. This project tackles these challenges with a focus on comfort, ergonomics, and user activity, promising valuable insights for the interior design of future automated vehicles.

A rigorous review of literature spanning 2014 to 2023 was conducted, with a focus on NDRAs in automated vehicles. The review retrieved 2315 papers from various databases, from which 47 articles encapsulating 66 cases and 50 types of activities were selected based on strict eligibility criteria. These activities were then categorized into 13 clusters, with the top five being Entertainment and online activities, Work and productivity, Interpersonal communication and interaction, Sleep and relaxation, and Observation and monitoring.

An exploratory experiment was conducted within a simulated automated vehicle environment to study the ergonomic and spatial needs of five significant NDRAs. These activities were the most representative of each of the five main clusters: talking to passengers, looking out the window, working on a computer, sleeping, and using an iPad for entertainment. This investigation filled a crucial research gap, providing valuable insights for designing more ergonomic and comfortable interiors for future automated vehicles.

The project further leveraged 3D modeling and Augmented Reality (AR) technologies to analysis the spatial requirements of users engaging in the identified NDRAs within a Range Rover Evoque. The research indicates that the current interior design of the Range Rover Evoque can accommodate average-sized (P50) users performing 5 major Non-Driving-Related activities at small or medium comfort joint angles, yet struggles to support larger comfortable joint angles, particularly for activities such as sleeping, entertainment, or work. The results suggest a future design could include slimmer seats and dashboards and potentially transition from a four-seater layout to a two or three-seater layout to provide more space for users for activities.

After evaluation of initial concepts for future automated vehicle interior design, I have combined their strengths and minimized their shortcomings to develop a final iteration. This design focuses on flexible space allocation by incorporating a slim dashboard and thinner seats and can shift between a standard four-seat configuration to a 2 or 3-seater layout, and include independent seats, and an adjustable table to cater to various user needs, setting the stage for the future of comfortable Non-Driving-Related activities within vehicles.

In conclusion, this project integrates theoretical and practical approaches, focusing on user activities and comfort in automated vehicles. The study leaves out considerations of commercial viability, manufacturing, and socio-cultural aspects. Future improvements should include these factors and align design with commercial and manufacturing realities.

Chapter 1. Introduction

1.1 Background

The evolution of the automated driving industry has seen growth fast over the past decade, and the implications of this progress are far-reaching. The Society of Automotive Engineering (SAE) classifies the levels of automated driving into six levels, spanning from Level 0, fully manual driving, to Level 5, or Full Automated Driving (FAD) (SAE International, 2021). Each level of automation has its unique characteristics and requirements, as illustrated in Figure 1. Market predictions suggest that by 2030, an estimated 12 percent of new passenger cars will feature Level 3 or higher autonomous technologies, contributing to an impressive revenue potential of $300 to $400 billion by 2035, as per a McKinsey analysis (Deichmann et al., 2023).

The safety enhancements, the value of time, and resource optimization brought forth by automated vehicles underpin the growing interest and investment in the sector. Research indicates that human error plays a significant role in approximately 94 percent of all fatal crashes (Chao, n.d.). Thus, by mitigating human error, automated vehicles have the potential to dramatically reduce injuries and save lives. Moreover, environment perception, navigation, path planning, and other autonomous technologies can equip these vehicles with capabilities to enhance resource allocation, improve road capacity, mitigate traffic congestion, decrease labor needs, and even minimize fuel wastage (Bagloee et al., 2016).

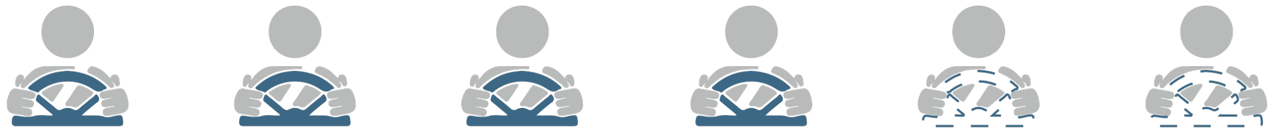
Furthermore, self-driving technology can free drivers from the task of driving, facilitating the performance of additional activities that were previously inconceivable when humans were in control. And as self-driving cars become more automated, users have more and more time to spend on Non-Driving-Related activities (see Table 1 for a detailed explanation). Consequently, the role of humans is gradually shifting from drivers to passengers, transforming the vehicle from merely a means of transport to a mobile activity platform.

Yet, since there are currently no consumer-available vehicles on the market that genuinely achieve Level 3 automation or above, Non-Driving-Related activities that users will engage in remain ambiguous. This poses the first challenge - determining the types of Non-Driving-Related activities passengers will engage in during their journey.

The transformation in human activities within the vehicle implies an alteration in the vehicle's functionality, necessitating a corresponding change in the design of the car's interior. This presents the second challenge - determining how the interior of automated cars should adapt to accommodate this shift in human activities.

In conclusion, exploring these challenges is a viable way to shape the future of the automated vehicle interior. The significance of this study lies in its human-centric approach, focusing on user activities within the vehicle. This path of research promises to provide valuable insights for the interior design of automated vehicles, derived from user comfort and ergonomic perspectives.

Level of automation (SAE)



0	1	2	3	4	5
No Automation Zero autonomy; the driver performs all driving tasks.	**Driver Assistance** Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	**Partial Automation** Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at al times.	**Conditional Automation** Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.	**High Automation** The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	**Full Automation** The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

Figure 1. Level of automation (SAE)

Non-Driving-Related activities

Kern & Schmidt (2009) classified driver tasks in traditional vehicles into three types. The primary driving tasks encompass all necessary actions to navigate to a destination, while secondary tasks, such as using a turn signal, support but are not vital to the driving process. Tertiary tasks include activities unrelated to the act of driving, such as operating infotainment systems. As automation increases, the human role transitions from driver to passenger. As a result, the importance of former primary and secondary driving tasks decreases, giving prominence to previously tertiary tasks. To mitigate potential confusion, Pfleging & Schmidt (2015) recommended categorizing the primary and secondary tasks as Driving-Related Activities or Tasks, and tertiary tasks as Non-Driving-Related Activities (NDRAs).

Table 1. Terminology update

<table>
<tr><th>Tasks in manual cars</th><th>Updated terminology</th></tr>
<tr><td>Primary driving tasks</td><td rowspan="2">Driving-Related Activities</td></tr>
<tr><td>Secondary driving tasks</td></tr>
<tr><td>Tertiary tasks</td><td>Non-Driving-Related Activities (NDRAs)</td></tr>
</table>

1.2
Project Assignment

The advent of automated driving frees users from the constant control of the car's steering and shifting, and they have more time for Non-Driving-Related activities. And these activities can profoundly affect the comfort of the person when interacting with the vehicle and the design of the interior. But because automated cars are not yet available, it is difficult for users to imagine driving in such a car (e.g., when asked in a survey), and user activities cannot yet be extracted from real-world use cases. Many researchers have used online surveys, driving simulator studies, participatory design, real-world Wizard-of-Oz studies, etc. to find activities that users would perform in automated cars. This project aims to explore activity-based interior design for automated cars, with a focus on creating an interior design that enhances passenger comfort while engaging in Non-Driving-Related activities during the journey.

To comprehensively understand and tackle this problem, I will focus on the following three key questions:

• What activities will users perform in automated cars in the future?

• What is the comfortable range of motion for users to engage in some important Non-Driving-Related activities?

• How can I design a new interior layout to support those activities in a comfortable manner?

1.3
Project Scope

Establishing project boundaries is crucial as it guides the design process, focusing efforts on key aspects and avoiding unnecessary diversions. Essentially, it is a vital step in efficiently transforming ideas into tangible solutions. The research questions for the project are given below, along with the parts that are out of scope and the parts that are in scope.

Out of Scope:
The influence of social relationships, transition to manual control, and the interaction of passengers with elements such as the vehicle dashboard or the outside environment are not considered in this project. In addition, the aesthetic design of the vehicle and the specific product design of the vehicle interior such as the seat design are also outside the scope of this project.

In Scope:
• Automation level: The project focuses specifically on an activity-based approach to automated vehicle interior design, concentrating on vehicles with levels 4 and 5.
• Users: The project focuses on designing a vehicle interior that would facilitate comfortable Non-Driving-Related activities for P50 users and allow P95 users to perform Non-Driving-Related activities with a minimum of comfort.
• Time horizon: Most of the results show that some Level 4 automated cars will reach the market in 2035. Therefore, in this project, I choose to specify the time horizon of my project to be around 2035 (see Appendix B).
• Car types & dimensions: The dimensions of the Range Rover compact SUV Evoque were used for the project, including 55.4 inches of shoulder room, a 105.6 inches wheelbase, and a height of 64.9 inches (see Appendix B).

1.4 Project Approach

The Double Diamond model, a design approach tool developed by the British Design Council, serves as the overarching guide for my project approach. This model consists of four key phases - Discover, Define, Develop, and Deliver. Each phase is represented as a diamond, where the initial and final stages involve divergent thinking (expanding thoughts and gathering information), while the middle stages involve convergent thinking (synthesizing information and making decisions).

My project approach, as guided by the Double Diamond model, can be described as follows:

Discover (First Diamond, Diverge): An extensive literature review was conducted to gather information about two primary elements: 1) the study design and automation level of each research; 2) the potential activities or tasks users might engage in Level 3, Level 4, and Level 5 automated vehicles.

Define (First Diamond, Converge): Based on the literature review results, I was able to identify differences in Non-Driving-Related activities (NDRAs) performed by users at different levels of automation and obtain important NDRAs. Then, an exploratory experiment was launched to identify the joint angles necessary for performing those activities comfortably.

Develop (Second Diamond, Diverge): Using the determined joint angles obtained from exploratory experiments, mannequins were constructed to simulate the comfortable range of motion for the users when performing important NDRAs, and the space occupation of the 3D models was further analyzed to help design the new car interior layout.

Deliver (Second Diamond, Converge): From these, the most promising concept was selected and subsequently modeled, signifying the final phase of the approach.

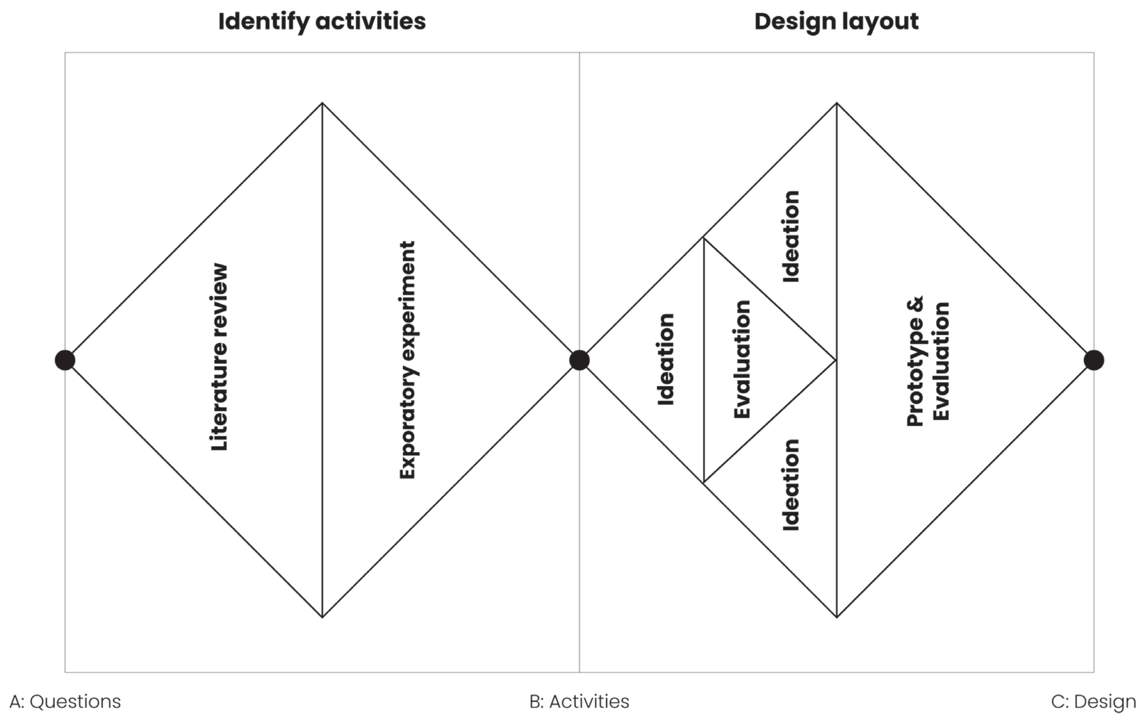


Figure 2. My Project Approach (Double Diamond Model)

Chapter 2.
Literature review
Non-Driving-Related Activities in Automated Driving: a systematic review

2.1
Background

With the rapid advancement of technology, automated vehicles have shifted from the realm of science fiction and films to becoming a tangible reality. This technological leap presents a promising potential to revolutionize transportation by increasing road safety, reducing traffic congestion, and providing new forms of mobility to those unable to drive.

However, despite the swift progress in the automated vehicle industry, substantial challenges remain. One such challenge arises from the increasing level of automation, freeing up time for occupants to engage in Non-Driving-Related Activities (NDRAs) during travel. This shift in activity during transit gives rise to a new demand for automobile interiors and transforms the vehicle from merely a mode of transportation to a mobile space for various activities.

However, since there are no fully automated vehicles commercially available in the market yet, understanding potential NDRAs becomes a complex task as real-world examples are scarce.

To gain insight into this issue, researchers have deployed various methodologies, including questionnaires, driving simulator studies, participatory design, Wizard-of-Oz studies, etc. These studies aim to ascertain potential NDRAs in an automated vehicle context. However, due to variations in participants, research methodologies, and other factors, each study has reported a different set of NDRAs, leading to a lack of uniformity and consensus in the field.

From my research, there is no comprehensive literature review synthesizing all the potential NDRAs in automated vehicles to date. Therefore, this gap in the literature needs addressing, and it forms the motivation for the present systematic literature review. This review aims to consolidate current literature and provide a comprehensive overview of NDRAs that users may engage in within automated vehicles. This understanding could inform future design decisions for automobile interiors and contribute to the ongoing discourse in automated vehicle research.

Research Objectives

The primary aim of this review is to identify the Non-Driving-Related activities that users may perform in automated vehicles. Accordingly, the review seeks to answer the following questions:

i. What Non-Driving-Related activities do users intend to, or expect to, engage in while in automated cars?
ii. What is the likelihood or priority of these Non-Driving-Related activities being performed?

To establish a robust understanding of Non-Driving-Related activities, it's essential to gather reliable evidence in a transparent manner. Furthermore, by addressing these questions, the aim of this review is to offer insights related to Non-Driving-Related Activities for guiding the future automated vehicle interior design.

2.2 Methods

Information sources and search strategy

The scope of the literature selected for this review spans from 2014 to March 18, 2023, a period that is particularly relevant due to the rapid development of automated vehicle technology during these ten years. Literature was retrieved from multiple databases including "Scopus", "IEEE Xplore", "Web of Science", and "PubMed". The specific search terms used are presented in Table 2, and the search was restricted to English-language literature only.

In total, this approach resulted in the retrieval of 2315 pertinent papers. To ensure a comprehensive review, the references cited within the retrieved literature were also scrutinized to avoid missing any crucial studies that may not have surfaced in the initial search. These papers were subsequently organized and screened using the Rayyan software, a web-based application useful for systematic review processes.

Table 2. Databases & Search terms

Databases	PubMed	Scopus	Web of Science	IEEE
Search Terms	("autonomous car" OR "autonomous cars" OR "autonomous vehicle" OR "autonomous vehicles" OR "automated car" OR "automated cars" OR "automated vehicle" OR "automated vehicles" OR "self-driving car" OR "self-driving cars" OR "self-driving vehicle" OR "self-driving vehicles" OR "automated driving" OR "autonomous driving" OR "self-driving" OR "automobile" OR "vehicle automation") AND ("non-driving activity" OR "non-driving activities" OR "non-driving-related activity" OR "non-driving-related activities" OR "non-driving-related task" OR "non-driving-related tasks" OR "ancillary activity" OR "ancillary activities" OR "secondary activity" OR "secondary activities")	("autonomous car" OR "autonomous cars" OR "autonomous vehicle" OR "autonomous vehicles" OR "automated car" OR "automated cars" OR "automated vehicle" OR "automated vehicles" OR "self-driving car" OR "self-driving cars" OR "self-driving vehicle" OR "self-driving vehicles" OR "automated driving" OR "autonomous driving" OR "self-driving" OR "automobile" OR "vehicle automation") AND ("non-driving activity" OR "non-driving activities" OR "non-driving-related activity" OR "non-driving-related activities" OR "non-driving-related task" OR "non-driving-related tasks" OR "ancillary activity" OR "ancillary activities" OR "secondary activity" OR "secondary activities" OR "position preferences" OR "seating positions" OR "L3pilot")	((ALL=("automated car")) OR (ALL=("automated vehicle")) OR (ALL=("autonomous car")) OR (ALL=("autonomous vehicle")) OR (ALL=("self-driving car")) OR (ALL=("self-driving vehicle")) OR (ALL=("automated driving")) OR (ALL=("autonomous driving")) OR (ALL=("self-driving")) OR (ALL=("automated cars")) OR (ALL=("automated vehicles")) OR (ALL=("autonomous cars")) OR (ALL=("autonomous vehicles")) OR (ALL=("self-driving cars")) OR (ALL=("self-driving vehicles")) OR (ALL=("automobile")) OR (ALL=("vehicle automation"))) AND ((ALL=("non-driving activity")) OR (ALL=("non-driving activities")) OR (ALL=("non-driving-related activity")) OR (ALL=("non-driving-related activities")) OR (ALL=("non-driving-related task")) OR (ALL=("non-driving-related tasks")) OR (ALL=("ancillary activity")) OR (ALL=("ancillary activities")) OR (ALL=("secondary activity")) OR (ALL=("secondary activities")) OR (ALL=("position preferences")) OR (ALL=("seating positions")) OR (ALL=("public opinion")) OR (ALL=("pilot")) OR (ALL=("L3pilot"))	("Full Text & Metadata":"autonomous car" OR "Full Text & Metadata":"autonomous cars" OR "Full Text & Metadata":"autonomous vehicle" OR "Full Text & Metadata":"autonomous vehicles" OR "Full Text & Metadata":"automated car" OR "Full Text & Metadata":"automated cars" OR "Full Text & Metadata":"automated vehicle" OR "Full Text & Metadata":"automated vehicles" OR "Full Text & Metadata":"self-driving car" OR "Full Text & Metadata":"self-driving cars" OR "Full Text & Metadata":"self-driving vehicle" OR "Full Text & Metadata":"self-driving vehicles" OR "Full Text & Metadata":"automated driving" OR "Full Text & Metadata":"autonomous driving" OR "Full Text & Metadata":"self-driving" OR "Full Text & Metadata":"automobile" OR "Full Text & Metadata":"vehicle automation") AND ("Full Text & Metadata":"non-driving activity" OR "Full Text & Metadata":"non-driving activities" OR "Full Text & Metadata":"non-driving-related activity" OR "Full Text & Metadata":"non-driving-related activities" OR "Full Text & Metadata":"non-driving-related task" OR "Full Text & Metadata":"non-driving-related tasks" OR "Full Text & Metadata":"ancillary activity" OR "Full Text & Metadata":"ancillary activities" OR "Full Text & Metadata":"secondary activity" OR "Full Text & Metadata":"secondary activities")

Eligibility criteria and selection process

Studies were deemed eligible for inclusion in this review if they satisfied the following criteria:

• The study must engage in an investigation or experiment concerning the diverse types of Non-Driving-Related Activities (NDRAs) that users are likely or have been reported to perform under conditional, highly, or fully automated driving (SAE level 3 and above).
• The participants in the study should have the freedom to select or engage in natural NDRAs, as opposed to activities that are pre-designed and mandatory.

The most frequently encountered reasons for dismissal were:

• The activities compiled for the study were observed or surveyed from public transportation modes such as trains or buses.
• The study primarily aimed to identify user activities within the scope of manual or partially automated driving (SAE levels 0, 1, and 2).
• The research required users to engage in mandatory pre-designed activities for purposes unrelated to NDRA exploration (for instance, comparing takeover times after different NDRAs).
• The article primarily focused on takeover speed and quality in the context of level 3 automated vehicles, instead of the activities that follow takeover behavior.
• The study did not encompass any Non-Driving-Related activities.

The titles and abstracts retrieved from the search were imported into the Rayyan systematic review software. One researcher performed an independent initial screening of all titles and abstracts. In instances of uncertainty, the decision to screen the full text of an article was arrived at by consensus, following discussions with the second and third researchers. For potentially eligible studies, the full text was examined by one reviewer, with the second and third reviewers offering advice to confirm eligibility based on study design and analysis methods.

Data collection process and data items

We devised a standardized data extraction form to systematically collect study characteristics (see Appendix C). The extraction process was carried out independently by one reviewer, with the extracted data subsequently checked by two additional reviewers. This collaborative process allowed for the resolution of discrepancies, ensuring the accuracy and completeness of the data extraction.

Key characteristics extracted from each study included:
• Level of automation
• Study design
• Number of participants
• Type of activity

Additional characteristics such as geographical location (country or area) and participant characteristics were also collected.

Synthesis methods

For the data extraction phase concerning Non-Driving-Related activities, my initial plan was to employ meta-analysis as a tool for synthesis. This process would have involved determining the weight of each study according to its sample size and grouping similar data sets based on the study design and automation level.

However, due to time constraints, I ultimately opted not to proceed with the meta-analysis. Instead, I employed a more straightforward frequency-based approach, where I estimated the significance of each activity by tallying the number of times it was mentioned across the studies (A study only counts once).

I meticulously recorded the different types of activities and their corresponding quantitative data, which can be found in Appendix C. While the method provided an initial understanding of the importance of various activities, I acknowledge that a meta-analysis could refine this understanding further in the future, leading to a more accurate ranking of activity importance.

Study risk of bias assessment

Assessing the risk of bias in individual studies is a critical part of conducting a systematic review or meta-analysis. This process can help researchers evaluate the internal validity of a study, or the degree to which its design, conduct, and analysis have minimized biases.

I undertook an evaluation of multiple quality assessment scales including, but not limited to, the Newcastle-Ottawa Scale and the Cochrane Risk of Bias Tool. These tools are predominantly utilized to assess risk in experimental, cohort, case-control, and cross-sectional studies that necessitate an evaluation of comparability or exposure. However, the studies analyzed in this review largely comprise exploratory research into user Non-Driving-Related activities within automated vehicles. Consequently, the application of the bias assessment tools above presents challenges in appropriately evaluating the study risk of bias.

To navigate these complexities, I turned to the Critical Appraisal Skills Programme (CASP) checklist for qualitative research, which provided a more fitting framework for assessing the potential bias in the studies under review.

2.3
Results

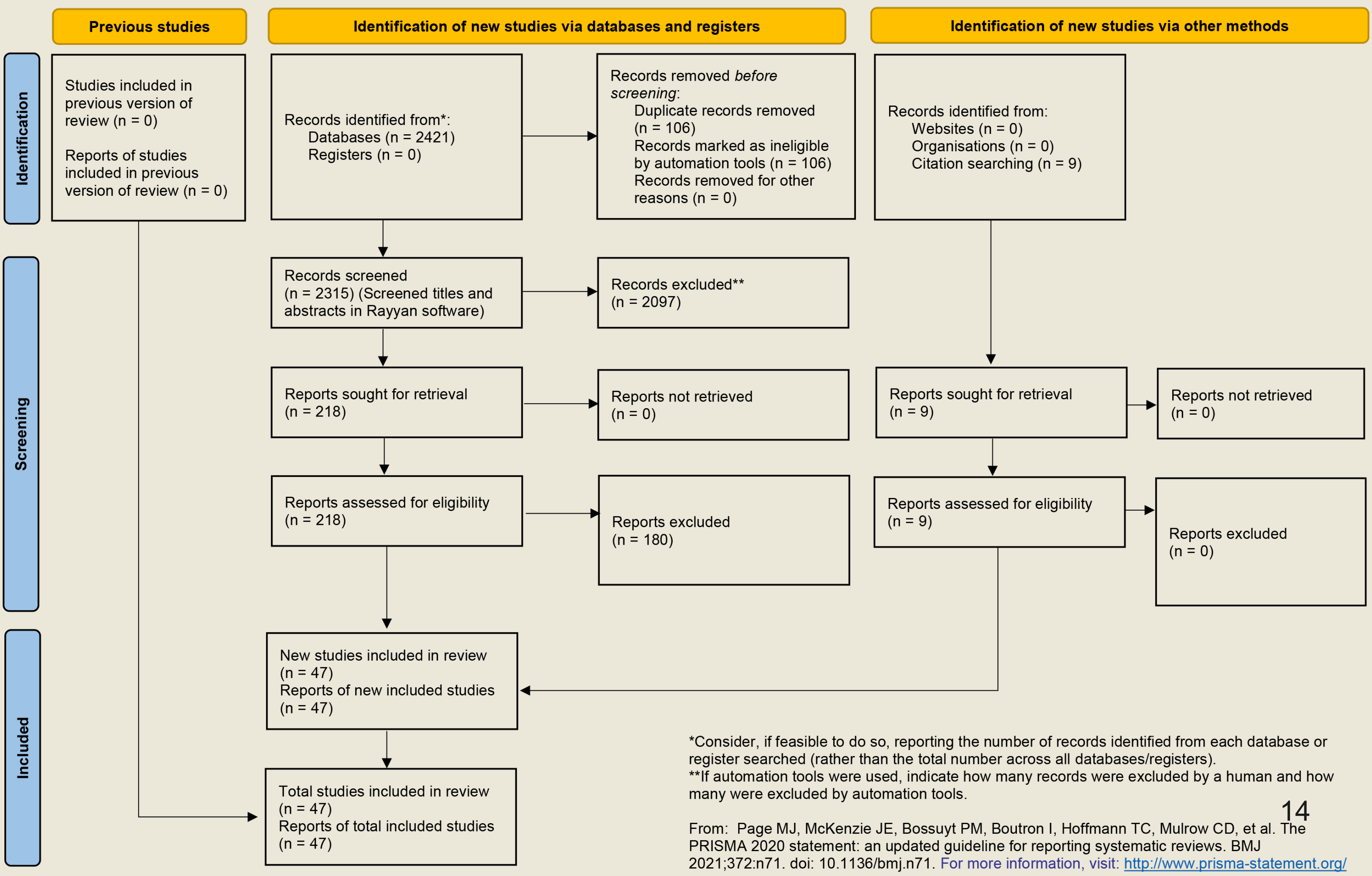
Study selection

The literature search and study selection process adhered closely to the guidelines proposed by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). The specific process is shown in Figure 3.

Initially, a total of 2,421 articles were identified through the search strategy given in 2.2. After the removal of duplicates, 2,315 articles were left to screen. We selected the titles and abstracts of these articles using the eligibility criteria given in 2.2 and excluded 2,097 of them. This phase left us with 218 articles eligible for a thorough full-text review. As we progressed with the full-text screening of these 218 articles, we found that 180 articles failed to meet our eligibility criteria and were subsequently excluded. This left us with 38 articles. We further scrutinized these 38 articles and their bibliographic references. This comprehensive cross-reference check allowed us to identify nine more relevant articles, accounting for 19% of all articles.

Finally, we included a total of 47 articles including one meta-analysis research in our systematic review after this rigorous process, providing a strong foundation for our review of Non-Driving-Related activities in automated vehicles.

Figure 3. PRISMA 2020 flow diagram for updated systematic reviews



Risk of bias in studies

All 47 studies included in this review passed the Critical Appraisal Skills Programme (CASP) checklist evaluation. Detailed scoring for each study can be found in Appendix D. Overall, the quality of the studies varied moderately, with scores ranging from 6 to 10 and an average score of 8.5. Predominantly, the risk of bias stemmed from selection bias due to different participant characteristics and diverse study designs across the included studies. Additionally, numerous studies lacked a clear explanation for the activities listed, leading to information bias. These, coupled with inherent limitations in some study designs, may amplify the uncertainty surrounding the research findings. These issues will be addressed more comprehensively in the discussion section.

Study characteristics and results of synthesis

Upon meticulous review, we extracted 66 cases and 50 types of activities from 47 studies, with detailed study characteristics. The eligible outcomes were classified based on the level of automation and study design, the results were synthesized as follows (n refers to the number of cases in each category). See Appendix C for the complete data extraction form.

Table 3. Different automation levels and their number of cases

● Level of automation	
L3 (conditional automation in SAE, highly automated driving in VDA, highly automated driving in BASt, limited self-driving automation in NHTSA)	n=24
L4 (highly automation in SAE)	n=5
L5 (fully automation in SAE, automated driving with train sets, driverless driving in VDA, driverless cars)	n-19
L3 & L4 (SAE)	n=5
L4 & L5 (SAE, completely self-driving automation in NHTSA, based on the scenario whereby vehicles can drive autonomously, fully automated driving in BASt, did not have any operator controls)	n=9
L3 & L4 & L5 (AVs)	n=3
No differentiation was made regarding target groups or automation levels	n=1

Table 4. Different study designs and their number of cases

● Study design	
Online survey	n=30
Driving simulator study	n=18
Participatory Design (such as focused groups)	n=6
Real-world Wizard-of-Oz study or simulated car or Pilot site	n=11
Literature review with meta-analysis	n=1

In an effort to analyze the activities further, I employed a clustering strategy based on their relevance (e.g., use of electronic devices, socializing with others, and mainly mental activities were grouped separately). The activity clusters formed in this manner allowed me to categorize the vast number of Non-Driving-Related activities identified in the systematic review.

It is important to note that among all the activities, I chose to exclude categories such as "doing nothing" and "other" due to the ambiguity associated with what they exactly entail. For instance, "doing nothing" activities in Pudāne et al.'s study (2021) encompassed looking out of the window, thinking, and listening to music. "Other" activities included activities like sleeping, shopping, and household tasks. These activities overlap with some of the activities in other studies. By excluding these two activities, 48 activities were left, which I then grouped into 13 clusters. Detailed clusters on these activities can be found in Appendix E. Table 5 below provides an overview of the five most significant activity clusters (sorted by count), which are Entertainment and online activities, Work and productivity, Interpersonal communication and interaction, Sleep and relaxation, and Observation and monitoring. Significantly, this project's scope is confined to Level 4 and Level 5 automated driving, so the table below does not count the cases that specifically address Level 3 automated driving.

Table 5. Five main clusters of activity and their number of cases (No count for L3 automated driving cases)

● Entertainment and Online Activities (n=99)	Emailing/surfing the Internet (n=13)
	Play games (video games/board games/…) (n=18)
	Take selfie (n=2)
	Social media (n=8)
	Watch video/movie/… (n=24)
	Use smartphone (n=17)
	Laptop usage (n=10)
	Browsing the tablet (n=5)
	Trade stocks (n=0)
	Shopping (n=2)
● Work and Productivity (n=71)	Work/office task (n=26)
	Study/learn/training (n=4)
	Planning/thinking/analyzing (n=7)
	Making a to-do list/writing (n=2)
	Organization/clean up (n=2)
	Reading (n=30)
● Interpersonal Communication and Interaction (n=60)	Texting (n=9)
	Video conference (n=6)
	Talking to passengers (n=21)
	Phone calls (n=17)
	Interaction with passengers/friends or family (n=7)
● Sleep and Relaxation (n=45)	Relax/rest (n=15)
	Sleep (n=25)
	Use a massage chair (n=1)
	Wellness/praying/meditating/worshiping (n=4)
● Observation and Monitoring (n=37)	Observing the landscape/looking out of the window (n=22)
	Monitoring the driving/watching vehicle or road (n=15)
	Communicate with other vehicles (n=0)

2.4 Discussion

I will analyze this literature review from four perspectives: Comparison with other similar reviews, Risk of bias in studies, Limitations in the review process, and Implications for practice and future research.

Comparison with other similar reviews

The literature review conducted by Fitzen et al., (2018) employed a literature search encompassing five research fields: Automated Driving, Customer Focus, Transportation, Ergonomics, and Interior of the Future. They eventually selected 17 papers, which primarily focused on secondary activities in automated vehicles and other means of transportation, for their meta-analysis. Their top 10 activities, derived from their meta-analysis, were: video conferences/virtual meetings, drinking, sightseeing, preparing food, eating, reading, using social media, making calls, texting, and surfing the internet.

My results have some differences from their results. The five most significant activity clusters I got by counting the cases were Entertainment and online activities, Work and productivity, Interpersonal communication and interaction, Sleep and relaxation, and Observation and monitoring. The key reason for this difference is that Fitzen et al. use meta-analysis without distinguishing automation levels and study designs, and the number of studies included in the meta-analysis is small. Moreover, their focus was not exclusively on automated vehicles but also incorporated secondary activities in other means of transportation like trains and buses. Due to the huge number of research objects in the study of adopting other modes of transportation, the results of adopting different modes of transportation may have a great impact on the final results.

In contrast, the data I extracted was strictly confined to automated vehicles ranging from Levels 3 to 5. Furthermore, during the synthesis phase, my project solely focused on Level 4 and Level 5 automated vehicles, hence data concerning Level 3 automated vehicles were not incorporated into the tally. Nevertheless, since I didn't conduct a meta-analysis, my ranking of activity importance may not be as robust.

Risk of bias in studies

There are some biases in the research collected in this literature review, which are listed here in order to correctly interpret the results.

• Information Bias: Information bias arises from the varied definitions of activities across the studies, with many not providing clear explanations of the listed activities. This variation in definition and interpretation introduces uncertainty in understanding and clustering the activities.

• Performance Bias: The use of simulators and questionnaires could introduce performance bias. The simulated environments are inherently safer than real driving conditions, potentially influencing the participants' perceptions and actions, and hence the reported activities. Besides this, given that automated vehicles are not yet available, the users' anticipations or envisioned activities obtained through questionnaires, might not accurately represent reality.

Limitations in the review process

This literature review strictly adhered to the PRISMA guidelines for literature screening, establishing a comprehensive review process, eligibility criteria, and bias analysis method from the outset. I ultimately identified 47 appropriate articles and extracted 50 activities. However, due to time constraints and the information bias present in the literature leading to unclear activity definitions, I encountered difficulties in activity clustering and meta-analysis. After several rounds of activity clustering, I selected the most reasonable approach for my final activity clustering, but the principles of activity clustering still need to be clarified and potentially refined through further discussion. As a result, the initially planned meta-analysis was replaced by a simple count, which may render the final activity results less robust than a meta-analysis would yield.

However, overall, this literature review employed a stringent paper screening process and ultimately provided comprehensive data, so the activity ranking derived from this review still possesses a high degree of reliability.

Implications for practice and future research

Firstly, the results gleaned from this literature review, specifically the five most significant activity clusters (Entertainment and online activities, Work and productivity, Interpersonal communication and interaction, Sleep and relaxation, and Observation and monitoring), offer a solid foundation for the subsequent interior design of automated vehicles. The interior design should primarily cater to the users' comfort while performing these significant Non-Driving-Related activities.

Secondly, in regard to the risk of bias in studies, future research should aim to reduce and improve their impact on the results. Minimizing information bias requires reaching a consensus on the definition and interpretation of activities, potentially facilitated through the development of standardized reporting guidelines. Performance bias could be addressed by improving study design. In the future, it would be beneficial to carry out additional research involving actual automated vehicles or within real-world contexts to glean further insights from authentic environments. The use of questionnaires could be supplemented with qualitative methods such as interviews or focus groups, yielding a deeper understanding of potential automated car users' activities. Above all, these biases underscore the importance of transparent, detailed research methods and result reporting. Future studies should provide clear, comprehensive descriptions of research methods and findings, facilitating accurate interpretation and comparison across studies.

Finally, regarding the limitations in the review process, specifically the lack of rigor in activity clustering and the absence of meta-analysis, it is hoped that future discussions will clarify activity clustering principles, leading to more reasonable activity clusters. Furthermore, a thoughtful meta-analysis of the data in Appendix C should be performed to achieve a more robust activity ranking.

Key Takeaways

• The five most significant activity clusters were Entertainment and online activities, Work and productivity, Interpersonal communication and interaction, Sleep and relaxation, and Observation and monitoring.

• Future related research needs to provide clearer and more uniform definitions of the different Non-Driving-Related activities, improve the study design, and increase the transparency and details of the studies.

• More discussion of activity clusters and meta-analysis of the extracted data is recommended. These will allow for a more reliable ranking of Non-Driving-Related activities.

Chapter 3.
Ergonomic Experiment

3.1 Background

The interior design of automated vehicles, particularly level 4 and level 5 automated vehicles, requires a shift in perspective. Given that users are no longer required to maintain constant control over the vehicle, they have increased time for Non-Driving-Related Activities (NDRAs). This change inevitably leads to a reevaluation of the vehicle's interior layout and the relationships between humans and their vehicles.

However, the current automotive market lacks automated vehicles beyond Level 3, and this lack leads to the lack of research on the spatial requirements and joint angles needed to perform different NDRAs comfortably. To fill this gap, I undertook an exploratory experiment using body angle measurements within a constrained space simulating a vehicle interior. My objective was to analyze how various activities impact users' comfort and range of motion within a limited car interior space.

The literature review (see Chapter 2) has identified 50 potential activities that users might engage in within automated vehicles and grouped them into 13 activity clusters. The five most significant activity clusters were Entertainment and online activities, Work and productivity, Interpersonal communication and interaction, Sleep and relaxation, and Observation and monitoring. Each cluster consists of unique activity types, and each of these activities require different postures, spatial requirements, and joint angles, with some even demanding additional elements like tables. This complexity considerably broadened the scope and difficulty of my experiment. Ultimately, due to time limitations, I decided to select one of the most representative and prevalent activities from each of the five activity clusters as the subject for my subsequent research.

The 5 Non-Driving-Related activities chosen include: talking to other passengers, looking out the window, working (typing on the computer), sleeping, and entertainment (watching videos on the iPad).

The research questions are as follows,
• How do the five Non-Driving-Related activities mentioned above affect users' joint angles and comfort in a limited car interior space?
• How can these findings inform the development of more ergonomic and comfortable car interior design?

The hypotheses are:
• Users engaged in work-related activities will require a table and may prefer a more upright seating position for increased efficiency.
• Entertainment activities need a table and likely a more reclined seating position for comfort.
• Work and entertainment activities require less space than activities such as sleeping.
• In automated vehicles, seat orientation may change from the forward-facing default, particularly for enhanced passenger interaction or landscape viewing.
• Rotating the seat angle can improve passenger communication and the viewing experience, but it also requires a larger space to allow for rotation.
• Activities like sleeping may require the largest space for increased legroom and a lower backrest, and even some sleeping positions may require additional assistive devices.

3.2
Method

Participants:
This test is an exploratory experiment, so 3-5 participants are sufficient. However, considering certain aspects of the test that required pairing, the participant pool was expanded to six individuals. The age group 17-27 was targeted as they represent potential future users of automated cars. To this end, the subjects were recruited from the student of TU Delft.

Environment & Tools:
The interior of a car was simulated using tape to mark out a restricted space, which was modeled after the shoulder room (1407mm) and couple (initial distance 825mm) of a compact crossover SUV, Range Rover Evoque (as shown in Figure 4). Four adjustable seats that could be rotated and altered were placed within this space. An adjustable table was also provided in the designated area (as shown in Figure 5). For work and entertainment tasks, a computer and an iPad were used respectively.

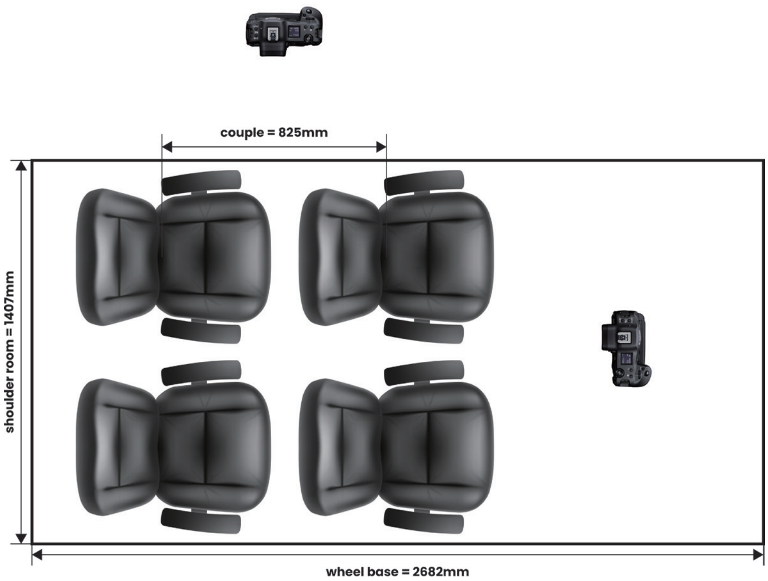


Figure 4. Test environment 1 setup

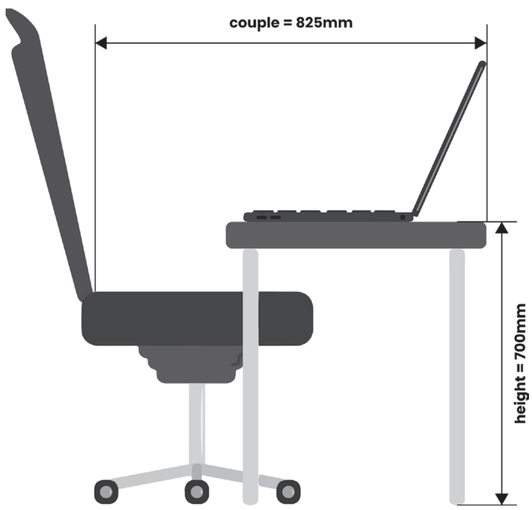


Figure 5. Test environment 2 setup

Procedure:
The experiment consisted of three parts. Initially, participants were introduced to the automated car and its significance. They then completed a demographic survey. In the second part, participants evaluated seat configurations and positions using pictures. The third part involved participants recalling and acting out their past and potential postures during specific activities in an automated car. Joint angles were measured using a motorized angle meter, and participants provided feedback on their comfort and any limitations experienced.

The activities that participants need to participate in are talking with other passengers, looking out of the window, working (typing an email), sleeping, and engaging in entertainment (watching videos). The complete sequence of activities is depicted in Figure 6. Each testing session lasted approximately 60 minutes.

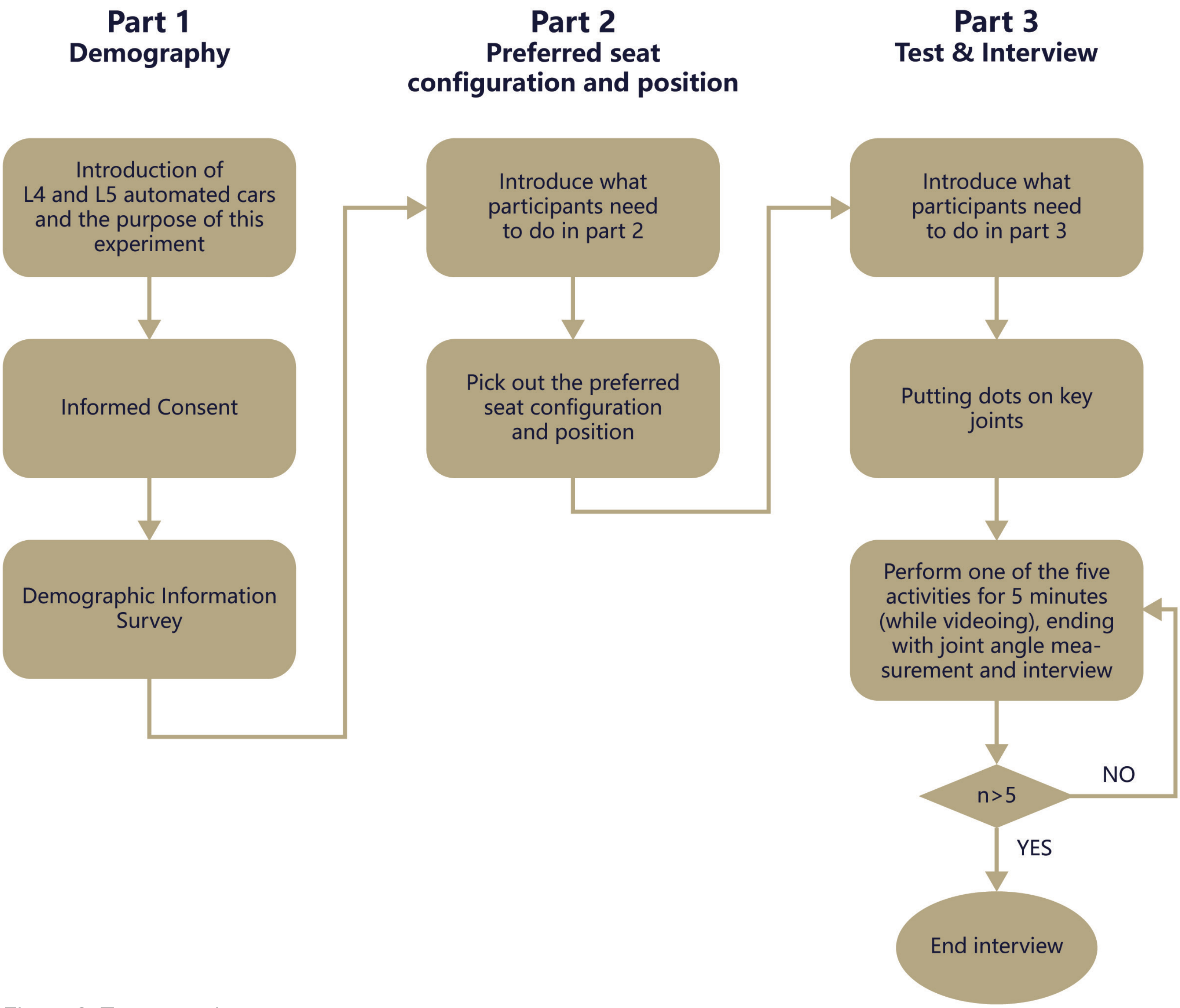


Figure 6. Test procedure

3.3
Results

Demography:
The study involved six participants ranging in age from 22 to 27 years, with an average age of 25 years. The participant group was evenly divided, consisting of three females and three males. The average stature of the female participants was 163cm, with an average sitting height of 842mm. The male participants had an average stature of 180cm and an average sitting height of 931mm.

Preferred configuration and position:
The participants were presented with six different seat configurations in the picture (as shown in Figure 7) and asked to indicate their preferred configuration and position when traveling alone or with one partner. The results revealed that most participants (4/6) preferred the B configuration, which represents the typical forward-facing seat arrangement in current vehicles. Their familiarity with this standard configuration primarily influenced their choice when traveling alone. Two participants expressed a desire to occupy the driver's seat, either for better visibility or to have the option of driving the vehicle themselves. The remaining two participants preferred the rear seat, as they were accustomed to this position during their previous travel experiences.

When participants were asked about their preferences while traveling with one partner, the majority (4/6) favored the F configuration, which involves all four seats oriented toward the center of the car. This arrangement was chosen due to its perceived convenience for communication between the occupants.

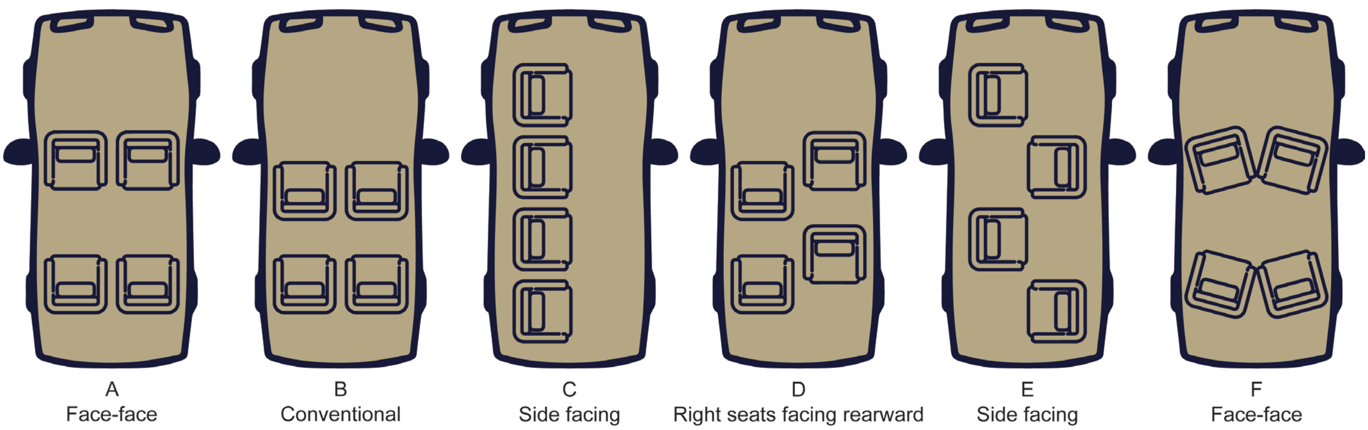


Figure 7. Seat configurations (Source: (Nie et al., 2020))

Comfortable joint angles:
Following a 5-minute period of engaging in a specific activity, participants were instructed to assume their most comfortable posture. Using an electric angle measurement tool, I recorded seven key joint angles on their bodies: foot-calf angle, knee angle, trunk-thigh angle, elbow angle, shoulder angle, trunk-neck angle, and neck-head angle, as depicted in Figure 8. Additionally, I measured two seat angles, namely rotation and backrest angle. Furthermore, for activities involving work and entertainment, I noted the height (in centimeters) and angle of the device used. The results of these measurements are presented in the bar charts.

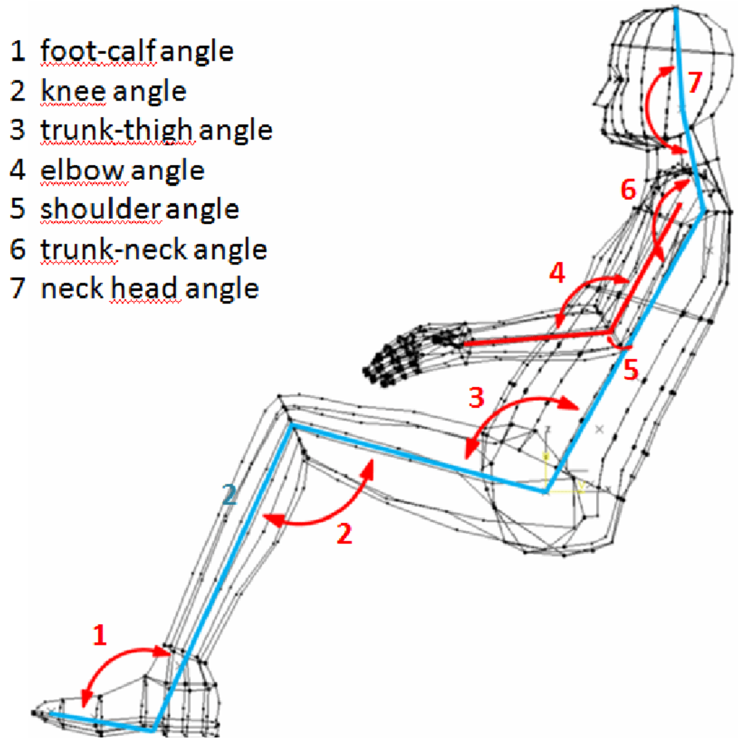
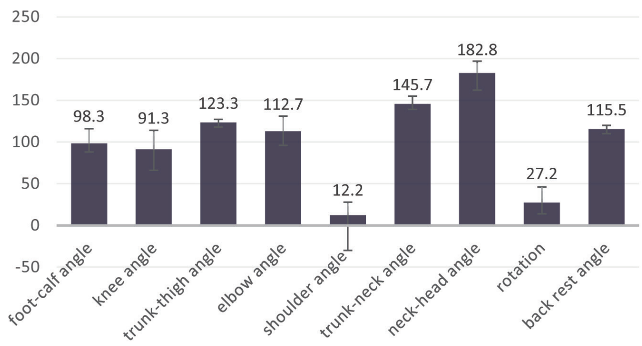


Figure 8. Measured joint angles (Source: (Bengler et al., 2014))

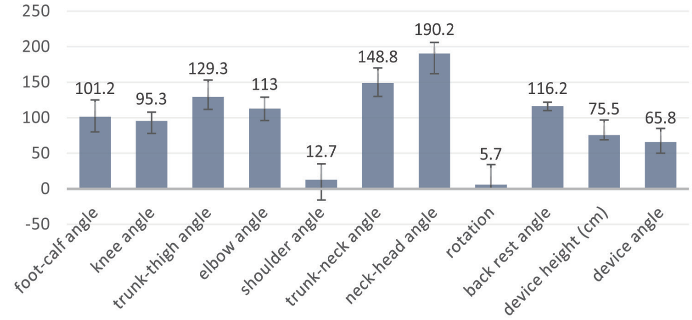
Pictures from the testing process

Talking to other passengers



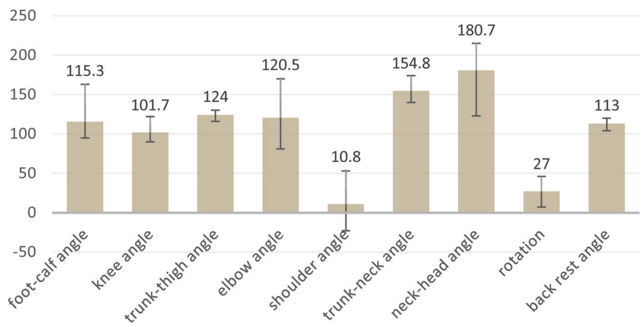
M	98.3	91.3	123.3	112.7	12.2	145.7	182.8	27.2	115.5
Max	116	114	127	131	28	155	197	46	120
Min	88	66	118	96	-30	139	162	14	110

Entertainment (watch a movie in an iPad)



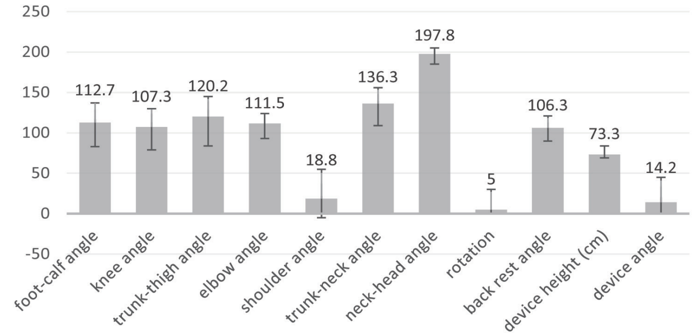
M	101.2	95.3	129.3	113	12.7	148.8	190.2	5.7	116.2	75.5	65.8
Max	125	108	153	129	35	170	206	34	122	97	85
Min	80	78	112	96	-16	130	162	0	110	69	50

Looking out of the window



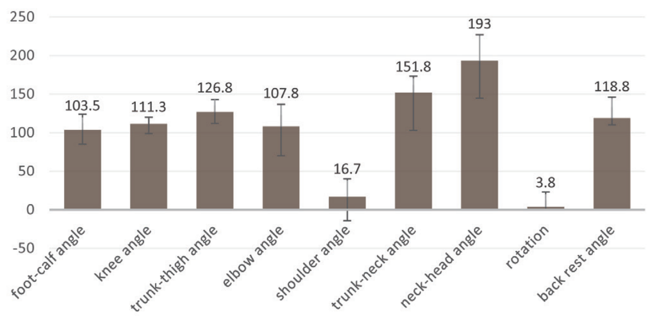
M	115.3	101.7	124	120.5	10.8	154.8	180.7	27	113
Max	163	122	130	170	53	174	215	46	120
Min	95	90	116	81	-23	140	123	7	104

Working (typing in a laptop)



M	112.7	107.3	120.2	111.5	18.8	136.3	197.8	5	106.3	73.3	14.2
Max	137	130	145	124	55	156	205	30	121	84	45
Min	83	79	84	93	-5	109	185	0	90	69	0

Sleeping



M	103.5	111.3	126.8	107.8	16.7	151.8	193	3.8	118.8
Max	124	120	143	137	40	173	227	23	146
Min	85	99	112	70	-14	103	145	0	110

In the table, M stands for average angle, Max stands for maximum angle and Min stands for minimum angle.

Interview:
After each activity, participants were interviewed to gather their feedback on their experiences, any limitations they encountered, and their overall comfort.

• Head support
A common concern mentioned by all participants was the absence of head support in the experimental seats, leading to discomfort, particularly during sleep and when attempting to look out of the window. Participants shared their preference for additional lateral support or something to lean on for improved comfort.

One male participant expressed, "*The main thing is that the neck is uncomfortable. I think the best-case scenario is actually something you can lean on*" (interview conducted after the sleeping activity). Another male participant mentioned, "*I would actually lean my head and neck against the window while riding in the car*" (interview conducted after the activity of looking out of the window).

Figure 9. Participants engaged in a looking out the window activity (left) and the chair used for testing (right)

• Backrest angle
Regarding the backrest angle, all participants expressed a desire to have the ability to adjust it, with a particular emphasis on the sleeping activity. Two participants mentioned that they or others they observed tended to sleep almost flat on their backs sometimes, requiring a near 180-degree backrest angle. However, one participant mentioned that such a flat angle would be too extreme and preferred a less reclined position. Another participant highlighted difficulties lying flat due to severe motion sickness.

One male participant suggested, "*If the angle of the backrest can be a little larger, and then perhaps the legs can be a little higher, it will be better*" (interview conducted after the sleeping activity). A female participant shared, "*But I get carsick, I can't lie face forward because it's very uncomfortable*" (interview conducted after the sleeping activity).

• Leg room & leg support
The limited legroom was a concern for four participants, causing discomfort during the activities. Two participants specifically mentioned the desire for calf support similar to a massage chair, allowing the legs to be lifted or lowered, especially when viewing the landscape or sleeping in the car.

One male participant stated, "*If this is not restricted, I will definitely choose to straighten the leg*" (interview conducted after the activity of looking out of the window). Another female participant expressed, "*I think my legs would want to flatten out, but if it had something like one of those massage parlors, you know the kind that allows the legs to go up and down, I think it would be very comfortable*" (interview conducted after the activity of looking out of the window).

• Armrest
Two participants mentioned that the presence of armrests made them uncomfortable when sleeping or looking out of the window, as the armrests pressed against their waist and they preferred not to have any parts touching their bodies.

One female participant stated, "*...armrests stuck to my waist, and I didn't want anything that could rest against my body parts*" (interview conducted after the activity of looking out of the window).

• Lumbar support
Four participants reported feeling uncomfortable due to a lack of lumbar support. Two participants specifically mentioned the need for more comfortable lumbar support during sleep. Additionally, two female participants expressed a desire for increased support during communication or when looking out of the window.

One female participant explained, "*I have an overhang here at the waist, and I want it to be adjusted to fit my waist better*" (interview conducted after the activity of looking out of the window). Another female participant stated, "*I think because there is something against my waist here, generally speaking when we sleep lying flat, it will be more comfortable*" (interview conducted after the sleeping activity).

• Rotation
The notion of rotation was highlighted by five participants, who believed it could enhance freedom and variety during activities. For instance, two participants mentioned they would rotate their bodies to improve communication with their partner in previous experiences, and it sometimes caused discomfort in their lower back. Additionally, two participants expressed that being able to rotate the seat would allow them to position one leg over the other, resulting in a more comfortable posture during work or entertainment activities. However, two participants expressed doubts about whether rotatable seats would provide enhanced comfort for viewing the scenery, as they believed the presence of doors and rotation might create conflicts.

One male participant shared, "*Sometimes in ordinary cars, I will choose to sit with half of my buttocks (that is, rotate my body), facing towards the window side... After a long time, my buttocks actually start feeling uncomfortable, and I will experience discomfort in my back*" (interview conducted after the activity of looking out of the window). A female participant added, "*It may be that the angle of rotation is not completely free, taking into account the limitations posed by the presence of doors*" (interview conducted after the activity of looking out of the window).

• Table
In terms of table usage, three participants preferred to sit upright without leaning on the backrest, desiring their computer screens to be at eye level. This indicates that an adjustable lifting table could improve their comfort. Conversely, three other participants preferred pulling the table close to them while reclining in their seats. All participants expressed the need to place all or most of their elbows on the table, highlighting the significance of the distance between the table and themselves as an influential factor.

One male participant stated, "*The lift table allows me to position my screen at eye level with my eyes*" (interview conducted after the entertainment activity). Another female participant expressed, "*My arms need a support point for relaxation, so I don't have to hang them, as hanging becomes tiring*" (interview conducted after the working activity).

3.4 Discussion

Through the conducted ergonomic experiment and interviews, valuable information has been gathered to address the research questions proposed earlier. However, it is essential to acknowledge that various factors, not accounted for in the study, may have influenced the obtained results. Therefore, it is crucial to engage in a discussion to provide a comprehensive understanding of the findings and their implications.

Seat configuration preferences revealed that participants generally favored the normal seat configuration when traveling alone due to its familiarity. Conversely, when traveling with a partner, participants expressed a preference for a face-to-face seating arrangement to facilitate communication. These results align with the findings of Nie et al. (2020), who reported that the conventional seat configuration (B configuration) was widely accepted for daily commutes and long trips. Additionally, Nie et al. (2020) found that the "face-to-face mode" was the preferred option (42.0% combined options A and F) for excursion scenarios. It is noteworthy that participants in my experiment also mentioned a desire to occupy the driving position, which allows for immediate control.

Comparing the results of backrest angles obtained in my experiment with those reported in existing literature reveals noteworthy similarities. Parida et al. (2019) reported a backrest angle range of 93-113 degrees for working on a laptop, closely aligning with the results obtained in my experiment (90-120 degrees, with a mean angle of 116.2 degrees). Furthermore, Parida et al. (2019) documented backrest angles of 138 degrees for sleeping in one study. In contrast, my experiment revealed a broader range of backrest angles, ranging from 110 to 146 degrees, with an average angle of 118.8 degrees. This finding was different from those of previous research, largely attributed to the restricted adjustability of the backrest angle on the office chairs employed. This factor complicated participants' attempts to find their ideal backrest angle for sleep. Despite this, subsequent interviews and angle measurements furnished valuable feedback and correction to this result. And a comparison of the backrest angle required for different activities can be found that the backrest angle required for sleeping is the largest.

Fleischer and Wendel (2021) reported that the angle between the horizontal line and the torso line (backrest angle) is around 117 degrees in conventional vehicles. Additionally, Fleischer and Wendel (2021) provided backrest angles for other activities, such as looking out of the window (115.5 degrees) and talking to other passengers (116.5 degrees), which closely match the results obtained in my experiment (113 and 115.5 degrees, respectively). For tablet use, Fleischer and Wendel (2021) suggested a backrest angle of 119.5 degrees, whereas my experiment yielded an average angle of 116.2 degrees. The credibility of my findings is enhanced by the fact that my results are close to most of the existing studies on the backrest angle. The obtained results hold significant importance for developing realistic mannequins that accurately represent individuals engaged in specific activities, as well as for informing the design of car interiors.

The interview results underscore the importance of incorporating several features into automated car design to enhance comfort and accommodate individual preferences. These features include head support, adjustable backrest angles, sufficient legroom and leg support, foldable armrests, additional lumbar support, rotational capabilities, and adjustable tables. These findings provide valuable insights for designing car interiors, particularly car seats.

Limitations:
Acknowledging the limitations of the experiment is crucial. The use of an office chair that does not lay flat, lacks headrest support, and features different armrests may have introduced inaccuracies in the results. A notable instance of this impact was evident when participants were sleeping. The mean backrest angle noted during the sleep activity of the experiment did not accurately represent the optimal sleep posture, as the range of backrest adjustment in the office chair was limited and rather challenging to modify. It was more difficult for some participants to adjust their chairs to achieve their most comfortable backrest angle. However, feedback from the interviews and angle measurements somewhat offset this limitation. It was gleaned from these sources that the majority of the participants leaned towards a larger backrest angle, approximating a reclined position. Furthermore, the experimental environment did not replicate a real car setting, which could have influenced participant responses. Additionally, the lack of experience with level 4 and level 5 automated cars among participants may have impacted their ability to envision future postures accurately. Measurement errors may have been present due to the equipment used for angle measurements. To ensure more meaningful and accurate results, future studies should consider conducting experiments in real car spaces with appropriate car seats and employ more precise methods, such as clothing that can automatically measure the joint angles.

In conclusion, the findings from the experiment and interviews offer valuable insights for designing car interiors. However, it is essential to address the identified limitations in future research to enhance the reliability and accuracy of ergonomic design considerations for automated cars.

Key Takeaways

• Participants typically preferred the traditional seat configuration (B) for solitary travel due to its familiarity, while a face-to-face seating configuration (F) was favored when traveling with a partner to enhance communication.

• Adding a lying down sleeping posture to complete the comfortable sleeping joint angles.

• The joint angles participants utilized during the five key NDRAs are critical for developing accurate human body models representing comfortable postures and guiding interior car design.

• Interview results highlight the necessity of integrating features such as seat functions, rotational capabilities, and height-adjustable tables into automated car design to improve comfort and cater to personal preferences.

Chapter 4.
Design Vision

4.1
Design vision

Integrating all the insights from research and creating a clear vision is crucial for the success of any project. By analyzing and synthesizing the information gathered from research, we can better understand the needs and expectations of users and develop a more comprehensive understanding of the problem we are trying to solve. Having a clear vision allows us to stay focused and aligned on the goals of the project, guiding decision-making and ensuring that all efforts are working towards a common objective.

Drawing upon insights from the literature review, comfort, and the user's perspective (see Appendix F for research about comfort and the user's perspective), a comprehensive design vision has been developed. This vision encapsulates the values that the design implementation aims to evoke, as shown below.

I want to design a car interior that is comfortable and promotes a sense of freedom, enabling users to seamlessly transition between activities, enhancing physical and mental pleasure, and transforming travel time into an enjoyable and valuable experience.

4.2
List of requirements

The most important requirements and wishes are listed here, please see Appendix G for the full list of requirements.

R.1.1 The interior design is designed for highly automated or fully automated vehicles (Level 4 or Level 5, the SAE Automation Level).
R.1.2 The interior is designed to be made for 2035 (see Appendix B).
R.1.3 The interior design must conform to the Range Rover compact SUV's spatial dimensions, including 55.4 inches shoulder room, a 105.6 inches wheelbase (see Appendix B).
R.2.2 The car interior should accommodate the maximum, average, and minimum comfortable joint angles required for five essential activities, including looking out of the window, working, entertainment, sleeping, and talking with other passengers, for P50 users (see Chapter 3).

The definition of looking out of the window in this context is looking out of the window with seat backrest angle between 110 and 130 degrees and seat rotation angle between 0 and 45 degrees.

The definition of working in this context is typing on a computer with seat backrest angle between 90 and 145 degrees and requiring a desk height of 75 cm.

The definition of entertainment in this context is watching movies in an iPad with seat backrest angle between 110 and 150 degrees and requiring a desk height of 75 cm.

The definition of sleeping in this context is a position of rest with a backrest angle that varies from 110 to 145 degrees.

The definition of talking with other passengers in this context is talking with other passengers with seat backrest angle between 110 and 130 degrees and seat rotation angle between 10 and 45 degrees.

R.2.4 The car interior should enable passengers to rotate the seats smoothly within a range of 0 to 45 degrees without any obstructions or interference.

W.2.1 The car interior can support configurable layout changes from configuration B (traditional seat configuration) to configuration F (face-to-face configuration) (see Chapter 3).
W.2.2 The interior can at least incorporate one seat adjustable to a flat sleeping position, allowing a backrest angle of at least 145 degrees or even up to 180 degrees (see Chapter 3).
W.2.3 The interior can accommodate a table with a height adjustable between 70 and 100 cm for work and entertainment (see Chapter 3).

Chapter 5.
Analysis using 3D models

5.1
3D Models

In this project, the interior design must comply with the spatial specifications of the Range Rover compact SUV, which includes 55.4 inches of shoulder room and a 105.6-inch wheelbase. In the Chapter 3, I detailed the comfortable joint angles for passengers in five primary Non-Driving-Related activities.

The question at this stage is:
• Does the space in the Range Rover Evoque allow users to perform five important Non-Driving-Related activities? Is the comfortable range of joint angles permitted by the space different for P95 and P50 users?
• To what extent does the space allow P50 users to perform five primary Non-Driving-Related activities within a comfortable range of motion? (The comfortable range of motion here is between the maximum and minimum joint angles obtained in Chapter 3).

To address this query, I employed 3D models that closely resembled the actual objects in dimensions. These models included a P50 mannequin, the car's seats, and a Range Rover compact SUV model. The primary focus was on securing the 3D models that accurately reflected the size and spatial parameters. I used these models to first integrate with Rhino (see 5.2) and then moved to HoloLens (see 5.4) to explore more through AR (augmented reality).

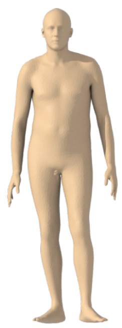
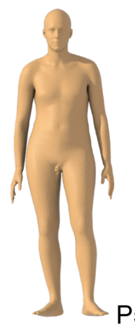
Mannequins

To achieve a realistic human model, I utilized the 'Mannequin' tool from DINED. The DINED platform offers a comprehensive strategy to effectively leverage anthropometric data, enhancing the overall design process. The 'Mannequin' tool from DINED allows users to create 3D human models or 'Mannequin' that are constructed from extensive 3D body scan databases. Furthermore, it provides an intuitive interface for investigating variations in 3D body shapes, thus enabling the creation of mannequins that accurately depict a diverse range of human anthropometric data.

Picture from DINED

Table 6 showcases the P50 mannequins. I also generated different manikins to represent the P70 and P95 mannequins to study the spatial occupation of a wider population, however my primary focus remained on the P50 group. The P50 mannequins, rigged in Blender for five different activities at various joint angles, are displayed in Figure 10. The chosen joint angles correlate with the minimum, average, and maximum values identified in the preceding chapter. Additionally, I've included a "sleep flat" position because the sleep angles obtained from the interviews in Chapter 3 may not completely represent the most comfortable sleeping position preferred by users, given the limitations of the experimental equipment. Therefore, by adding a lying position, my goal is to make all the positions listed in the table reflect the whole range of motion that the user is comfortable with.

Table 6. Mannequin body parameters

Dutch adults Male	 P95	 P70	 P50
Stature	1954mm	1861mm	1817mm
Body mass	104kg	90kg	83kg
Hip circumference	1149mm	1066mm	1027mm
Arm length	832mm	782mm	758mm

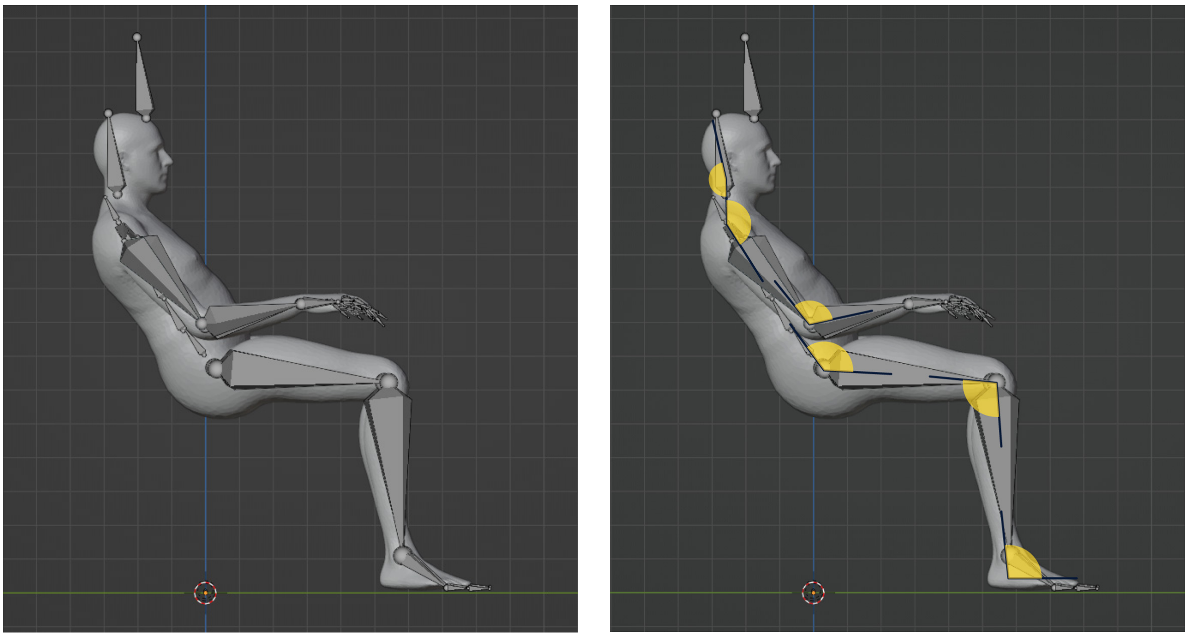
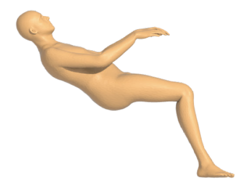
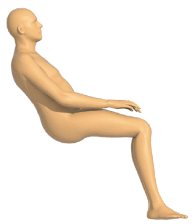
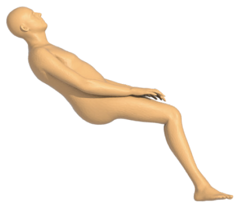
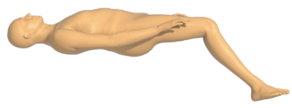
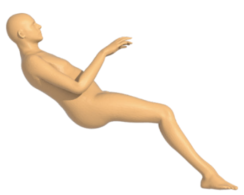
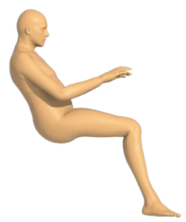
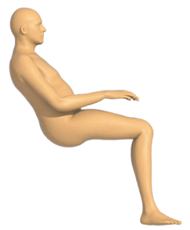


Figure 10. Rig a mannequin in Blender that is performing the activity of talk with other passengers in average joint angles

Table 7. P50 Mannequin postures in different activities

Activity \ Posture	Maximum angle	Average angle	Minimum angle	Other
Activity: Entertainment				
Activity: Look out				
Activity: Sleep				 **Sleep flat**
Activity: Work				
Activity: Talk with other passengers				

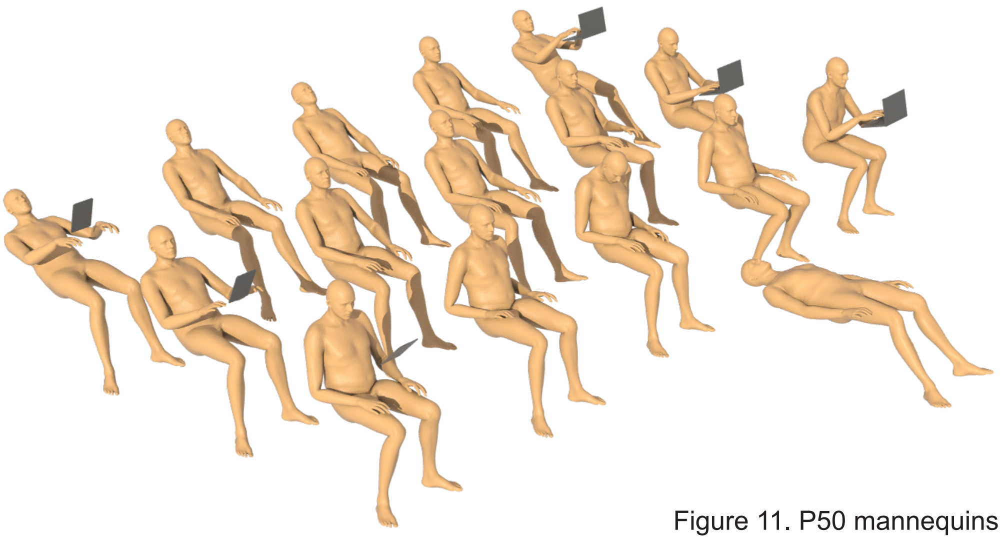


Figure 11. P50 mannequins in all comfortable joint angles

Seats

The seat's model primarily draws upon the design of the Knoedler Air-Chief Seat, illustrated in picture below. Parameters such as the angle of the seat backrest, leg support, headrest, and armrest are modulated using the Grasshopper software. Figure 13 shows part of the parametric modeling process. The principal dimensions of the finalized seat model are presented in Figure 12.

Picture from Knoedler Air-Chief Seat

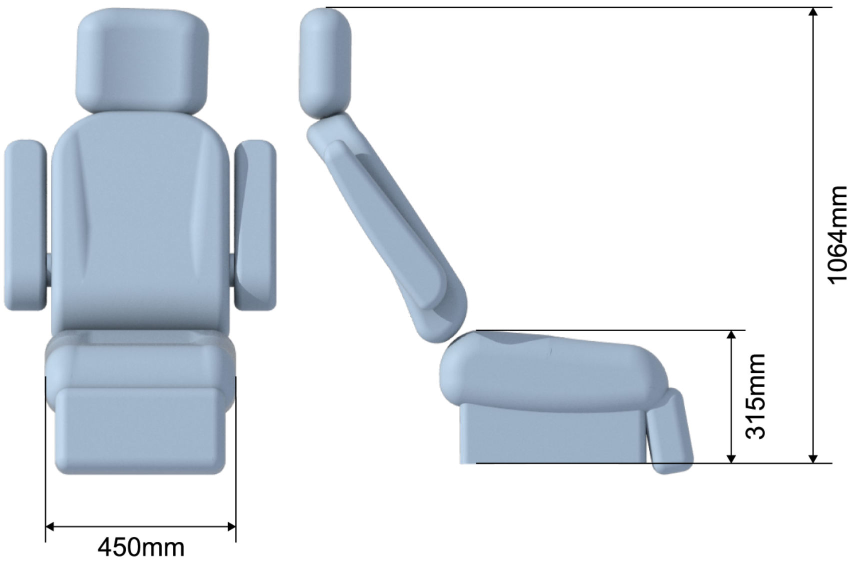


Figure 12. The main dimensions of the finalized seat model

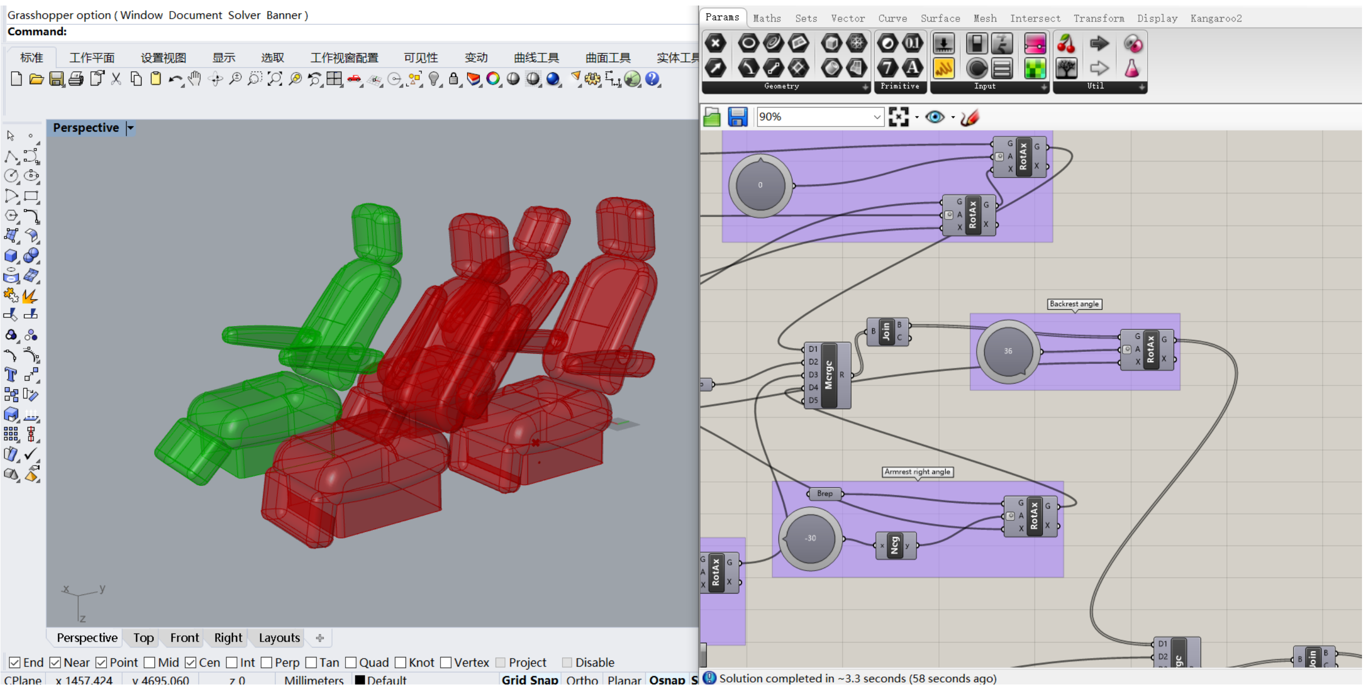


Figure13. Grasshopper parametric modeling of the seat

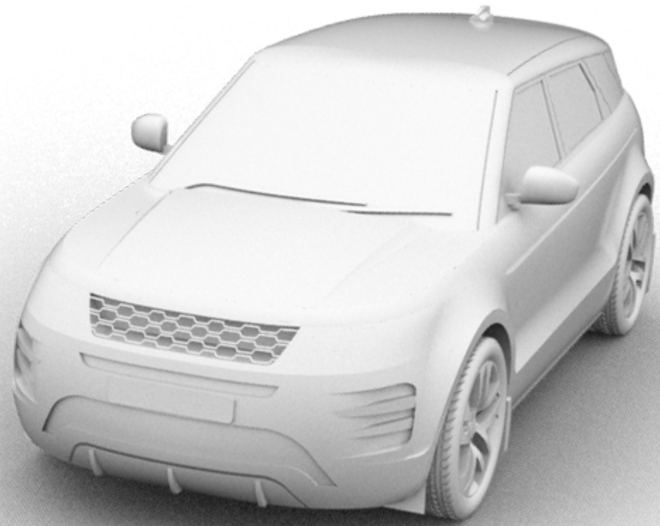
Range Rover Evoque

The dimensions of the Range Rover Evoque car model can be found in Table 8, and Appendix B for the specific meaning of dimensions. The picture at the bottom depicts the actual car model, while Figure 13 on the right shows the 3D model of the Range Rover Evoque, constructed using real dimensions.

Table 8. Range Rover Evoque

Wheelbase	268.22cm
Length, Overall	437.13cm
Height, Overall	164.85cm
Front	
Leg Room	101.6cm
Shoulder Room	143.76cm
Head Room	98.81cm
Second	
Leg Room	85.85cm
Shoulder Room	140.72cm
Head Room	97.28cm

Figure 13. Range Rover Evoque 3D model

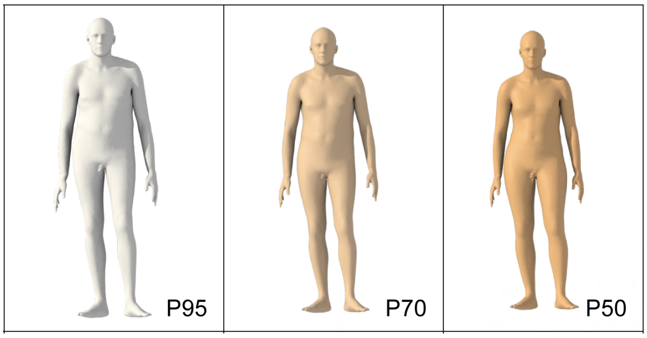


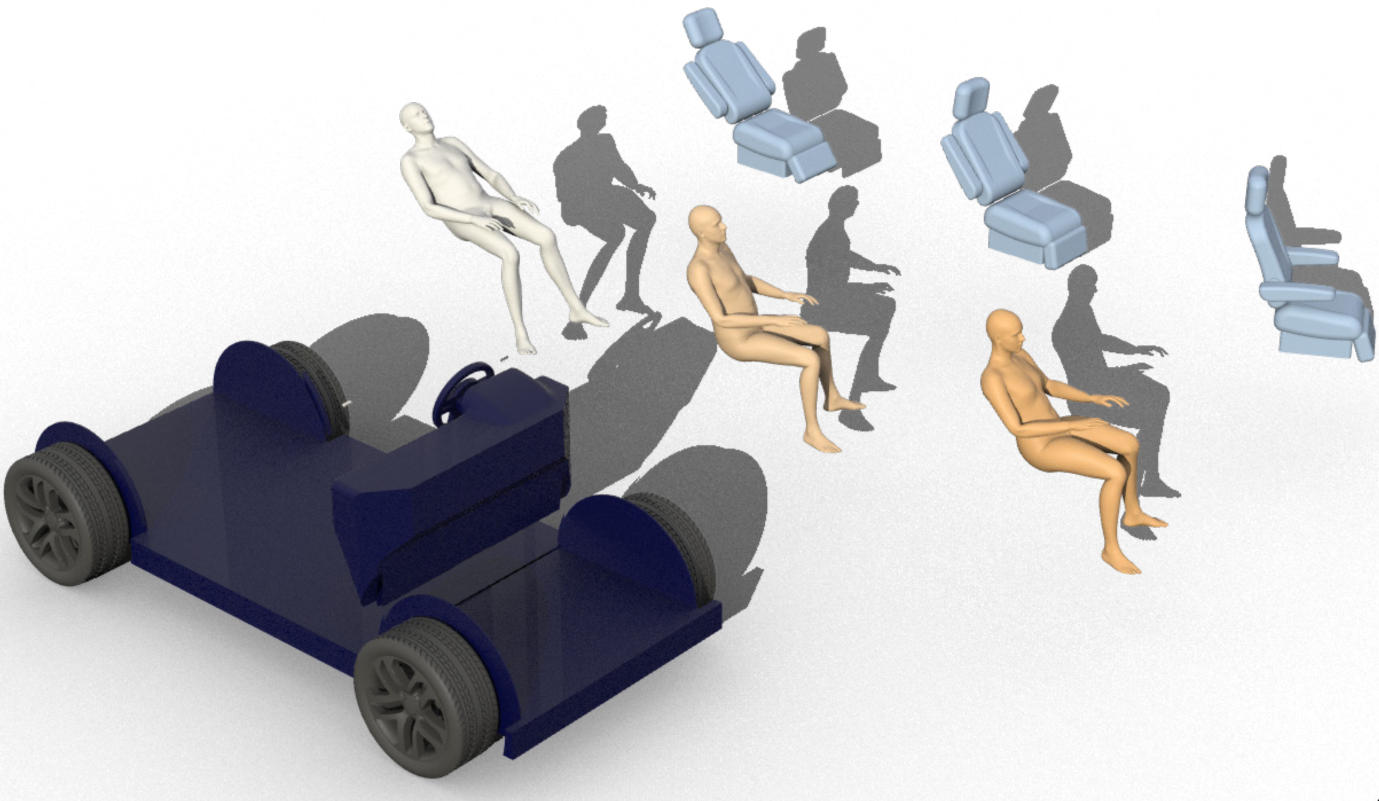
Picture from Range Rover

5.2
Findings for integrating 3D models in Rhino

Utilizing mannequins alongside the car seats within the Range Rover Evoque CAD model enabled an accurate representation of the real interior scenario, which help me directly realize if the space was enough for passengers to perform the important Non-Driving-Related activities in the car. I first analyzed this setup in the Rhino to ascertain whether the current car space's length, width, and height were adequate and whether the necessary space is available when equipment like tables, computers, and tablets are used for work or entertainment.

It's important to mention that in my use of Rhino, I incorporated not just P50 mannequins, but also P70 and P95 mannequins. This approach was taken with the aim of observing the spatial requirements of a more extensive population segment. For clarification, white denotes P95 mannequins, light orange signifies P70 mannequins and dark orange represents P50 mannequins.





Findings

My findings are:

• The existing interior dimensions, encompassing height, width, and length, fall short of fulfilling the requirements of important Non-Driving-Related activities.

When P95, P70, and P50 mannequins were placed inside the vehicle models, an apparent insufficiency in foot space height was discernible across all mannequins, as illustrated in Figures 14, 15, 16. To maintain the feet of the mannequins above the vehicle's floor, given the average SUV seat height of 315mm (typically within the 300mm to 350mm range), an additional 250mm is required for the P95 mannequins, while an extra 175mm is necessary for the P70 and P50 mannequins, as shown in Figure 17 and 18. Thus, the seat height must be adjustable within a range of 490mm to 565mm to cater to user needs during key Non-Driving-Related activities.

The red area is showing the spacial conflicts

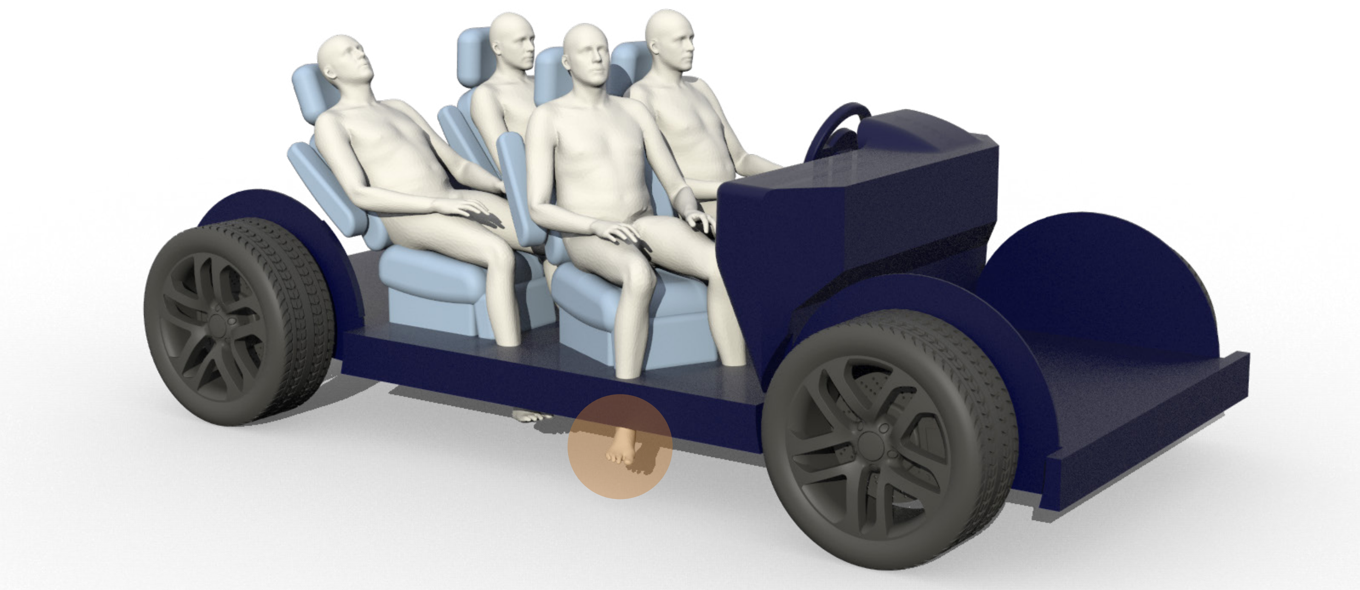


Figure 14. P95 mannequin in the current space

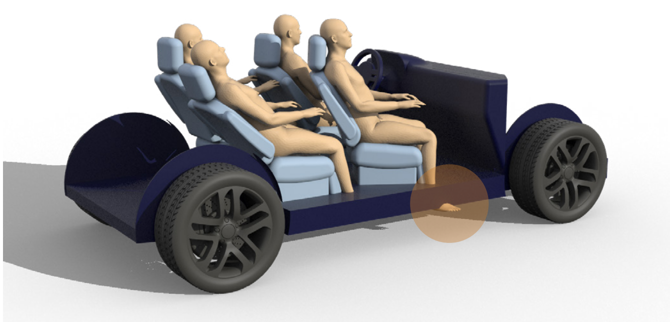


Figure 15. P70 mannequin in the current space

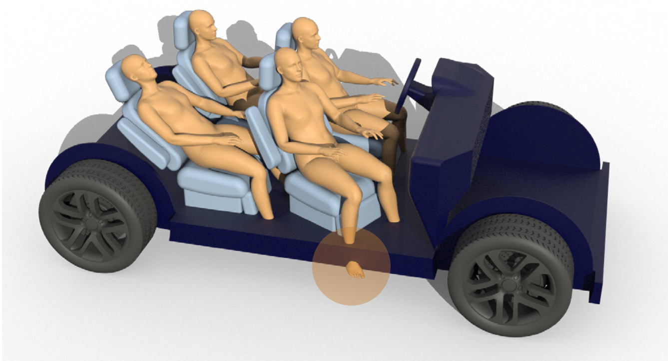


Figure 16. P50 mannequin in the current space

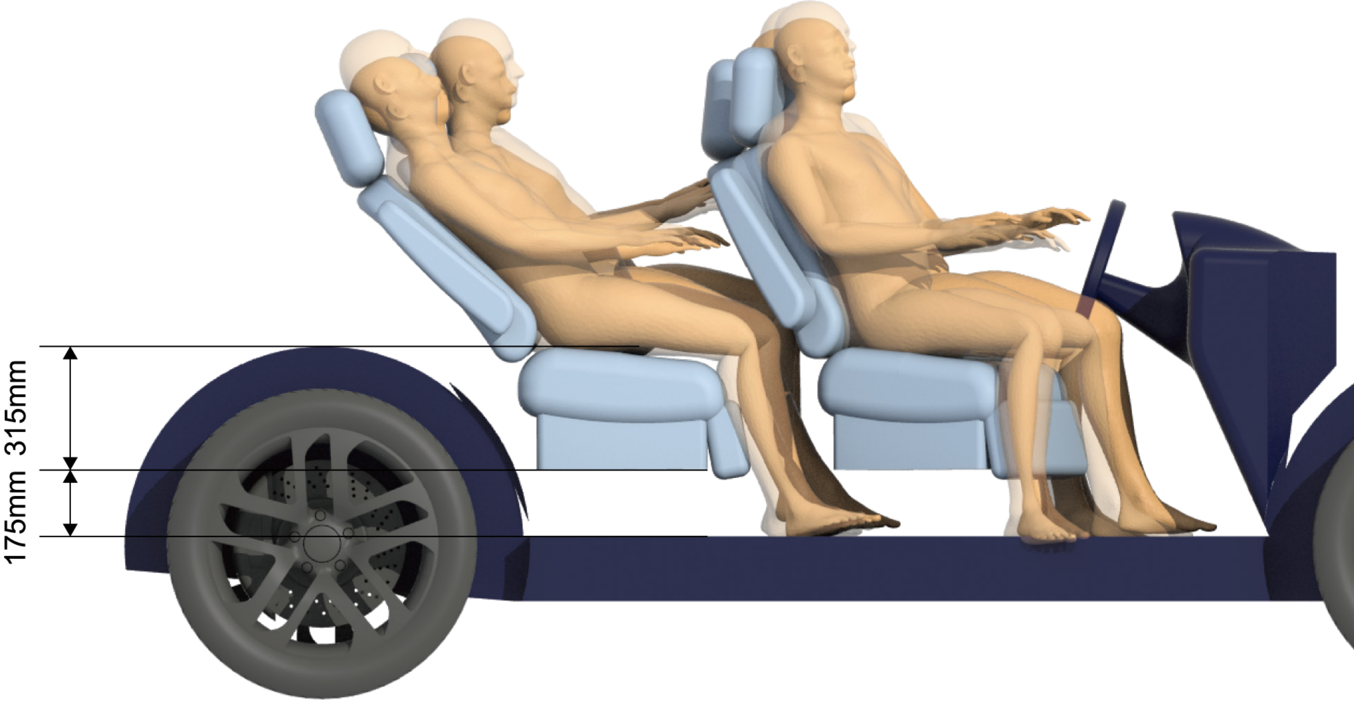


Figure17. P50 and P70 mannequins with extra seat height

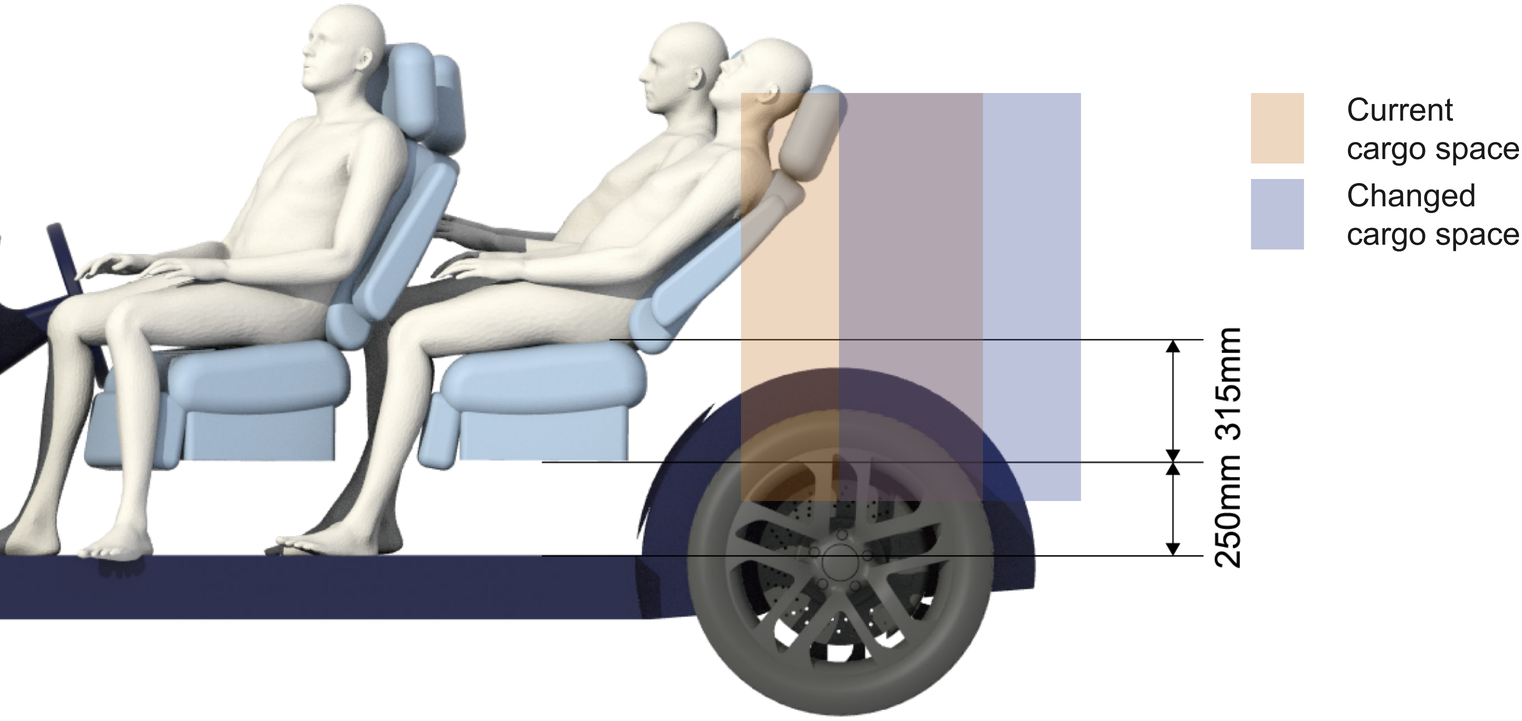


Figure 18. P95 mannequin with extra seat height

As for interior length, it was observed that to allow passengers to attain a more relaxed sleeping position in the rear seat, the current cargo space would need to be utilized. Consequently, an increase in the vehicle's interior length is required to satisfy the needs of rear passengers aiming for a comfortable sleeping position.

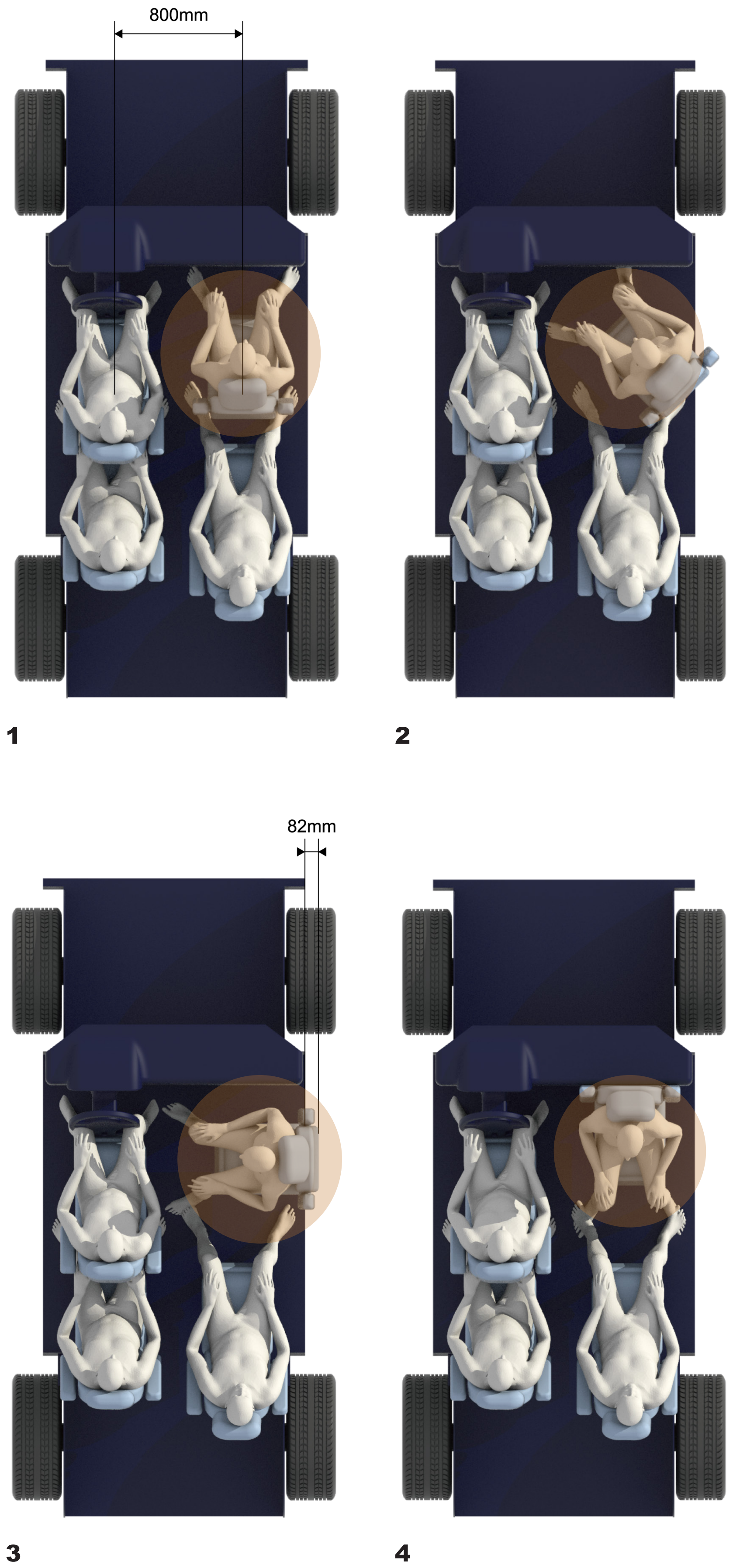


Figure 19. 180-degree rotation

In pursuit of a seating configuration offering interchangeability between the conventional B configuration and the face-to-face F seating configuration, a vehicle's interior must have sufficient width. The center distance (double the lateral location) among adjacent seats in SUVs usually lies between 750mm and 850mm, with 800mm selected as the base seat center distance in our model. Under these conditions, an additional width of 82mm is necessary to attain a 180-degree rotation with an upright backrest, as depicted in Figure 19. This added width, however, can be offset by laterally shifting the seat inward by a specific distance, as indicated in Figure 20. A 100mm inward movement of the seat allows a 180-degree rotation without expanding the vehicle's interior width.

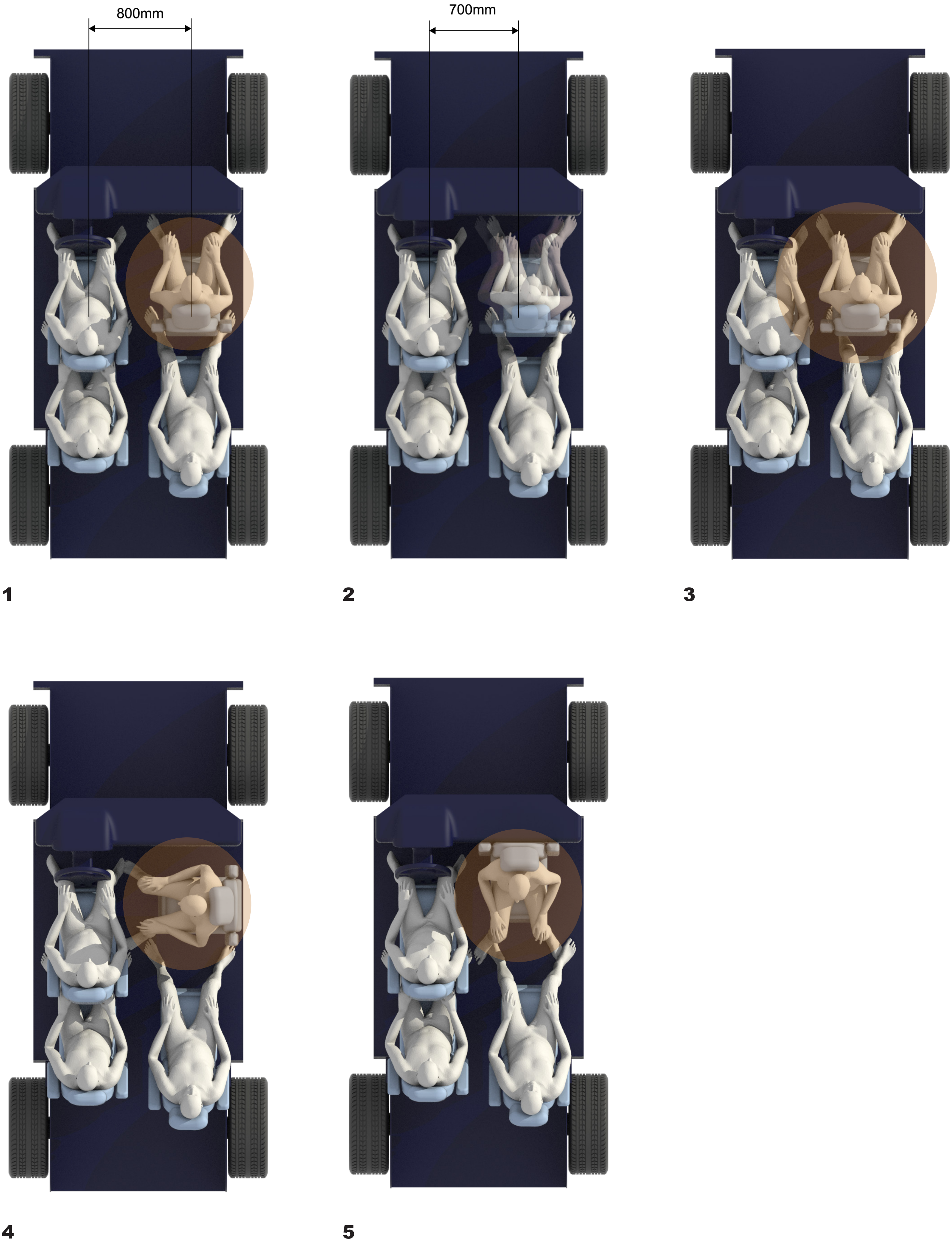
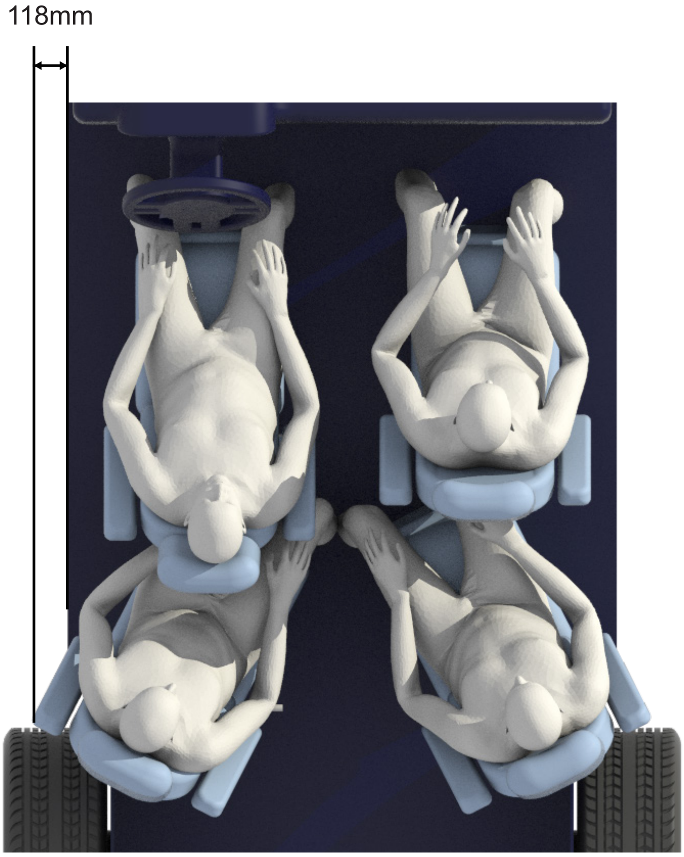


Figure 20. 180 degree rotation, seat moves inward 100 mm



The ergonomic experiments in Chapter 3 revealed that users, when communicating, tend to swivel the seat to create a certain angle, typically between 14 and 46 degrees, averaging around 27 degrees. Implementing this insight into our model, I deduced that the existing interior width is insufficient to accommodate user preferences, demanding an additional width of 118mm and 185mm for seat rotations of 27 and 46 degrees, as demonstrated in Figures 21.

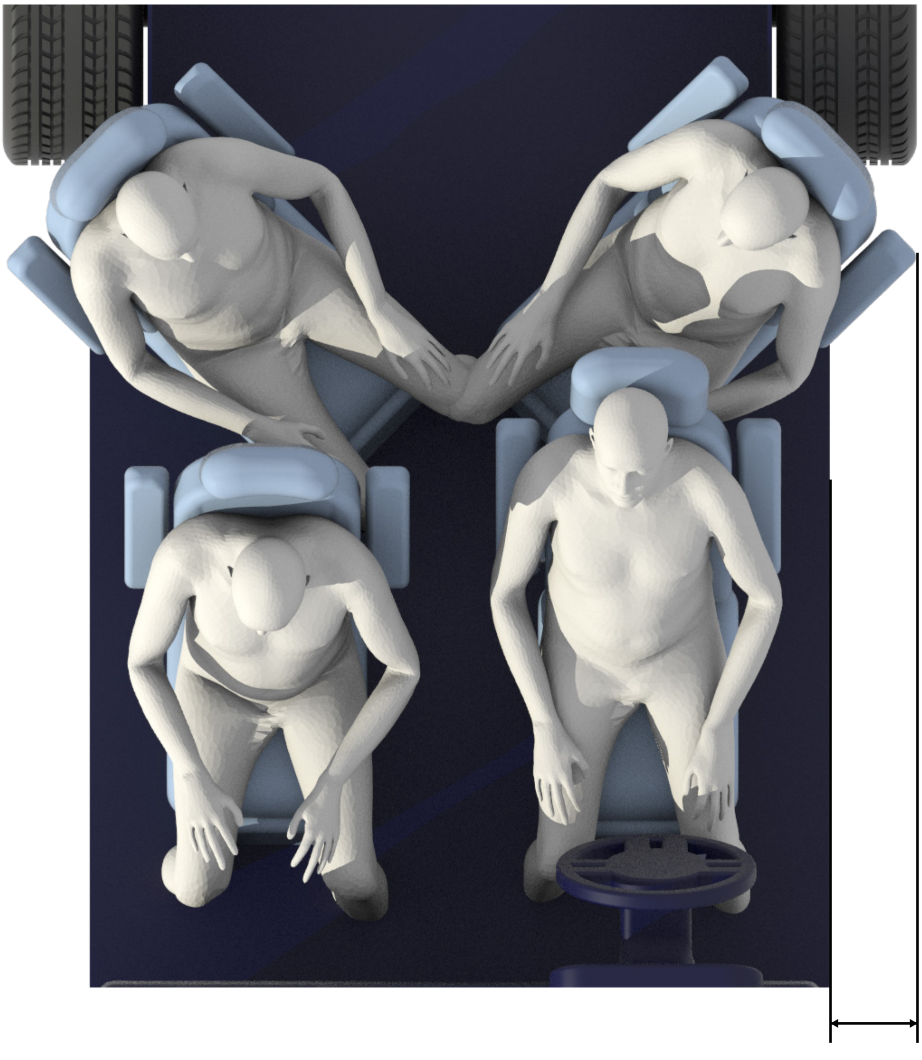


Figure 21. Communicating with other passengers

• The conventional seating layout falls short in fulfilling the needs of rear-seat passengers seeking comfortable space for computer use, be it for work or entertainment.

The P95 mannequin was incorporated into the model, and tables designed to hold computers or other devices were added to both front and rear seats, resulting in a model akin to the one shown in Figure 22. The height of the table was defined based on the outcomes of the ergonomic test, with an approximate average height of 730 mm. Depending on the requirements for entertainment or work, this height can be adjusted within the range of 690 mm to 970 mm and 690 mm to 840 mm, respectively. The illustration signifies that while front-seat passengers enjoy a generous workspace, the rear-seat occupants grapple with a constrained environment, making computer-related tasks difficult. Additionally, the existing interior layout poses a challenge to attaining the maximum comfortable table height.

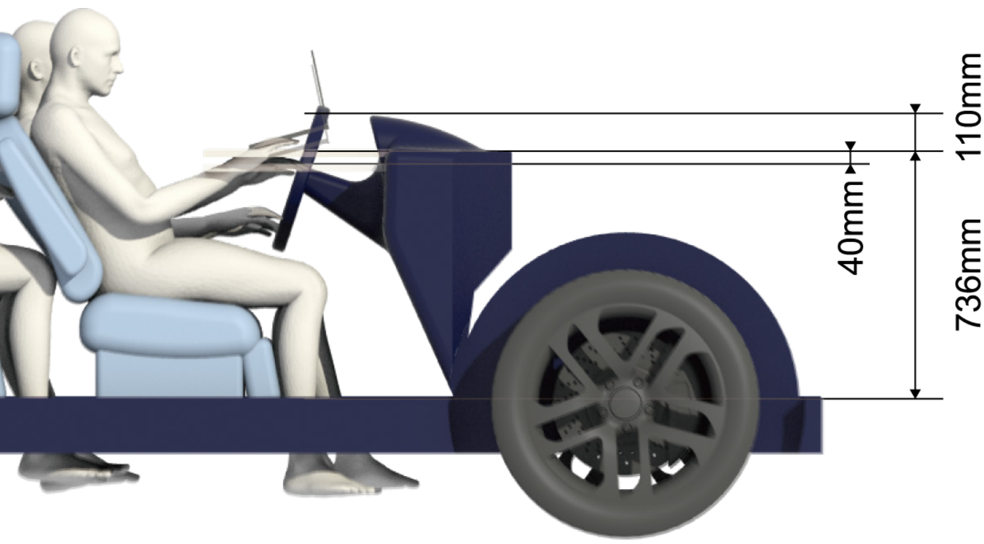
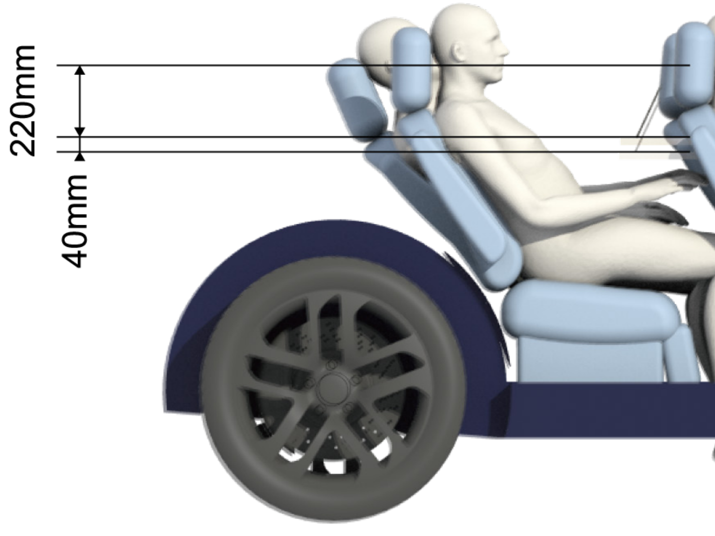
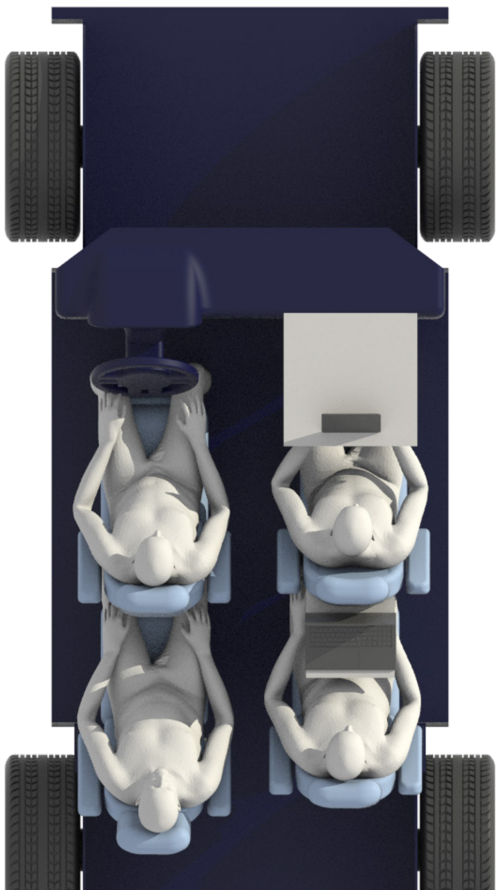
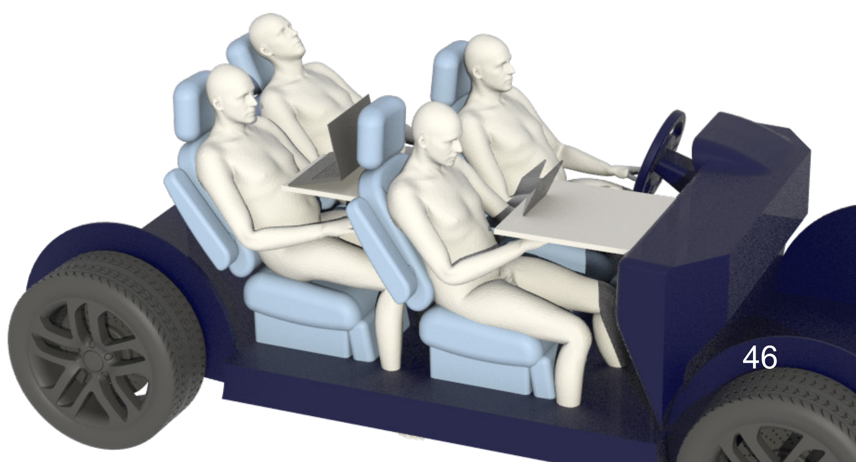


Figure 22. Mannequins with table and equipments







5.3
Discussion of 5.2 findings

By integrating the model in Rhino, I gained an intuitive understanding of the available space for passengers to engage in Non-Driving-Related activities within the vehicle. This analysis yielded two key insights. First, the interior space of the Range Rover Evoque does not suffice to satisfy the spatial requirements for comfortable Non-Driving-Related activities. Second, the current seating layout inadequately accommodates rear-seat passengers desiring ample space for computer use.

These conclusions were derived from an analysis that involved mannequins representing the P95, P70, and P50 with varying joint angles. It's worth noting that the different groups of mannequins mixed might introduce some degree of uncertainty, potentially making the final conclusions not universally applicable across all groups. Nevertheless, as I used the P95 mannequins most, which necessitates more space than P70 and P50, I can assert that the Range Rover Evoque's interior does not fulfill the spatial demands of P95 users engaged in Non-Driving-Related activities across a broad range of comfortable joint angles. However, it would be premature to definitively conclude whether there is sufficient space for the P50 group.

Moreover, it's important to mention that I retained the Range Rover Evoque's dashboard in the model. Despite it occupying a significant portion of the space, if technology advances in the future allow for a thinner dashboard by 2035, it would further augment the available space for users.

Lastly, the 3D seat model was built upon the design of the Knoedler Air-Chief Seat, a model currently in use. The thickness of this seat model, as apparent in the 3D rendering, occupies some space, particularly impacting the space between the front and rear seats. However, envisioning the automotive advancements of 2035, if seats could be slimmed down, it would potentially result in an increase in available activity space for passengers. For example, the RECARO Aircraft Seating SL3510 (shown in the picture) uses an innovative netting material to form the core of the backrest instead of the usual foams, which reduces the thickness of the backrest to 1.5 (3.81 cm) inches.

Picture from RECARO

I would like to modify the model based on the above discussion so that I can answer question two better: To what extent does the space allow P50 users to perform five primary NDRAs within a comfortable range of motion? It is important to note that the focus question two is the space occupancy of the P50 users to perform the activities, and the inclusion of a thinner seat (e.g., 1.5 inches thick as described above) will have little impact on the final results, so in order to simplify my research, I chose to use only the mannequin and not the seat model in the next exploration. However, in the final interior design, the seats will exist in a thinner thickness (less than 1.5 inches). So, the following changes were made to the model in the exploration in AR:

• Include a thinner dashboard in the model.
• Introduce only the mannequin, not the seat model.
• Focus only on the P50 mannequin.

5.4
Findings for integrating 3D models in AR

Based on the aforementioned discussion surrounding the integration of 3D models in Rhino (see section 5.3), I implemented the following modifications to the model: First, I reduced the thickness of the dashboard, which is demonstrated in Figure 23 depicting the thinner dashboard. Second, I put only mannequins, omitting the seat model in this phase of the study. Lastly, I limited my focus solely to the P50 mannequins.

To gain a more intuitive understanding of the space users may require when engaged in Non-Driving-Related activities, I utilized the HoloLens augmented reality (AR) device. Microsoft's HoloLens, a leading device in the AR realm, enables immersive and interactive AR experiences.

One of the critical advantages of AR is its capability to provide a spatial understanding that flat renderings or models on a screen can not adequately deliver. This technology enables me to visualise the car's interior space, perceive the space's dimensions more accurately, and intuitively understand the spatial requirements of different user activities. By allowing me to interact with the 3D models in a realistic and immersive manner, the HoloLens facilitates a deeper understanding of the potential spatial constraints and possibilities, making it an invaluable tool in this study.

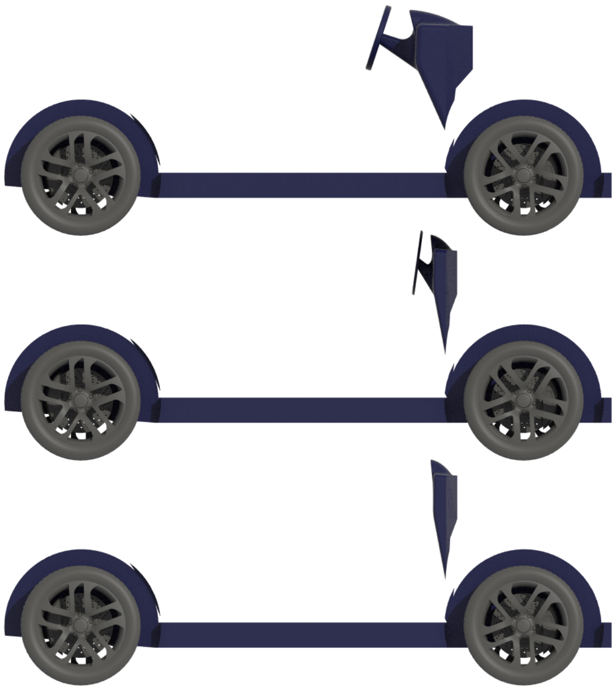


Figure 23. Changes to the dashboard

Top: Original dashboard
Middle: altered (thinner) dashboard (driving mode)
Bottom: altered (thinner) dashboard (non-driving mode)

Pictures from Microsoft HoloLens

To investigate whether P50 users can perform Non-Driving-Related activities within a large comfortable range of motion in the future Range Rover Evoque, featuring a slimmer dashboard and thinner seats, I incorporated 16 different P50 mannequins (see Table 7) into HoloLens. These mannequins represented various activities and joint angles. Additionally, I imported the Range Rover Evoque in two distinct configurations (see Figure 23): one in driving mode (equipped with a steering wheel) and another in non-driving mode (without a steering wheel).

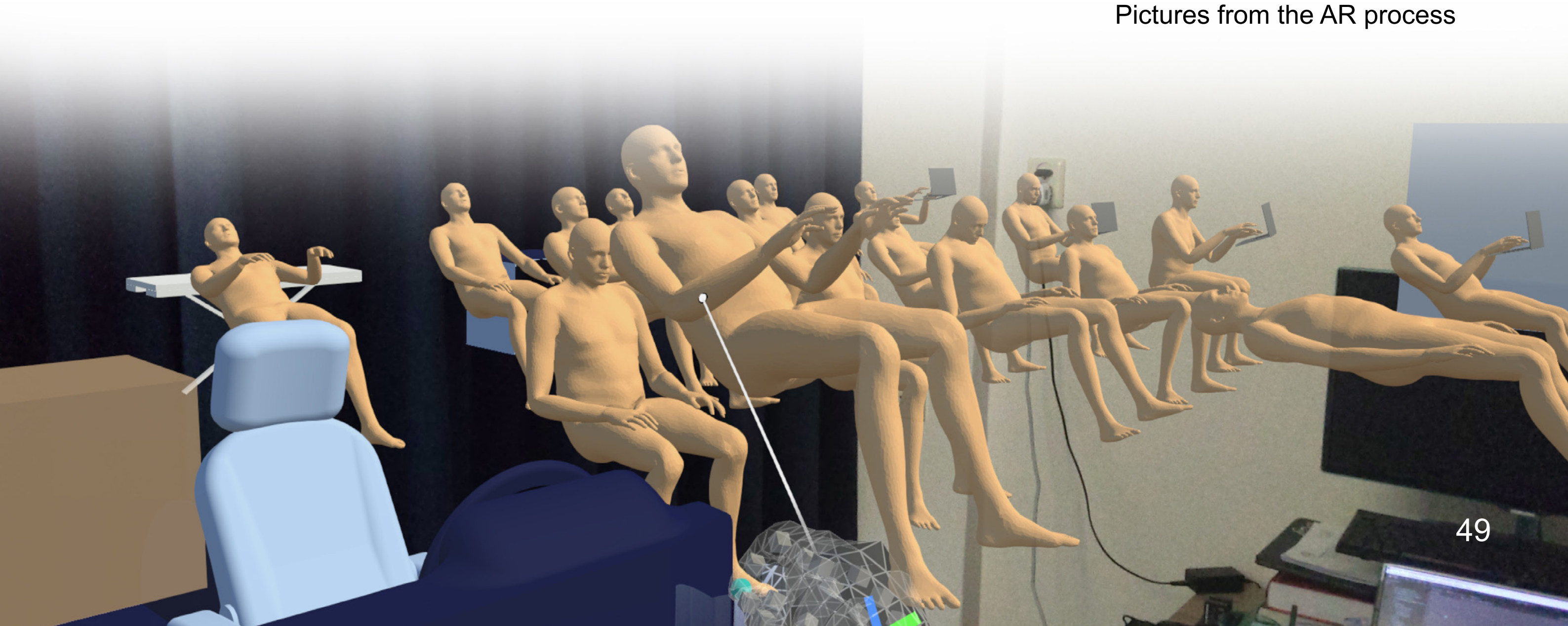
My methodology involved freely combining multiple mannequins engaged in different activities to examine the spatial occupation. The aim was to generate as many diverse combinations as possible, encompassing varying Non-Driving-Related activities and distinct joint angles.

To streamline subsequent descriptions, I've employed specific symbols (see Table 9) to represent the five Non-Driving-Related activities. Furthermore, I have used color coding for different joint angles: red for the maximum, orange for the average, and yellow for the minimum.

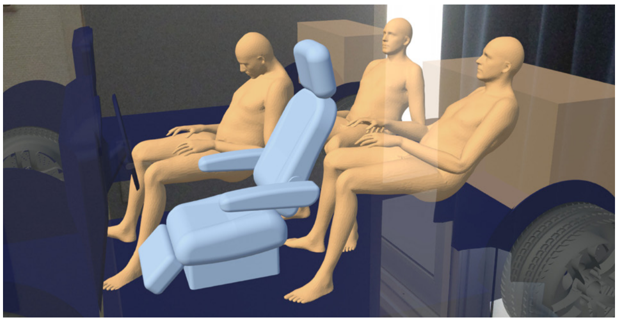
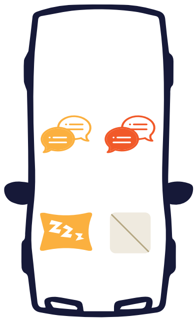
Table 9. Symbols for the activities and postures

	Maximum angle	Average angle	Minimum angle	Other
Activity: Entertainment				
Activity: Look out				
Activity: Sleep				
Activity: Work				
Activity: Talk with other passengers				

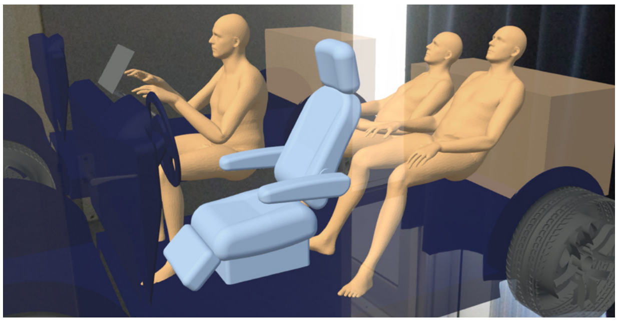
Pictures from the AR process



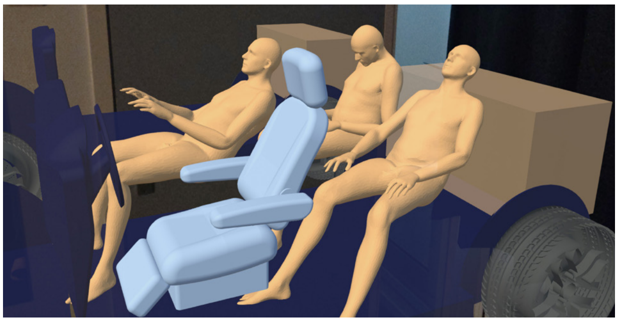
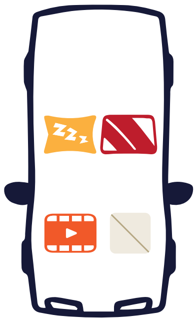
Driving mode
(with a steering wheel and a driver seat)

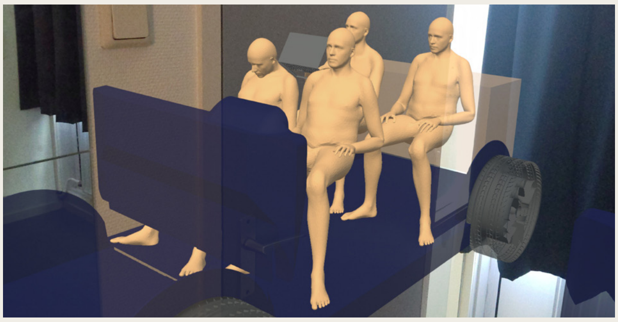
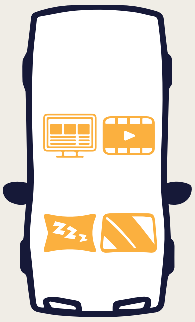



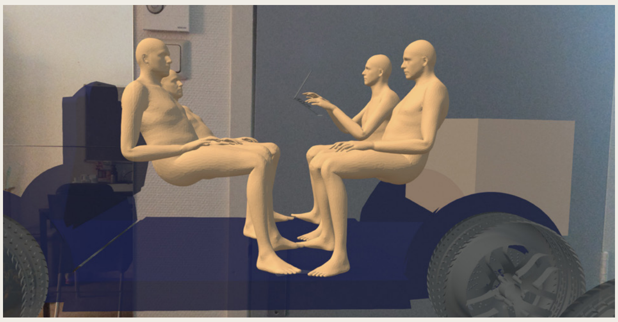
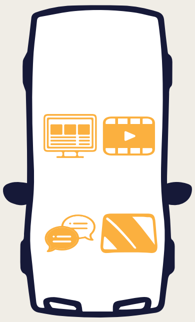
Findings




According to the characteristics of different combinations, the results can be classified into two categories. The first category is the combination that the internal space of Range Rover Evoque can meet the needs of activities and joint angles, as shown on this page.


It can be seen that it includes:

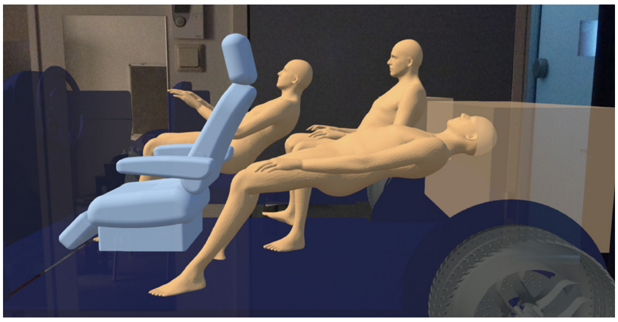
- Talking with passengers and looking out of the window at the minimum, average, and maximum joint angles (even at the maximum joint angle, the required backrest angle is still less than 130 degrees);
- Sleep and work at the minimum joint angle;
- Minimum and average joint angles for entertainment (watch IPad).

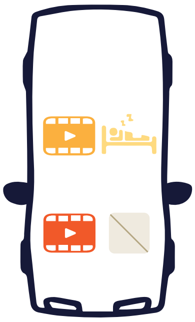
Non-driving mode
(No steering wheel or driver seat)

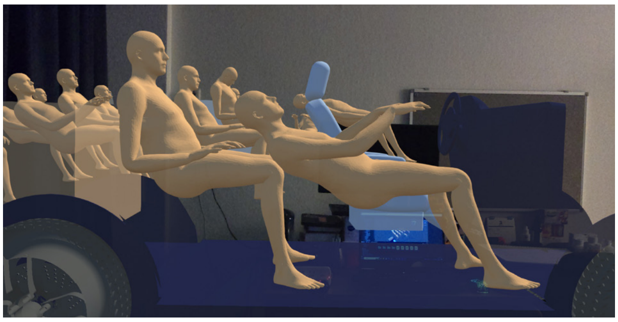
The second category is that the internal space of Range Rover Evoque cannot meet the needs of activities and joint angles, as shown on this page. It can be seen that the unsatisfied combinations include:

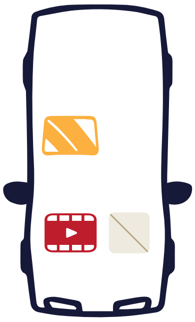
- Sleeping flat;
- Sleep, entertainment, and work at the maximum joint angle.

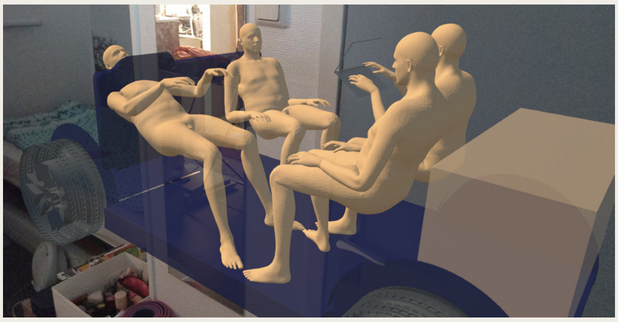
Driving mode
(with a steering wheel and a driver seat)

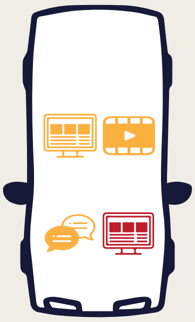


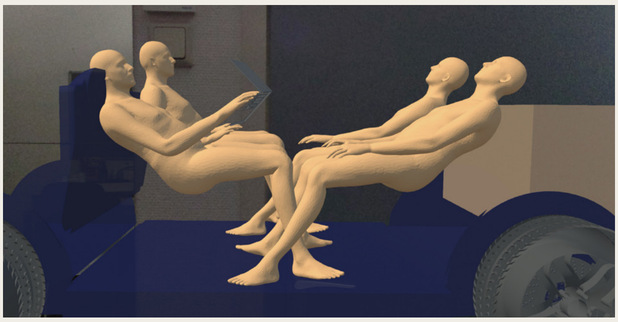


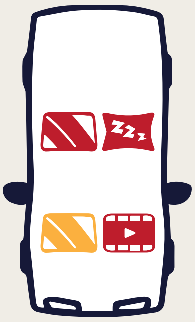








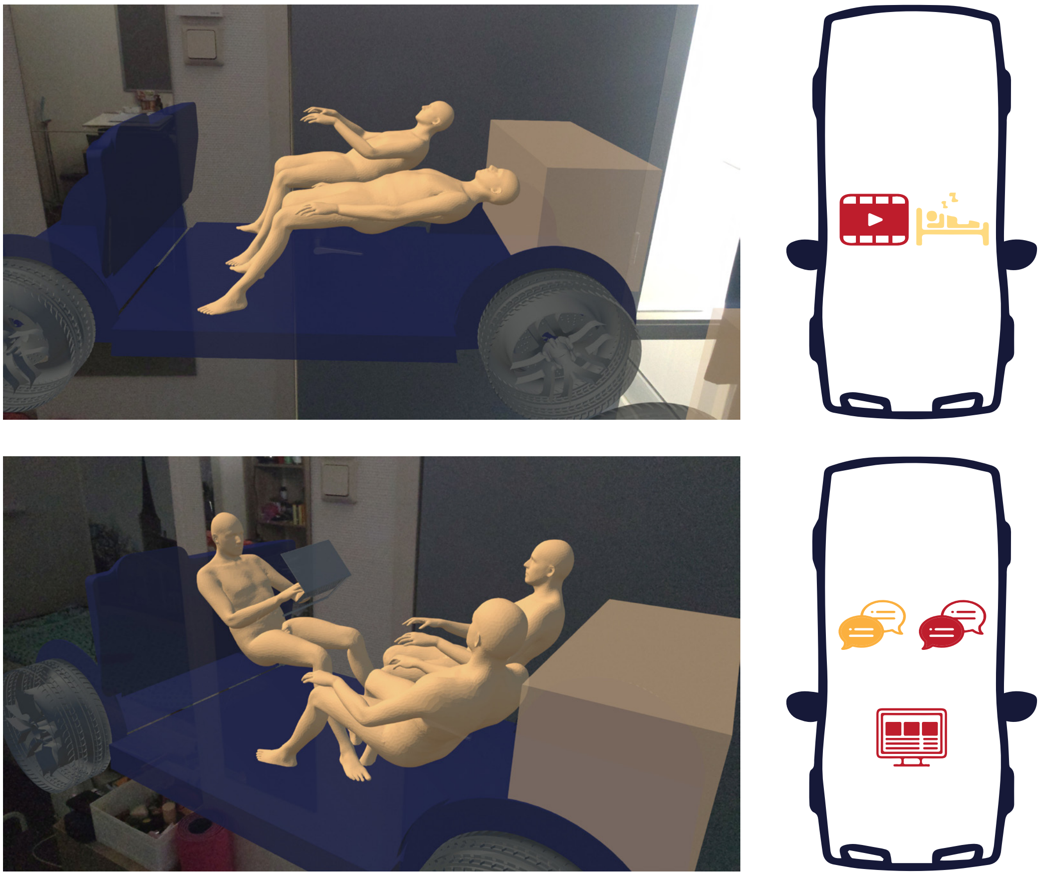




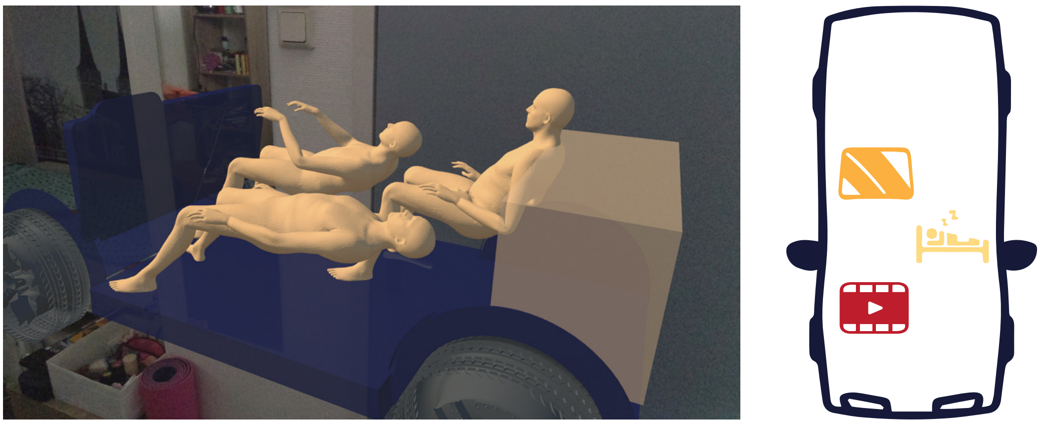
Non-driving mode
(No steering wheel or driver seat)

The aforementioned analysis is grounded on the configuration of a four-seater vehicle interior. However, what if we reconfigure the layout to cater to only two or three users? Could this potentially realize a broader range of joint angles that a four-person layout might struggle to provide? My exploration into this possibility revealed that indeed, with a smaller number of occupants (two to three), the interior can accommodate activities and joint angles that demand more space, such as laying flat for sleep, engaging in entertainment, or working at maximum joint angles. Nevertheless, notably, there may not be sufficient room if multiple occupants engage in the activities with maximum angle joints simultaneously (see the figure at the bottom).

Enough space



Not enough space



5.5 Conclusion

I have used the integration of 3D models to Rhino and 3D models to AR to investigate if the current interior space of the Range Rover Evoque can meet user requirements for five key Non-Driving-Related activities from a comfort perspective regarding joint angles. Using 3D models has enriched my perception of product space and accelerated my exploration process.

In the exploration of integrating 3D models into Rhino, I found that the existing interior space of Range Rover Evoque can't meet the needs of P95 users to carry out important Non-Driving-Related activities with a wide range of joint angles. Due to some loopholes in the exploration process caused by unclear targets, I elected to employ AR for a second investigation.

During the exploration of integrating 3D models into AR, I narrowed my focus to the P50 group. And I based this on the hypothesis that by 2035, dashboards and seats will likely be thinner. This analysis revealed that the current interior space of the Range Rover Evoque could facilitate four P50 users conducting five major Non-Driving-Related activities with narrow comfortable joint angles. In fact, even activities like chatting with passengers and viewing the outside could be achieved with larger joint angles. However, the space fell short of supporting four P50 users performing certain activities, such as sleeping, entertainment, and work, with larger joint angles. Furthermore, I also investigated scenarios accommodating just two or three individuals, discovering that the existing interior space could fulfill the needs of 2-3 P50 users participating in Non-Driving-Related activities with large joint angles.

Based on this research, I propose from a spatial occupation standpoint that future automated vehicles should feature slimmer dashboards and seats to afford users greater activity space. To achieve a wider range of comfortable joint angles, we might contemplate transforming a four-seater car into a two or three-seater or augmenting the vehicle's internal dimensions.

Key Takeaways

• The Range Rover Evoque's space falls short in supporting P95 users conducting 5 major Non-Driving-Related activities at larger comfort joint angles.

• The space can accommodate four P50 users for 5 major Non-Driving-Related activities at small or average joint angles. However, it lacks the space needed to sleep, entertainment or work at larger joint angles.

• It is recommended that future automated cars should have slimmer seats and dashboards.

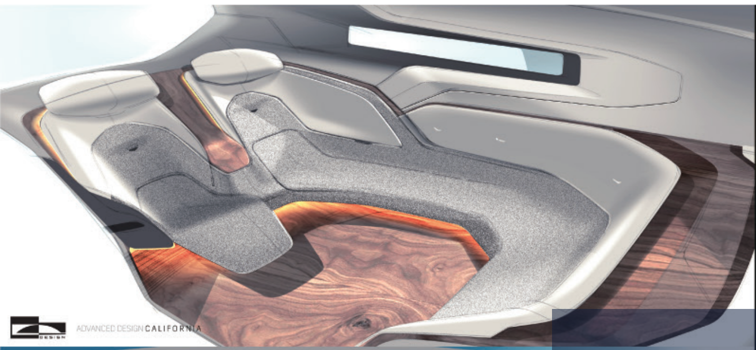
• Transitioning from a four-seat to a two- or three-seat layout, or expanding the interior space, allows users to perform important NDRAs at larger comfortable joint angles.

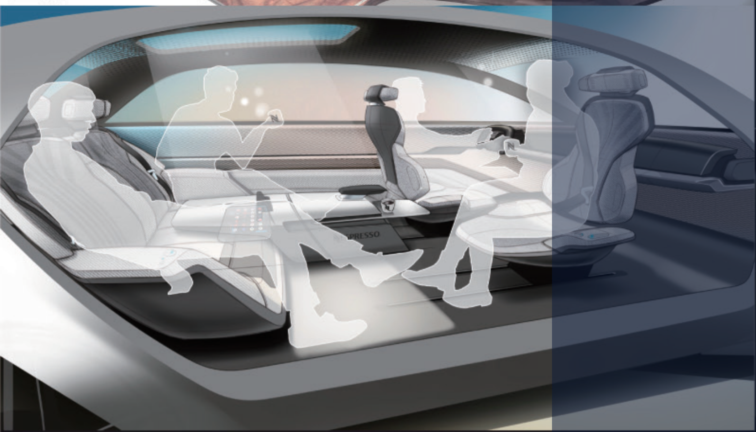
Chapter 6.
Design and iteration

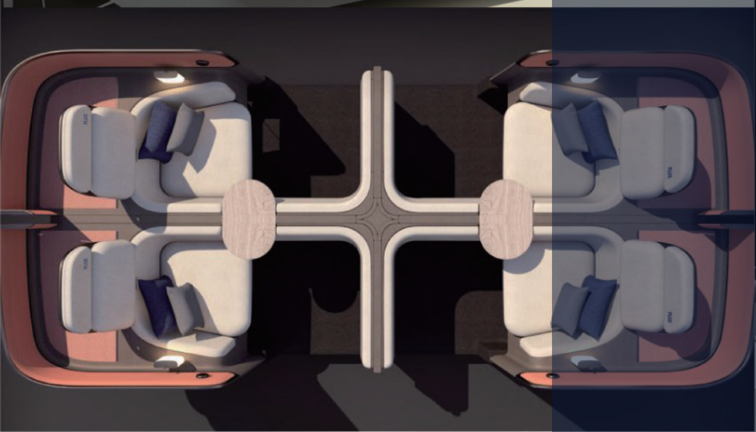
6.1 Introduction

Following a comprehensive literature review, I embarked on ergonomic experiments and interviews. The primary goal was to identify users' preferences for Non-Driving-Related activities, as well as their specific needs regarding comfort and layout. The data collected from these studies provided an empirical backbone for my design approach. Besides these, I utilized 3D models to gain a robust understanding of space occupation of different activities.

The ideation journey commenced with rudimentary hand sketches, a process that encouraged an unfiltered surge of creativity. And finally contributed to two car interior design concepts. Each was crafted to enable seamless transitions between activities, and designed to imbue users with a sense of comfort and freedom. Finally, by combining the advantages of the two concepts, a preliminary future vision of automated car interior design is obtained.

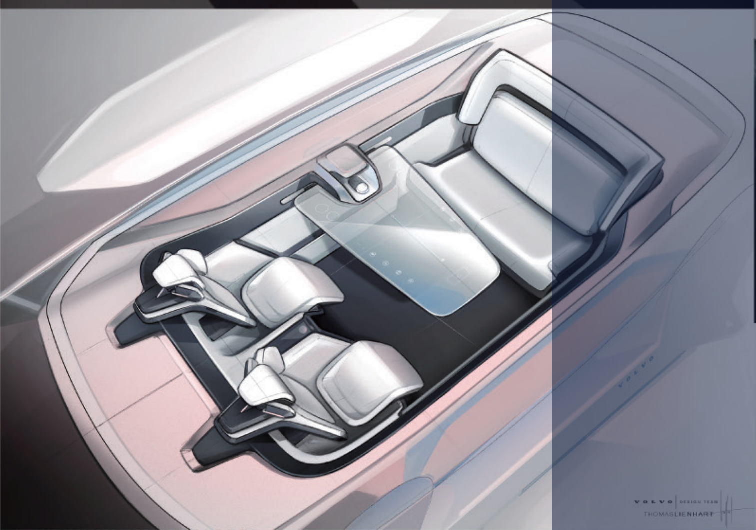






6.2 Moodboard

The mood board served as a canvas, capturing various sources of inspiration including current automated car designs, the innovative aircraft cabin concepts from the AIX exhibition, and office chair images. The primary objective was to explore the interior layout to enable seamless transitions between activities within the confines of an automated car. And it was especially focused on the activities such as viewing landscapes, engaging in work, partaking in entertainment, interacting with fellow passengers, and sleeping.



Pictures from Audi skysphere

Audi skysphere concept
- Future luxury sports car
- Automation level: level 4
- Seating Capacity: 2
- "Grand Touring" mode: will extend the wheelbase and thus increase the length of the car by 250 mm; the pedals and steering wheel disappear, allowing occupants to enjoy a more spacious interior

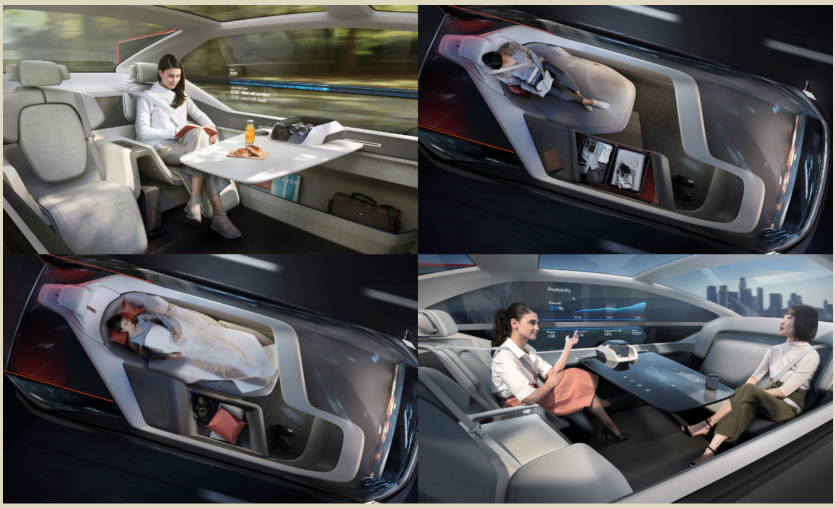
STELIA Aerospace
- STELIA Aerospace Business Class Seat
- Ultra-slim seating
- A large privacy door, turning the seat into a wide and comfortable private suite
- A spacious and comfortable full flat bed (realize the angle transformation of sitting and lying down)

Pictures from STELIA Aerospace

Franklin light aircraft seat
- Innovative netting material
- Ultra-slim seating

Pictures from STELIA Aerospace

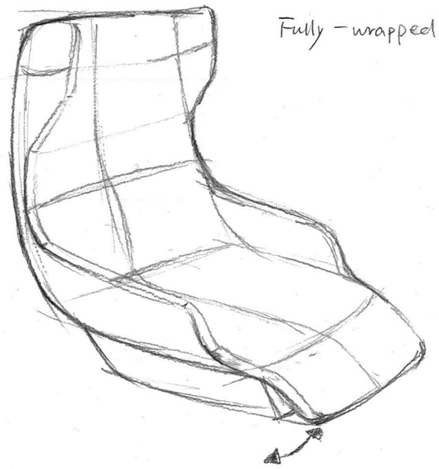
Pictures from Volvo

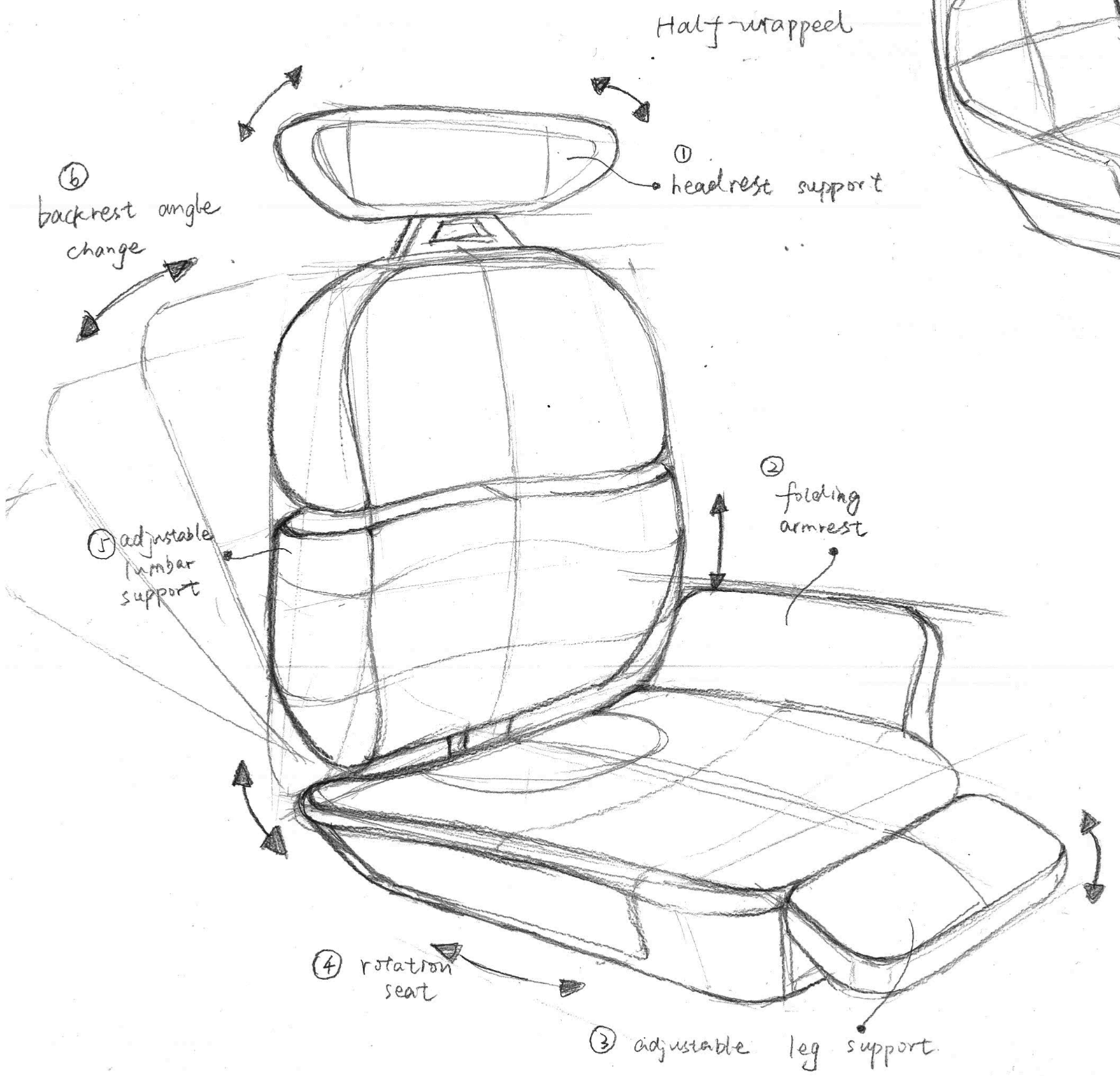


Volvo 360c concept
- An office-bed-living room mashup
- Automation level: level 5
- Show four potential uses of automated vehicles: as a sleeping environment, mobile office, living room, and entertainment space

6.3
Ideation and Development

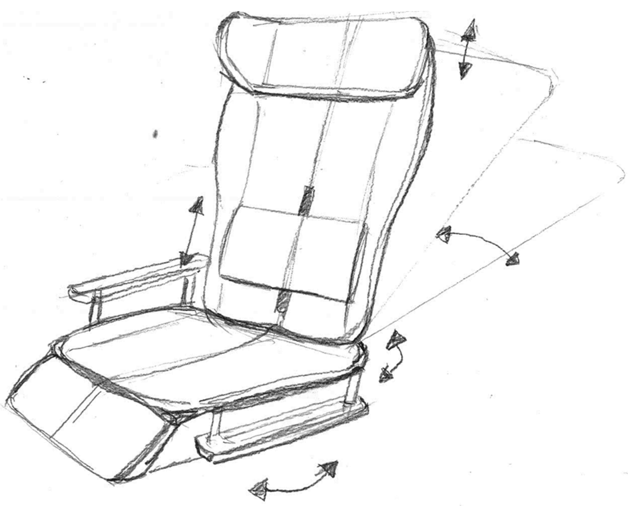
Drawing

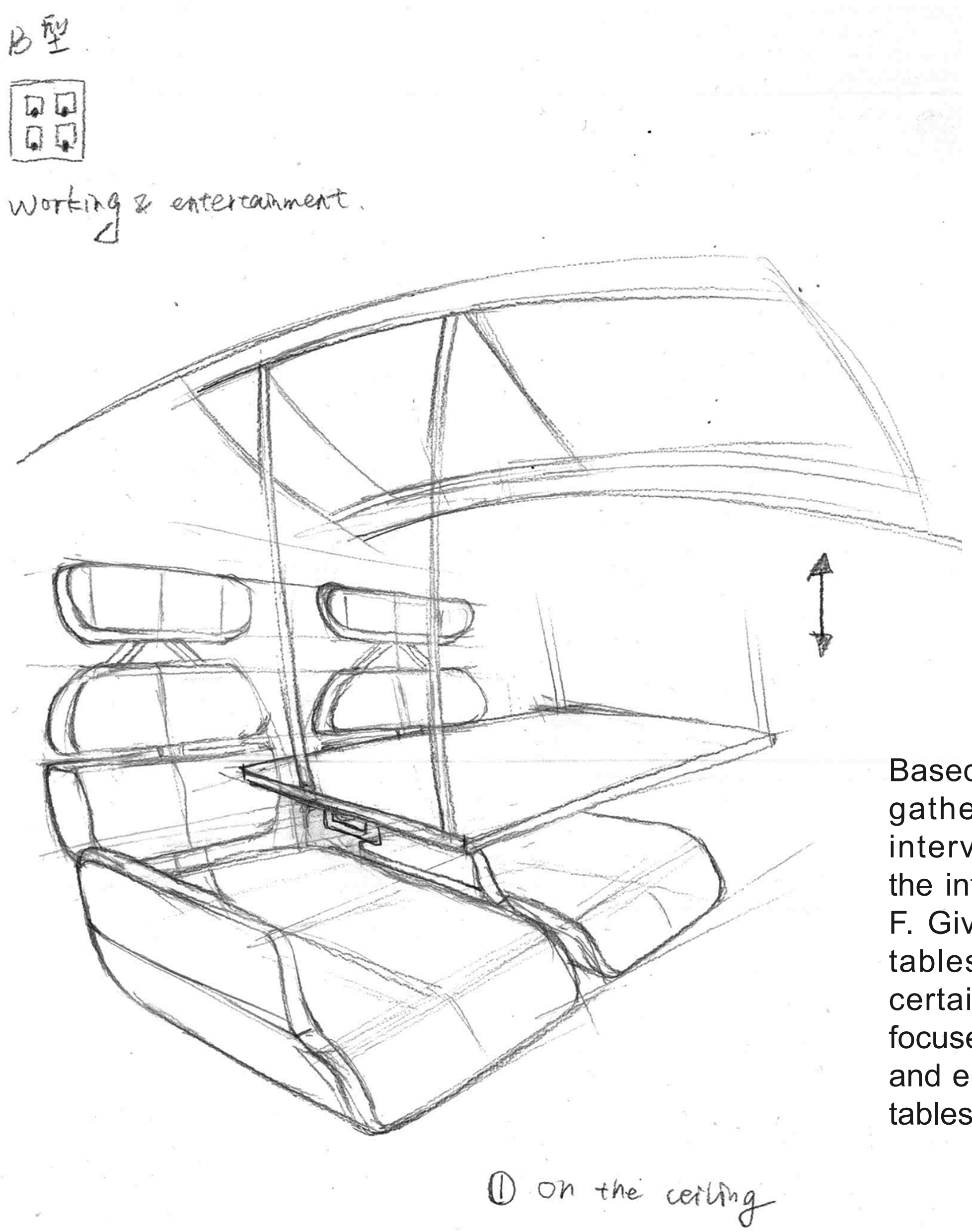


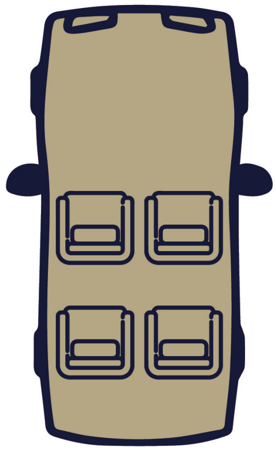


At the start of the ideation phase, I incorporated the insights made from the experiments and interviews to make a multi-feature seat design, as depicted in the picture. The six salient features include:

- Head support augmented with lateral support,
- A foldable armrest,
- An adjustable leg support,
- A rotatable mechanism,
- Customizable lumbar support, and
- A backrest angle that can be adjusted according to different activities.

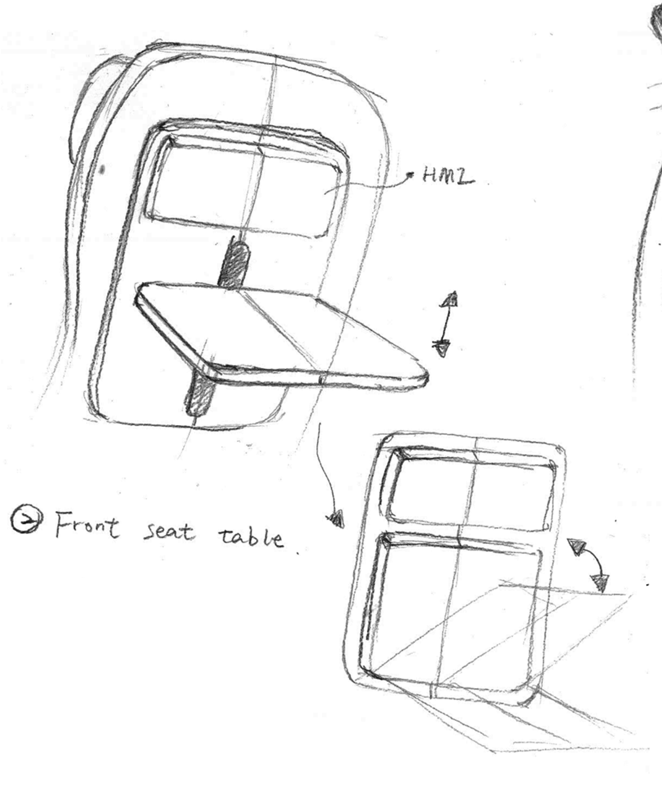


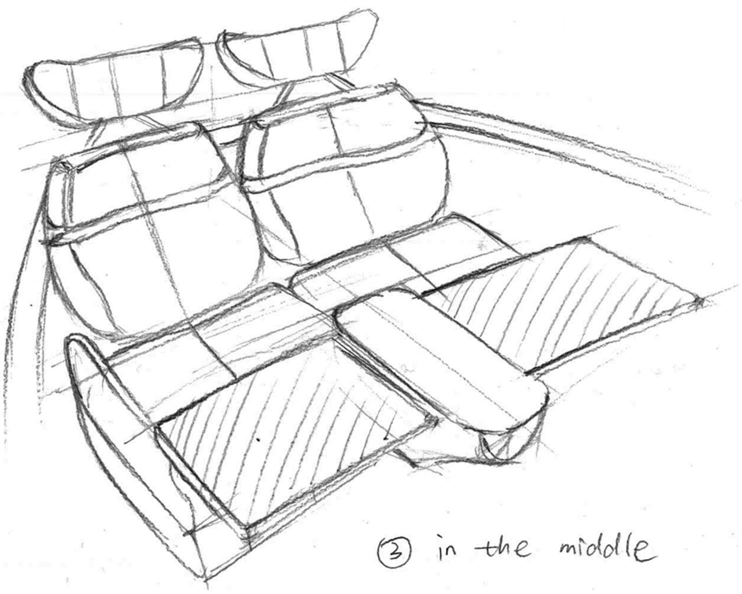




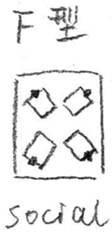
B
Conventional

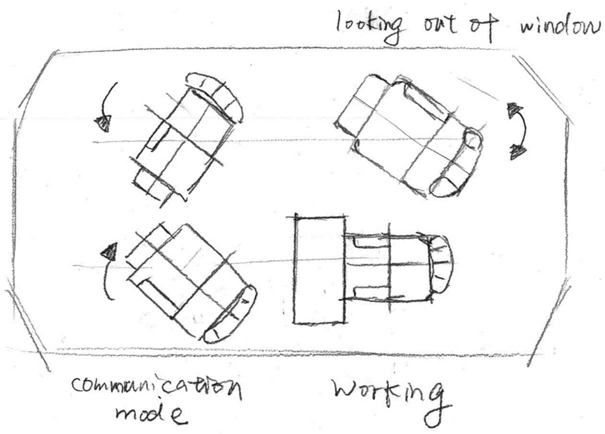
Based on the seating preferences gathered from users during the interviews, I manually sketched the interior of configurations B and F. Given the important role of the tables in work-related tasks and certain entertainment activities, I focused on drawing the positioning and emergence mechanisms of the tables.

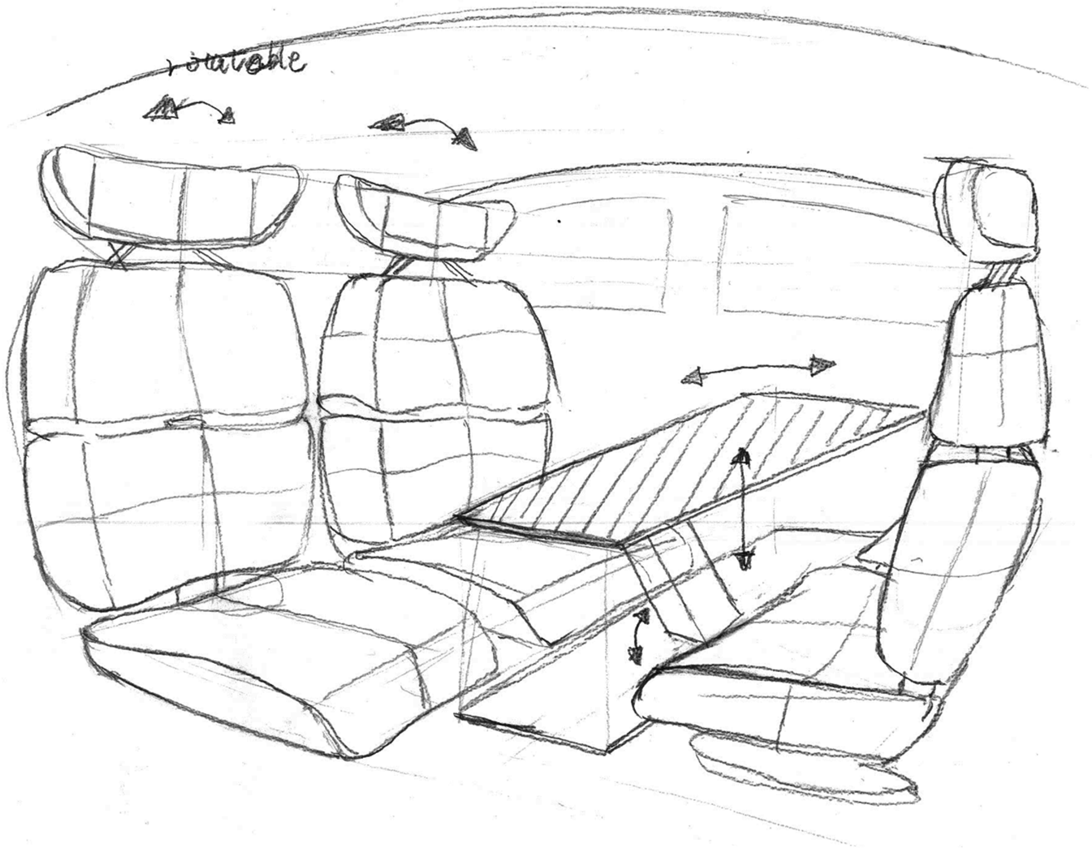


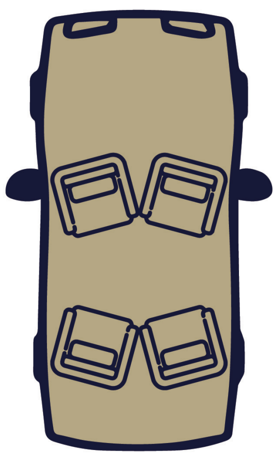


The transition from B to F configuration is achieved by the rotation of the seats.

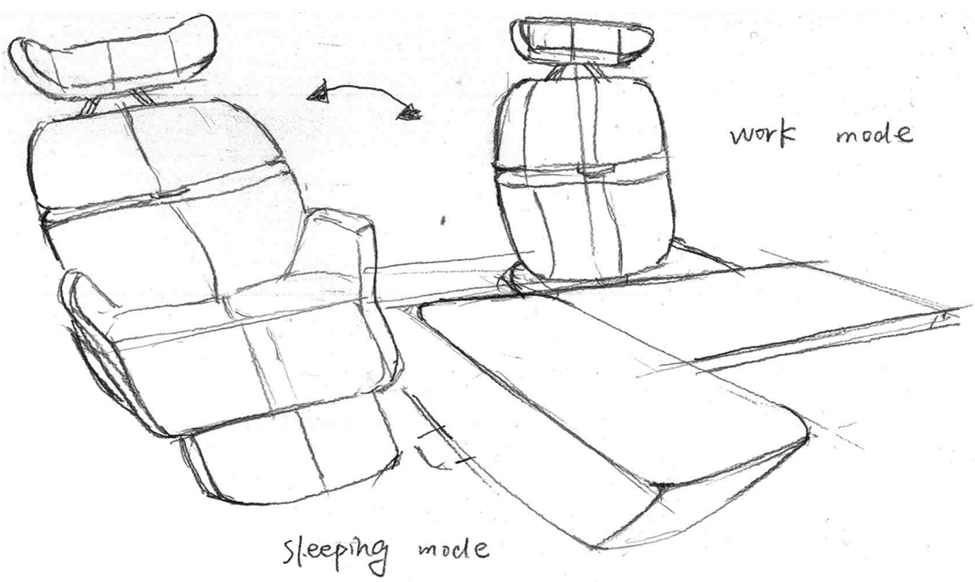








F
Face-face



6.4 Concepts

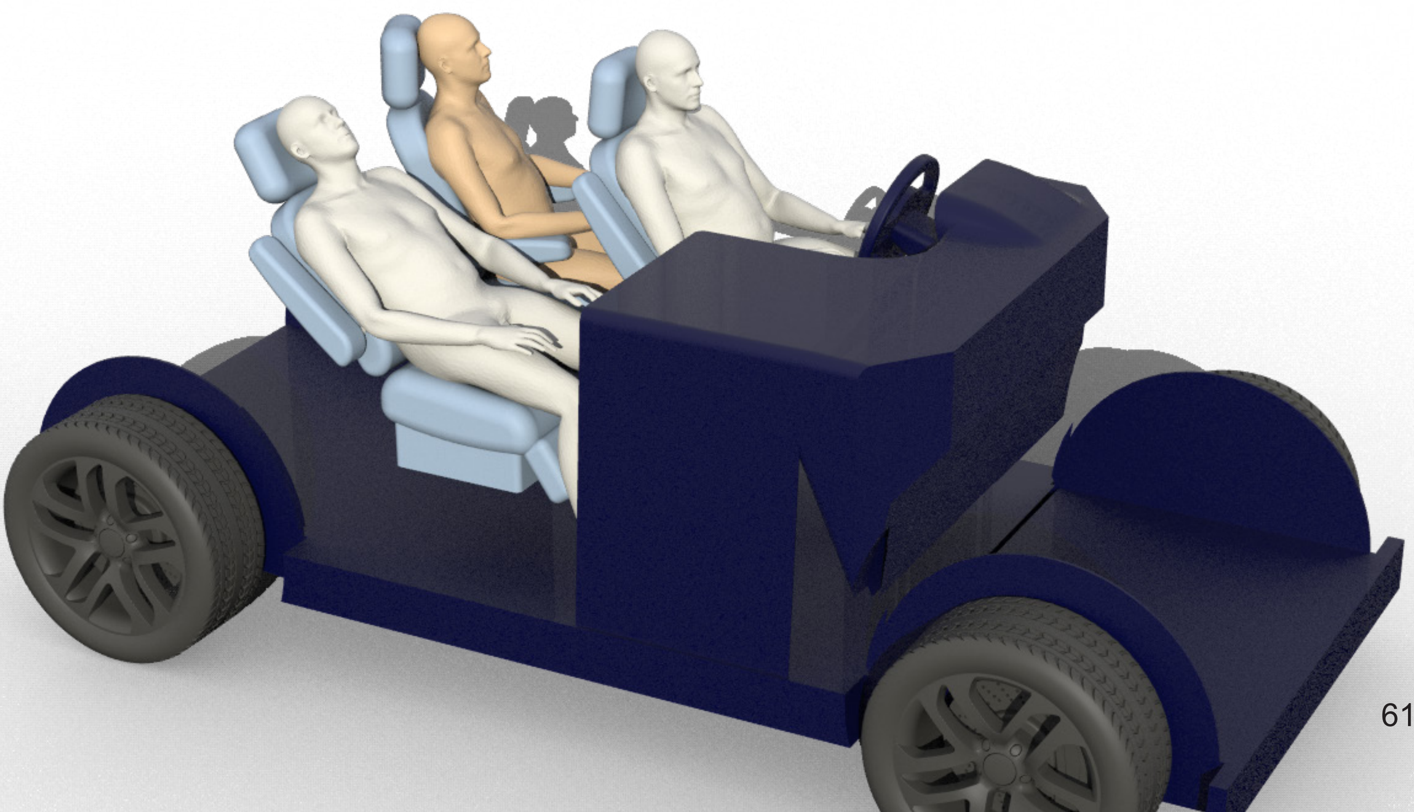
Concept 1

At the heart of this innovative concept is the reimagination and extension of the traditional car dashboard. Traditionally, the dashboard of a car serves a multitude of purposes, playing a pivotal role in vehicle control, storage, and vital communication with the driver. The escalating need for advanced information control in automated driving in the future suggests a potential shift towards an integrated dashboard model - one that harmoniously amalgamates various functions.

With the understanding that users engage in a range of Non-Driving-Related activities - such as sleeping, communicating, or working - this design expands the dashboard to foster these activities. Thus, the reinvented dashboard evolves into a core area conducive to major activities, where users can work, communicate, and more. This not only meets the user's needs for comfort during Non-Driving-Related activities but also situates them near the control hub of the vehicle, the dashboard. This proximity ensures users stay updated on essential vehicle information, potentially enhancing overall safety.

This concept sprouted from two critical findings during the 3D modeling phase. Firstly, I found that the current car space falls short of accommodating users' Non-Driving-Related activities comfortably, such as the space length required for a user to sleep. Secondly, I identified an evident lack of adequate space for rear passengers to engage comfortably in computer-related tasks.

Given these findings, my design concept envisions the removal of the front passenger seat and an extension of the dashboard. This innovative modification not only provides users with enhanced space for Non-Driving-Related activities but also ensures a more efficient interaction with the vehicle's controls and information. In essence, this revolutionary interior layout optimally merges comfort and control, steering toward the future of automated vehicles.

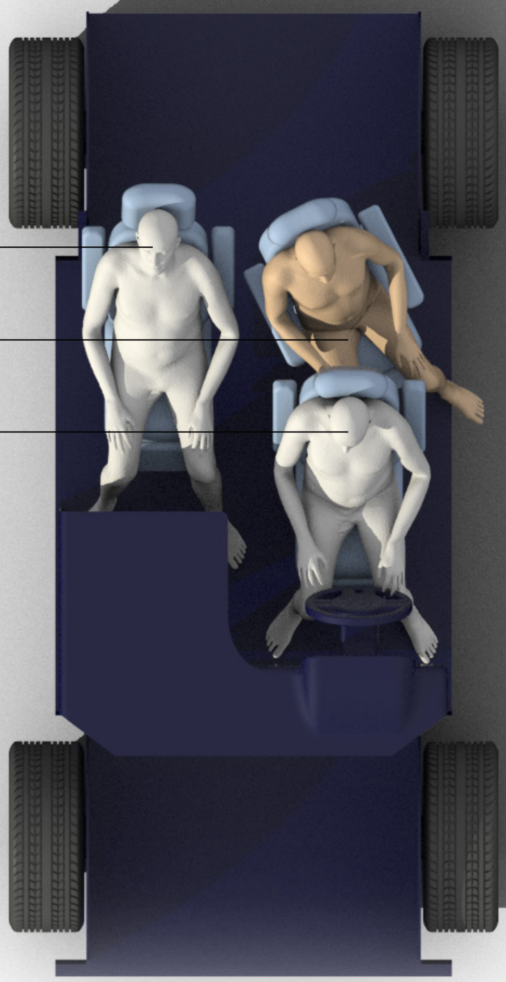


Scenario 1: Resting & Sleeping

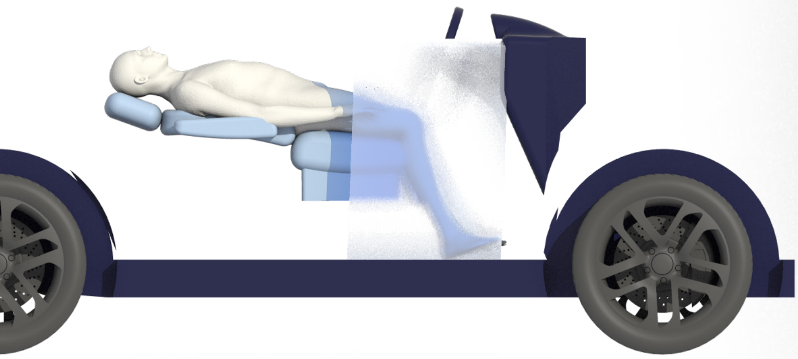
Sleeping

Looking out of window

Driving\Watch the road



Sleeping flat on the back

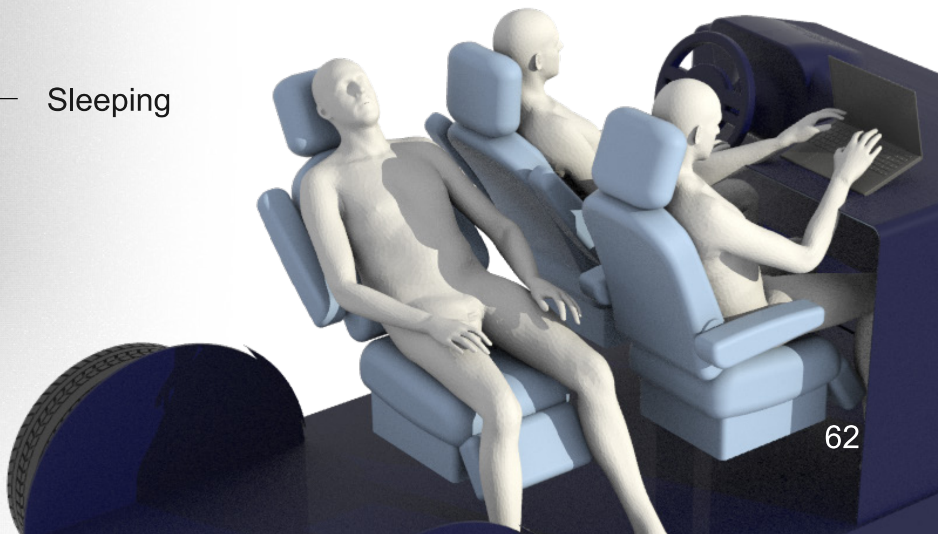


Scenario 2: Entertainment & Sleeping

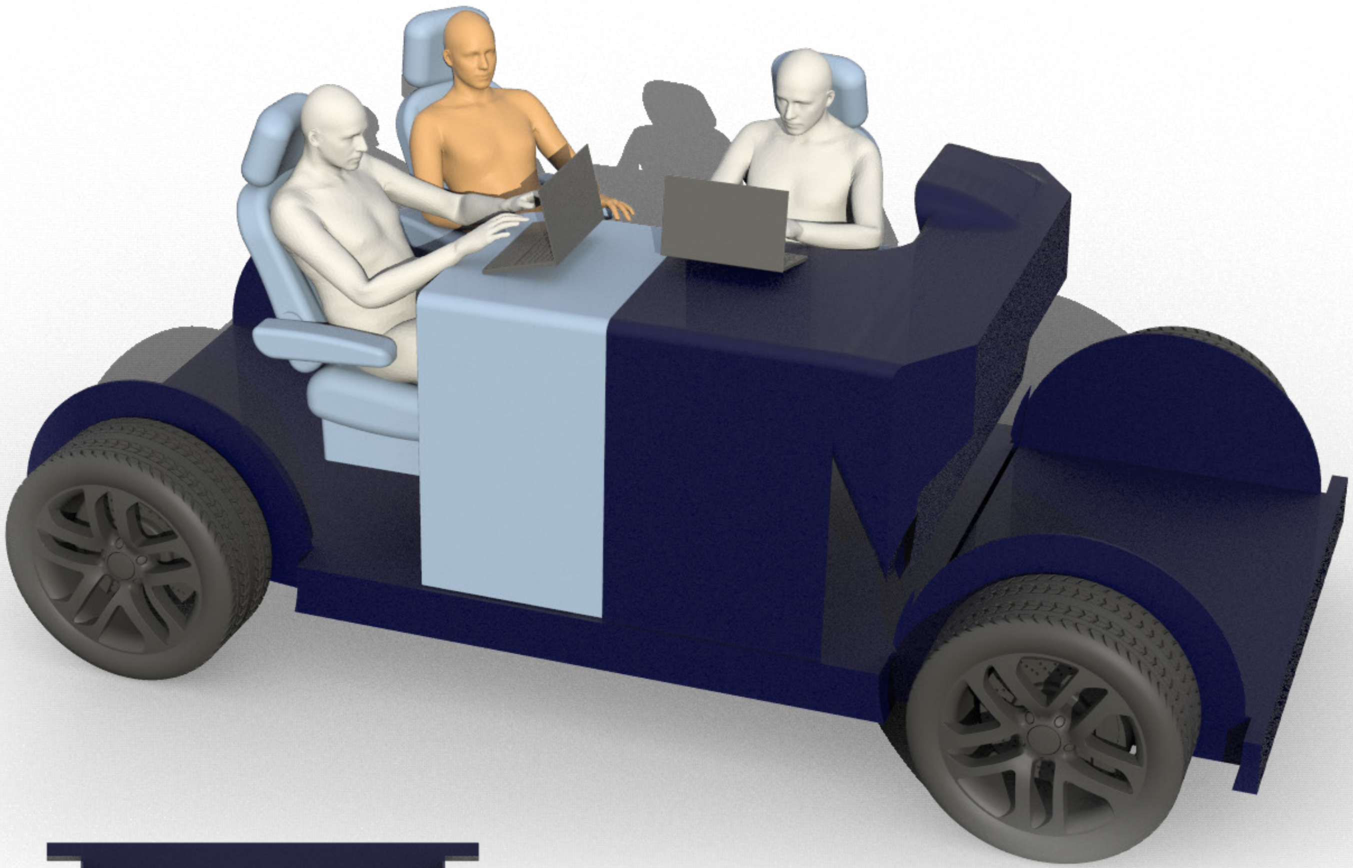
Entertainment\Working

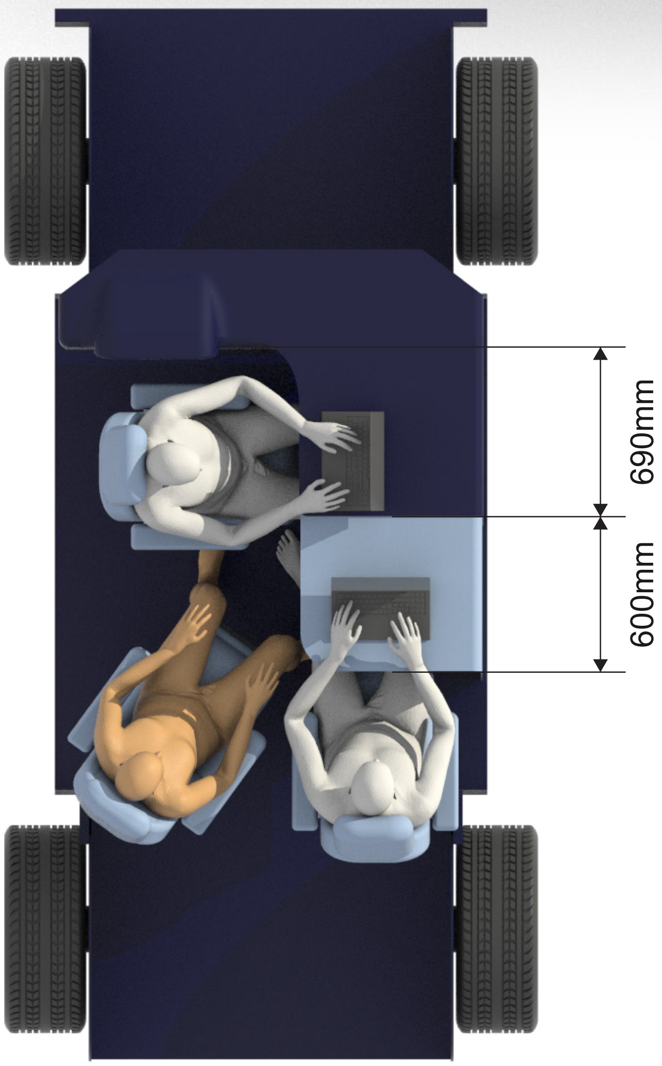
Driving\Watch the road

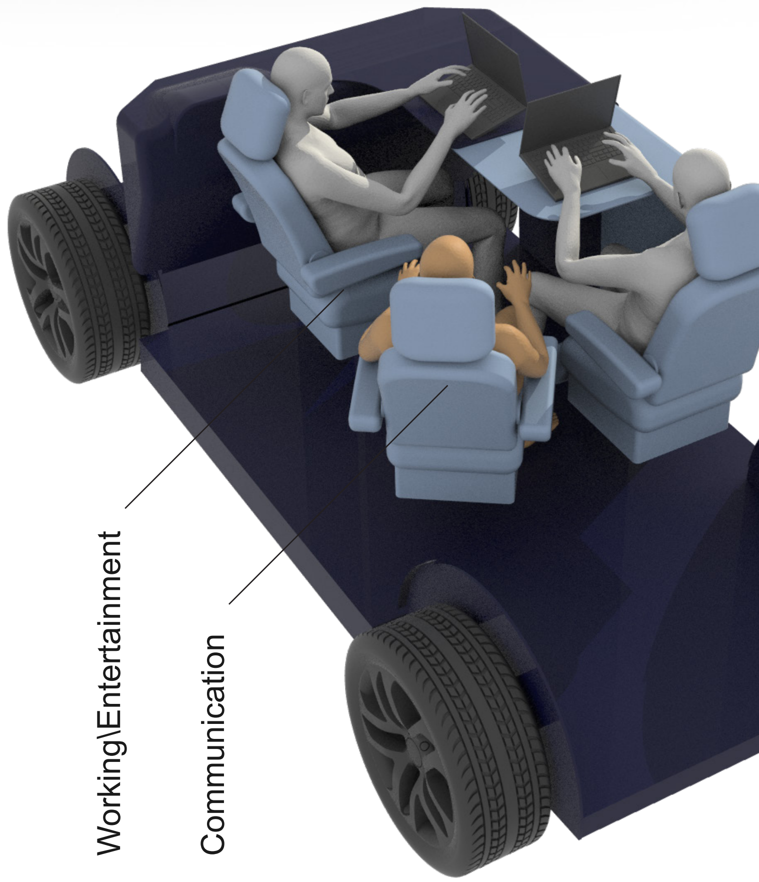
Sleeping



Scenario 3: Communication & Working & Entertainment







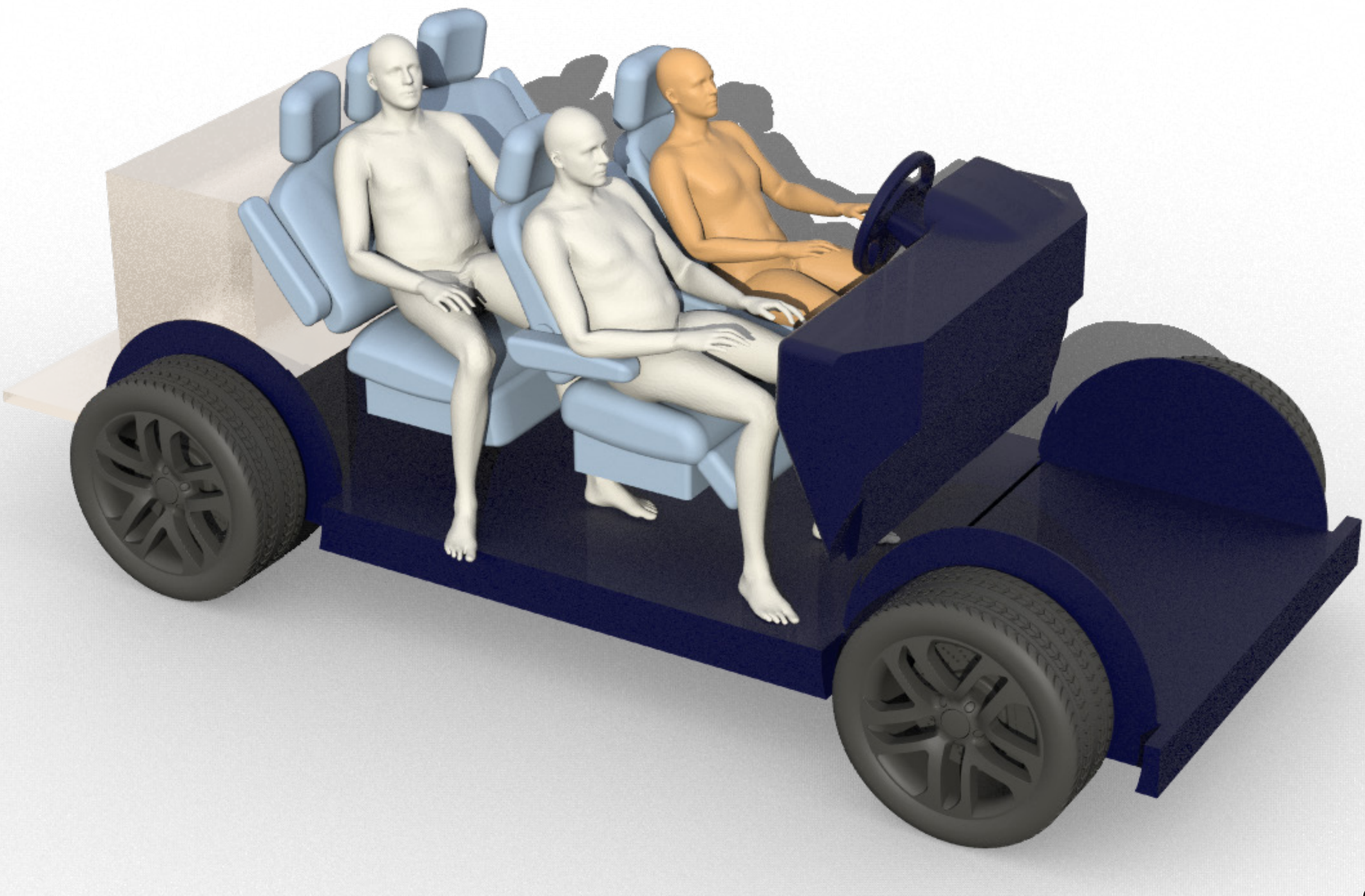
Concept 2

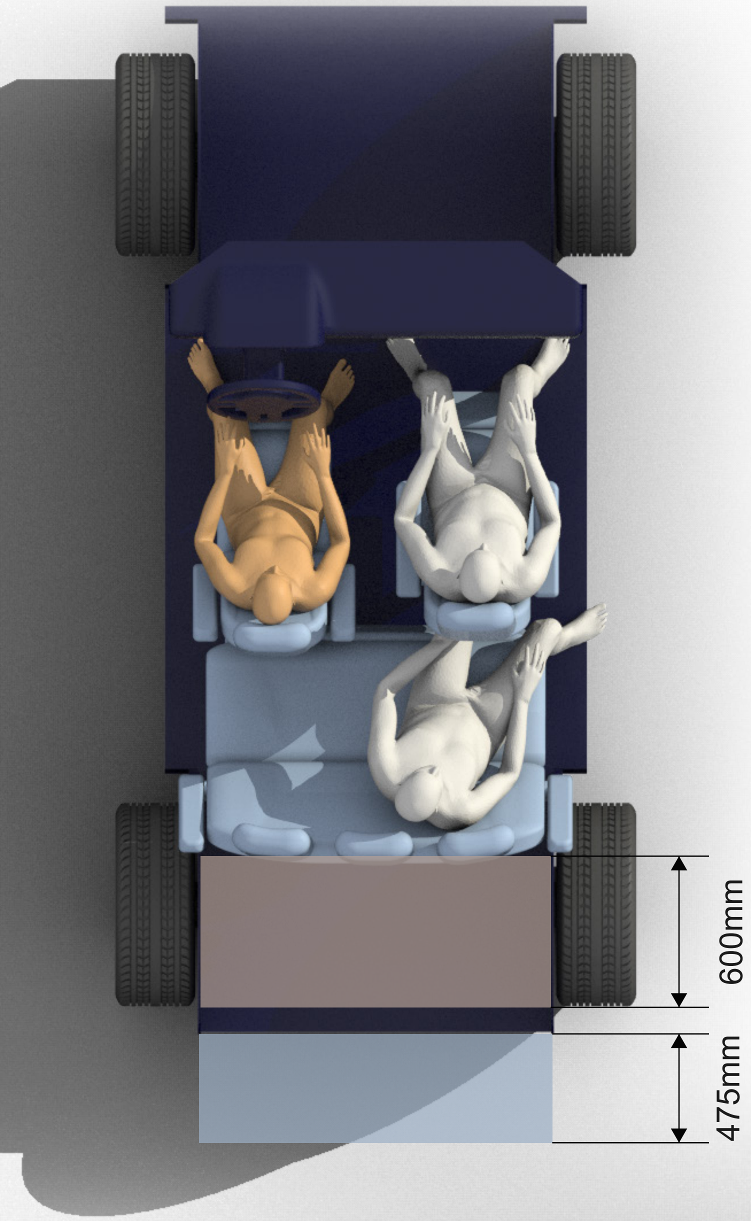
My second design concept ingeniously revolutionizes the traditional cargo storage area, converting it into a valuable activity zone within the vehicle. This transformation optimizes the spatial arrangement for users, amplifying their range of motion without compromising passenger capacity. It is tailored to fulfill the diverse Non-Driving-Related activities of users in an automated car, providing a broad and comfortable sphere for various activities.

Incorporating a 180-degree rotatable rear sofa into the design, the interior can adapt to offer a camp-like ambiance for long-haul travelers. The sofa can convert into sofa bed, further enhancing the versatility of the space. Additionally, a floor-embedded folding table that can elevate from the floor when needed is introduced to facilitate work, play, or communication.

My intent with this design is to craft a mobile "living room" - a snug space where users can sleep, work, play, and relax in ultimate comfort. This inspiration emerged from ergonomic experiments and enlightening interviews. During these sessions, respondents shared their experiences of sleeping on completely flattened seats, primarily during extended journeys. They also expressed a desire for an improved sleep experience during long trips and an aspiration to transform the traditional family car into a camping experience akin to RV travel.

Additionally, this concept aligns perfectly with the adventurous spirit inherent in SUVs, which are known to offer a more liberating, sporty, and outdoorsy experience. By converting the cargo storage into a part of the vehicle's interior activity zone, the concept offers an added dimension of interaction with the world outside through the trunk window. Thus, this innovative reconfiguration not only facilitates Non-Driving-Related activities but also engenders a deeper interaction with the outside world, amplifying the sense of freedom for users.

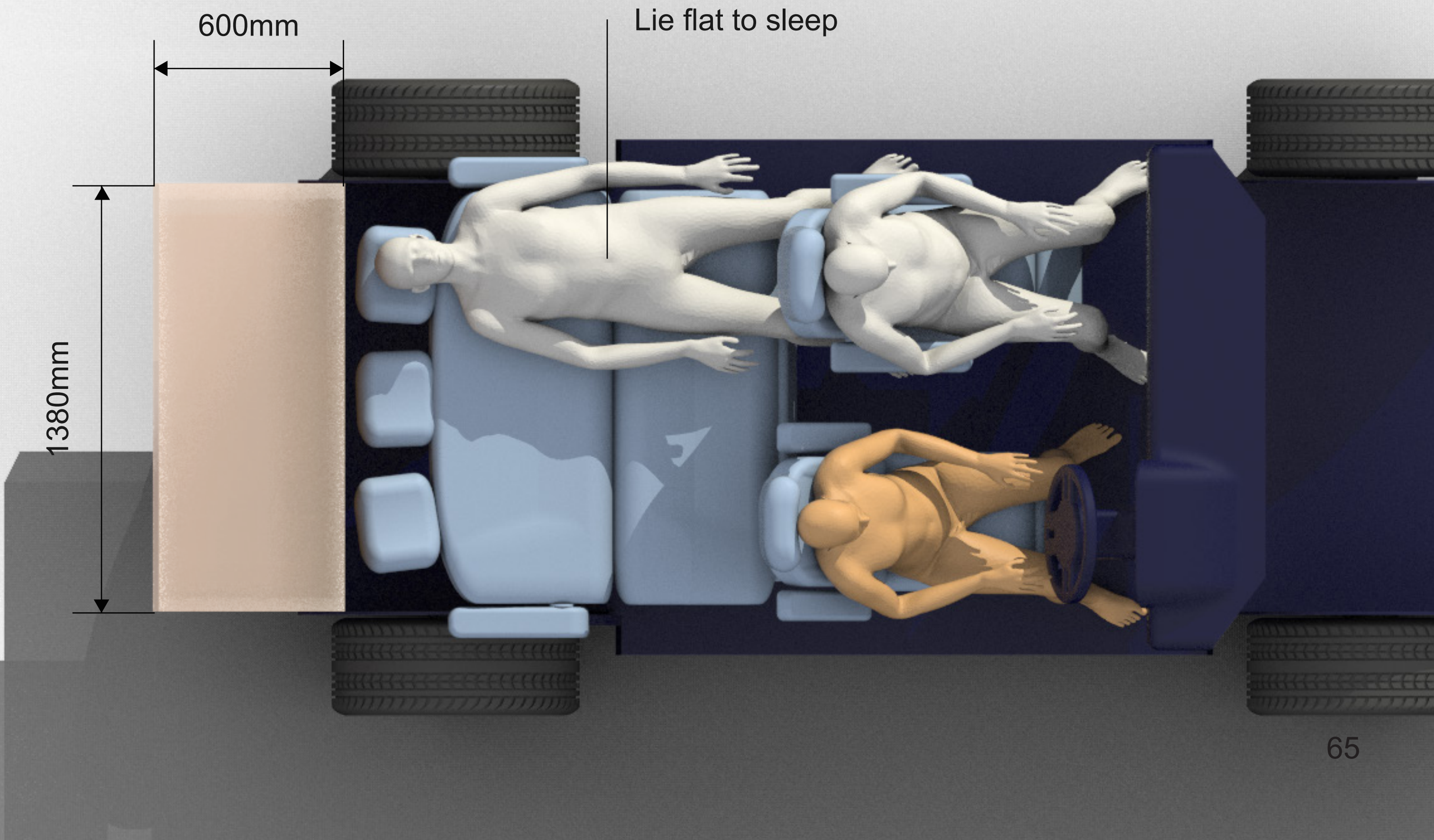


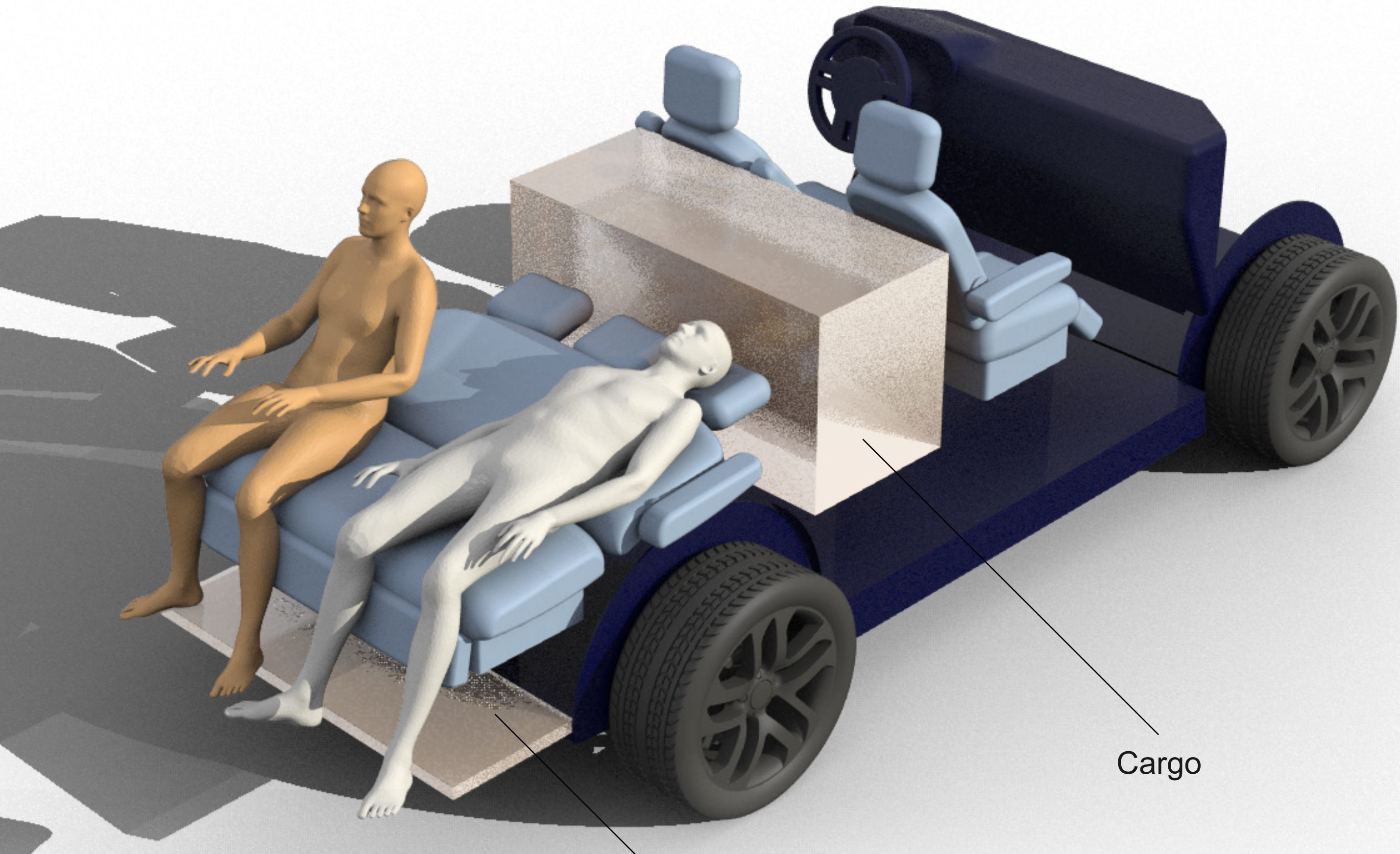


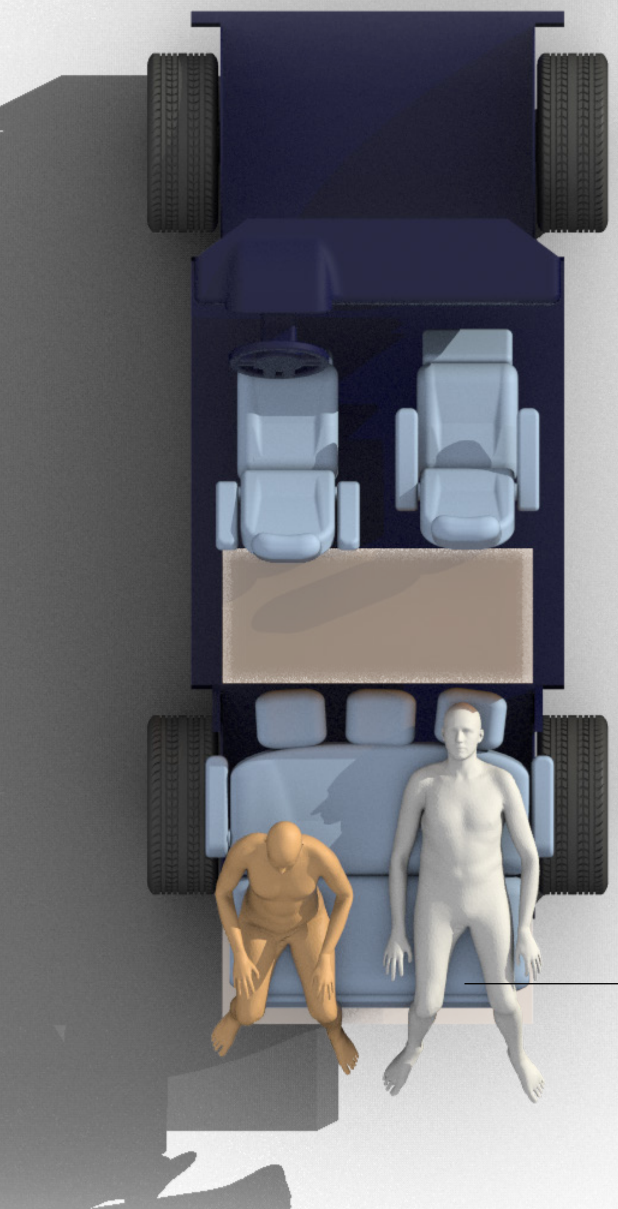
Cargo volume:
In the Range Rover Evoque, with all seats in place, the cargo capacity amounts to 21.5 cubic feet or roughly 608,811.2 cubic centimeters. While manufacturers often provide cargo volume specifications, they typically don't offer precise dimensions like average cargo length. Therefore, using the 3D model of the Range Rover Evoque and its known dimensions, I have approximated the cargo dimensions to be 138 cm (width) x 70 cm (height) x 60 cm (length). These dimensions yield a cargo volume of 579,600 cubic centimeters, which closely aligns with the specified maximum cargo volume. This approximation is represented by an orange transparent cube in the accompanying visuals.

Extended length:
The car trunk requires an additional 475mm extension.

General scenarios





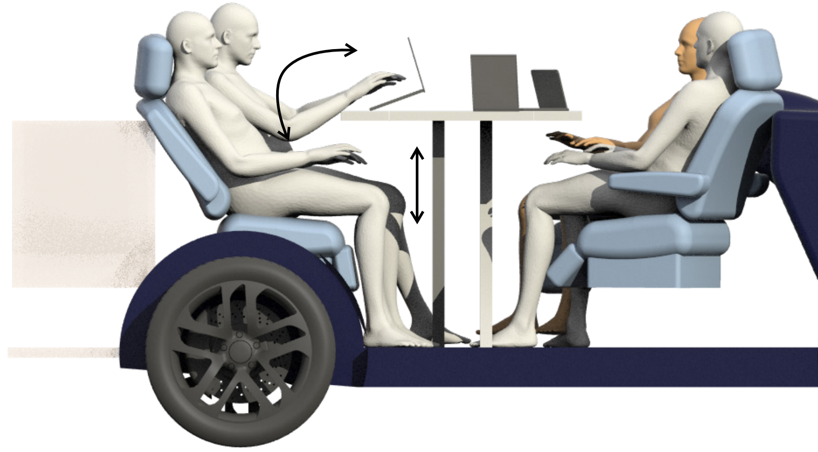


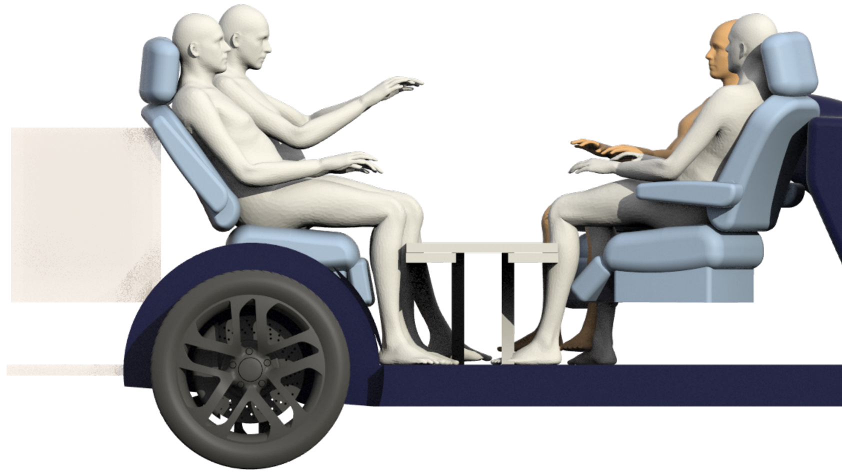
Scenario: Sleeping & Resting

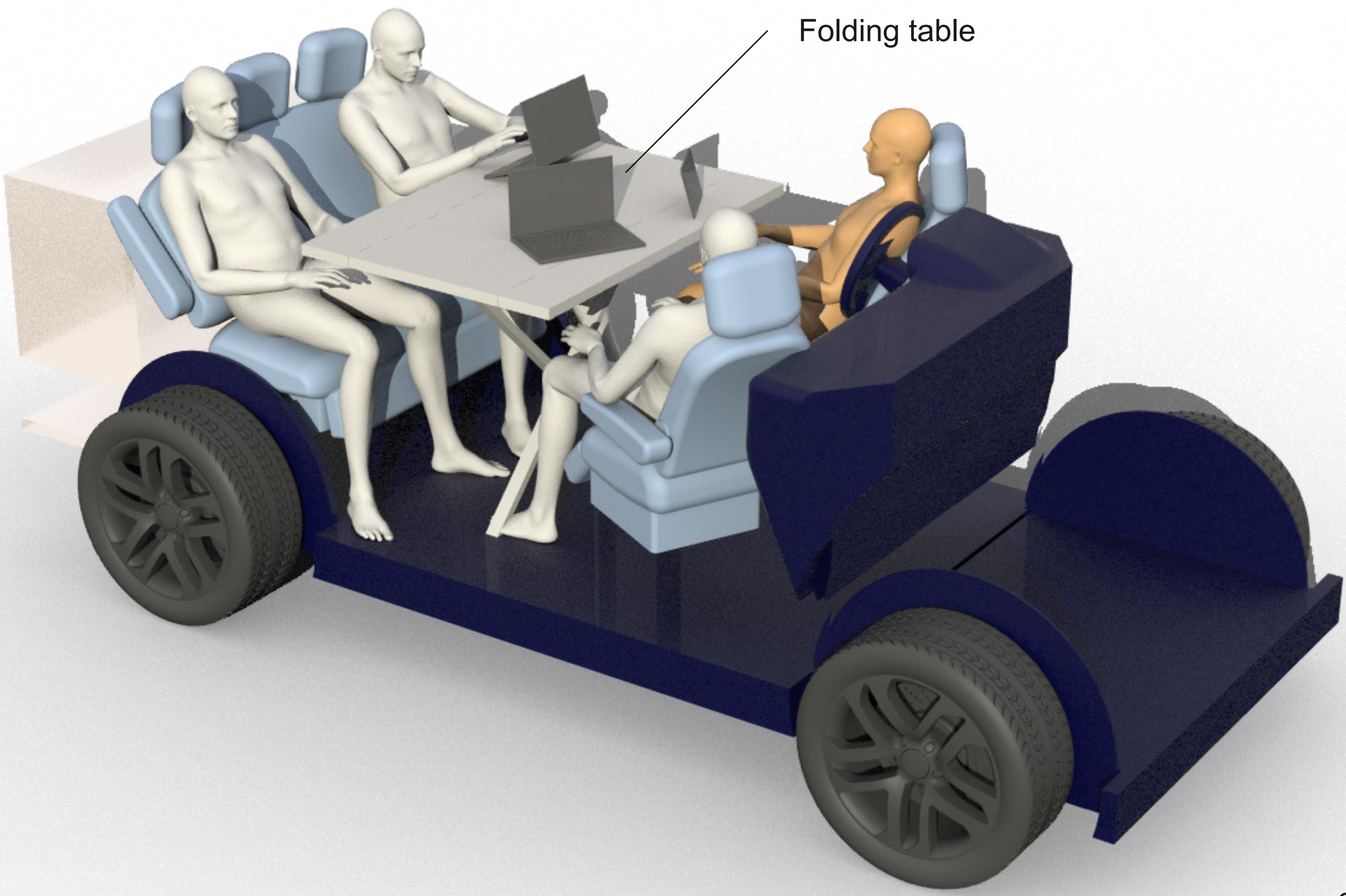
The design integrates a rear sofa that swivels 180 degrees and can convert with the cargo space to simulate the feeling of a campsite, especially for those who wish to travel long distances on their own. Also, the sofa can be turned into a sofa bed, expanding the space for activities.

Scenario: Communication & Working & Entertainment

The design features a folding table ingeniously embedded within the floor. This table can rise from the floor as needed, creating a practical surface for work, leisure activities, or fostering communication among passengers.







6.5
Evaluation of two concepts

Two concepts were evaluated using the Horris Profile based on the important requirements identified in the List of requirements and the results are shown below.

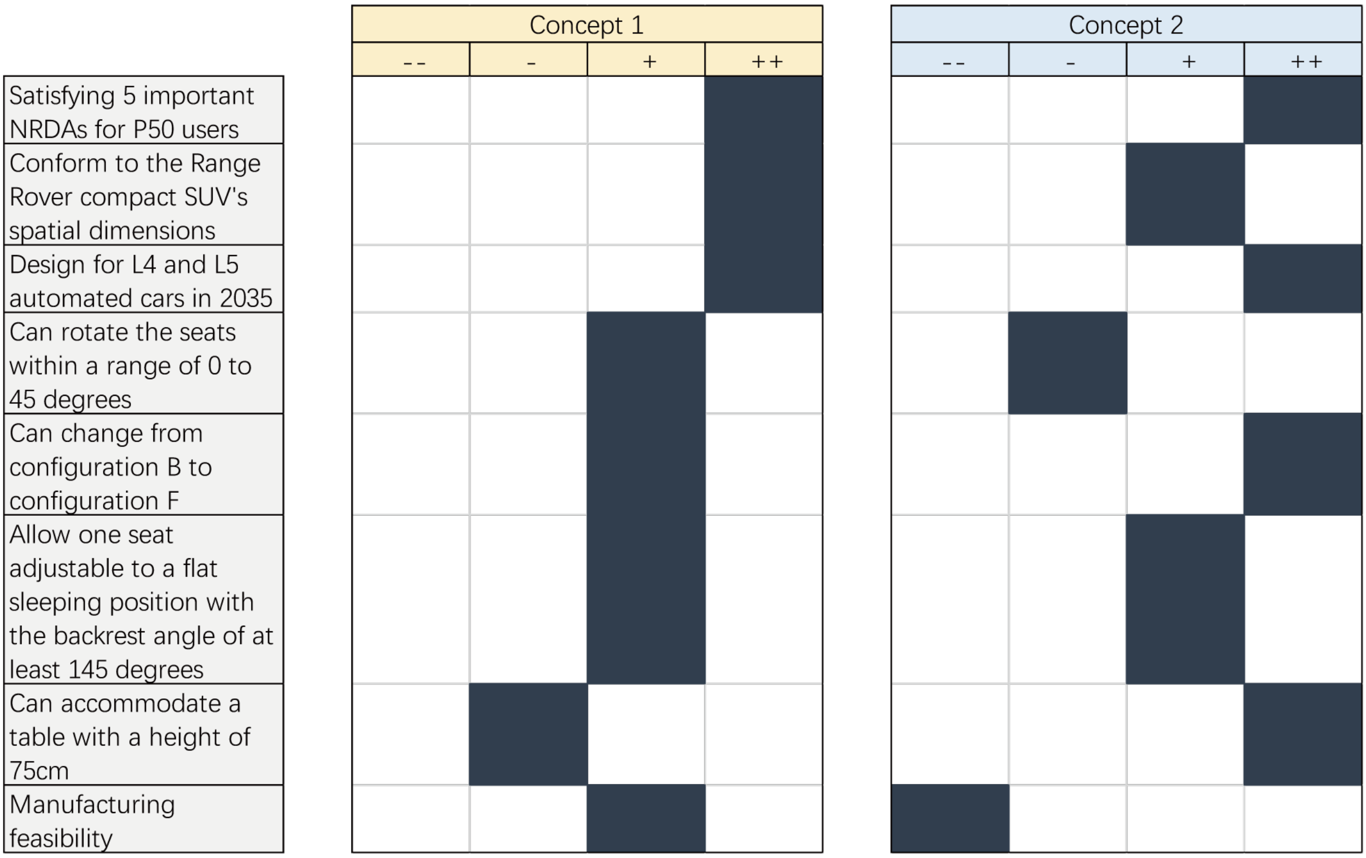


Figure 24. Horris Profile

Upon comparing the evaluation results of the two concepts in the Horris Profile, I found that Concept 1 satisfies key requirements from the List of Requirements (see Chapter 4) better than Concept 2. It enables better space allocation for 5 critical Non-Driving-Related activities within the Range Rover Evoque and has higher feasibility than Concept 2. However, it is essential to note that Concept 1, to provide users with greater activity space, forfeits the standard four-seat arrangement, potentially making it unsuitable for certain family or societal needs.

On the other hand, Concept 2 holds its unique strengths, such as better matching the requirement of switching between Configurations B and F, catering to multiple users' collaborative working and social needs. Nevertheless, Concept 2 has three shortcomings: the need for expanded interior space, the possibility of the sofa failing to provide sufficient adjustment in the backrest and rotation angles to meet specific activity needs especially when there is more than one rear passenger, and the low feasibility of a 180-degree rotation of the sofa.

By taking the strengths of both concepts and minimizing their disadvantages, coupled with the insights about the space occupation of different activities obtained in Chapter 5, I made the following modifications to the concept:

• Use of thinner vehicle seats (Figure 25, the thickness of the backrest is less than 1.5 inches, see Chapter 5) and slimmer dashboard (Figure 26).

• In usual situations, the standard four-seat configuration is retained, capable of accommodating 4 P50 passengers carrying out the 5 key Non-Driving-Related activities comfortably mostly within small to medium joint angles. However, when there are only 2-3 people in the car and they desire to perform activities such as sleeping, working, or entertainment in the larger joint angles, the layout can be adjusted from a four-seater to a 2 or 3-seater to create additional space.

• Usage of independent seats instead of the sofa.

• Retaining the design of the adjustable table that can be elevated from the floor and is situated in the middle of the interior, to meet the multiple users' collaborative working, entertainment, and social needs, while also enabling a change between configurations B and F.

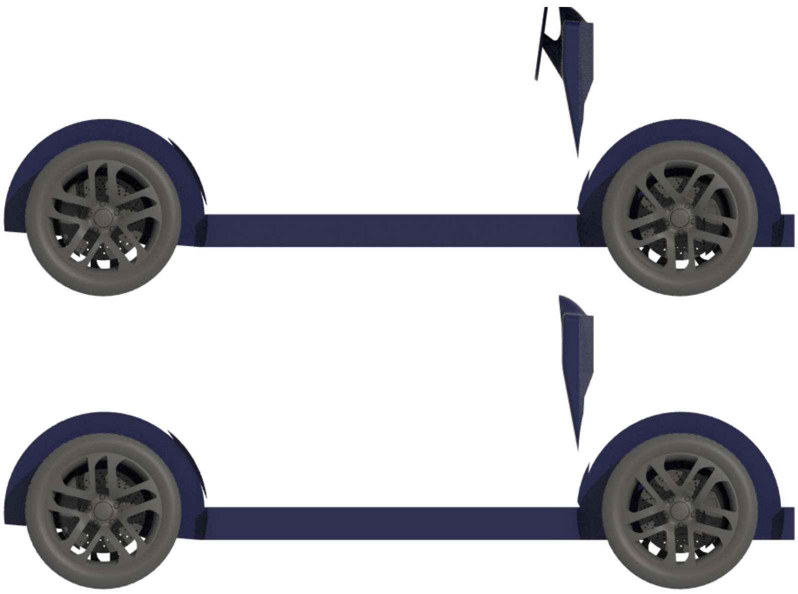


Figure 25. Thinner dashboard

Top: thinner dashboard (driving mode)
Bottom: thinner dashboard (non-driving mode)

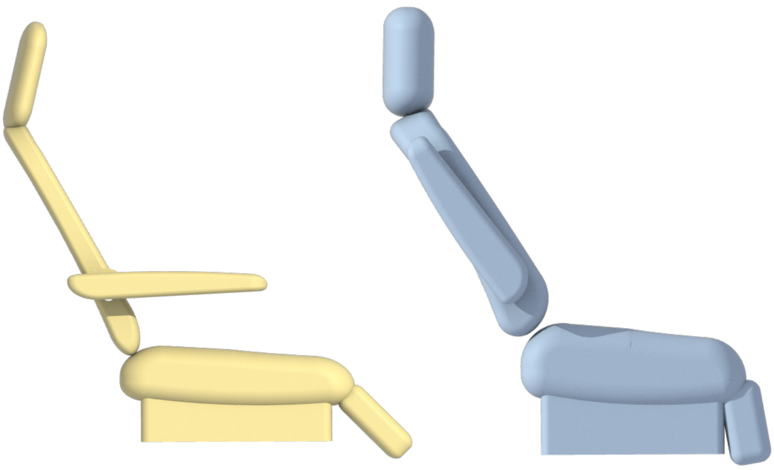


Figure 26. Thinner vehicle seats

Left: thinner seat (thickness < 1.5 inches)
Right: original seat

6.6
Preliminary car interior design for the future

After evaluating the two concepts in 6.5 and getting suggestions for changes to the model and concepts from Chapter 5, I identified parts to keep and parts to improve, and what follows is a preliminary vision of my interior design for the future automated vehicle.

Shift from 4-seat to 2- or 3-seat

The front seats, when folded, can be moved to and secured in front of the dashboard by means of slides or other devices on the floor, as shown in Figure 27. Similarly, the rear seats can be moved backward to near the trunk, and no further illustrations will be given here.

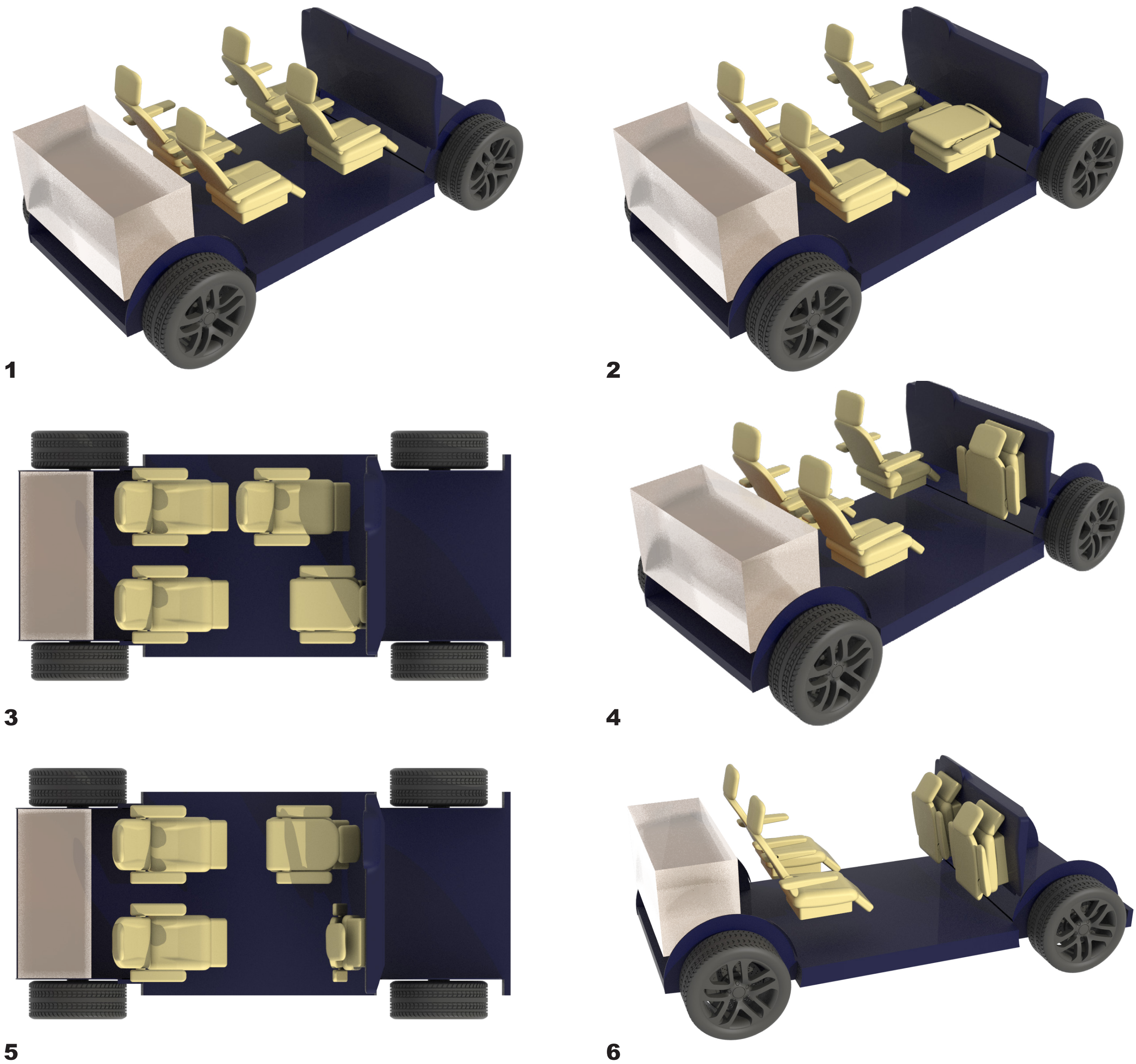
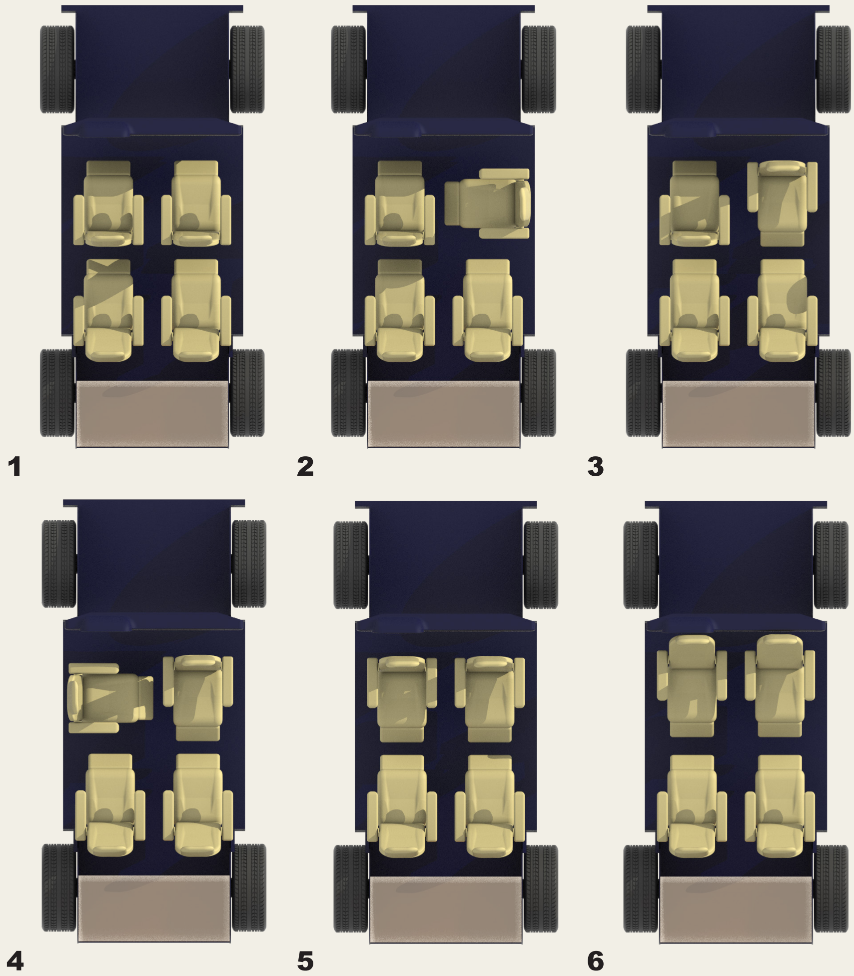


Figure 27. Moving the front seats to make 4-seat become 2- or 3-seat

Shift from traditional configuration (B) to face-to-face configuration (F)



The front seats can be rotated 180 to achieve a change from a conventional seating configuration (B) to a face-to-face seating configuration (F), and if there is not enough space, the seats can be displaced in the front-back or left-right direction before completing the rotation.

Figure 28. Shift from traditional configuration (B) to face-to-face configuration (F)

Height-adjustable table

The design features a table with a height adjustable between 70 and 100 cm ingeniously embedded within the floor. This table can rise from the floor as needed, creating a practical surface for work, leisure activities, or fostering communication among passengers.

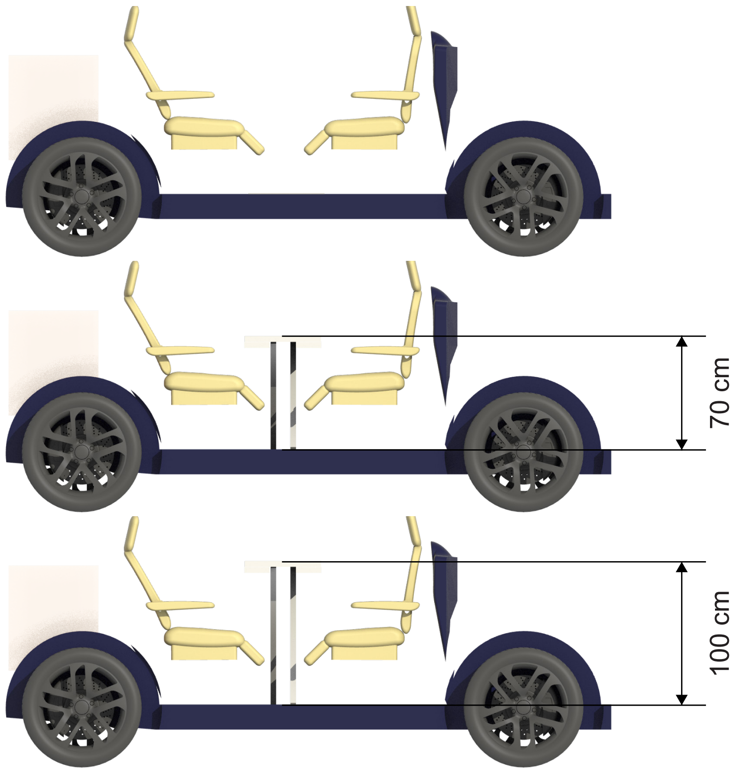


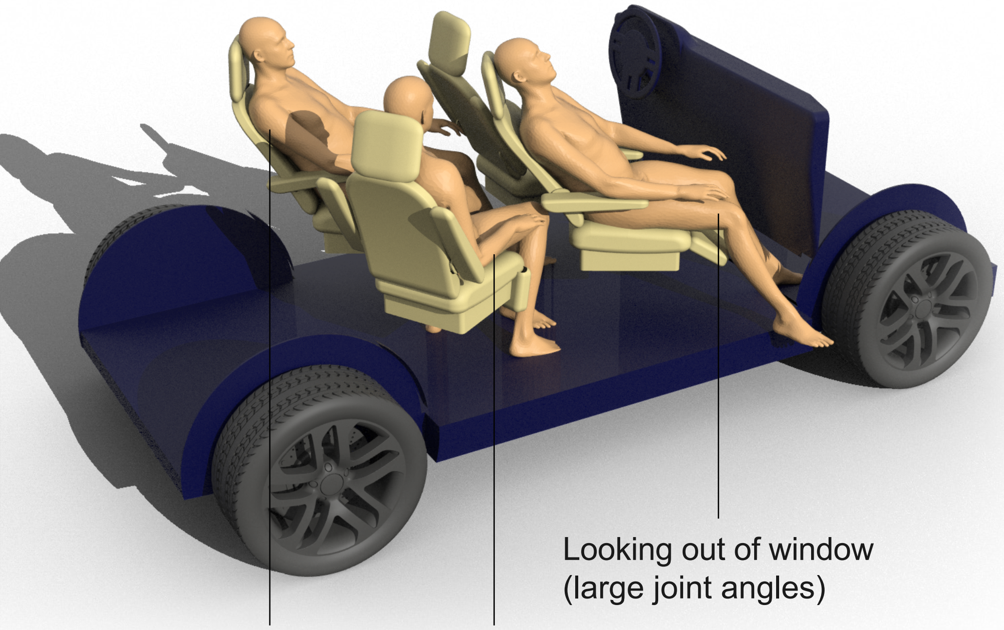
Figure 29. Table rises from the floor and adjust the height between 70 and 100 cm

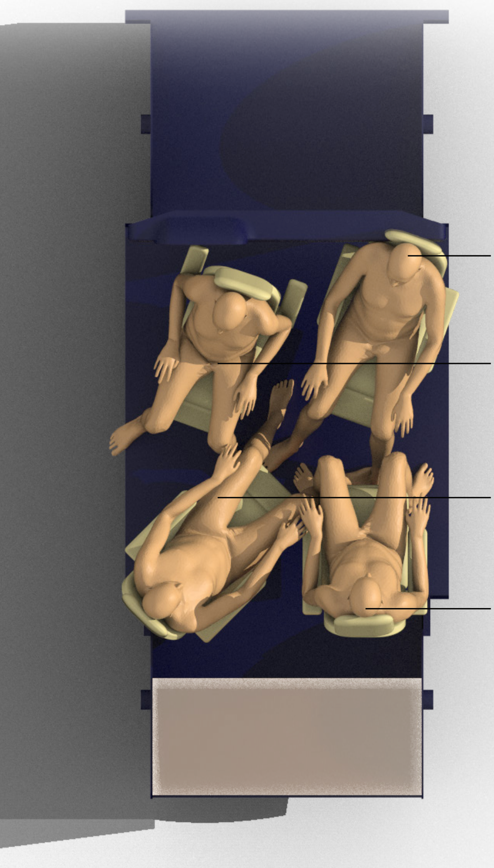
4 passengers scenario

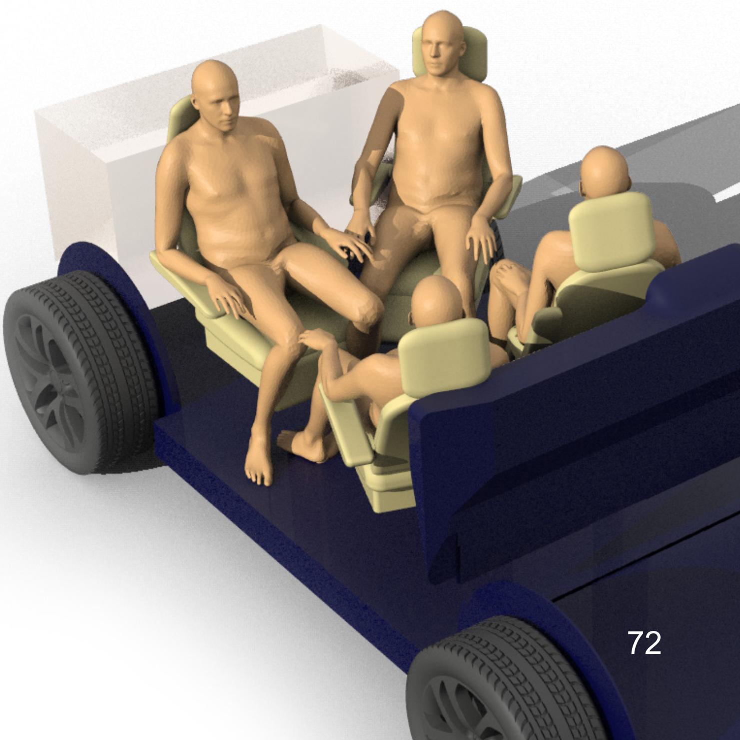
The joint angles for each activity that can be supported in a 4-passenger scenario are shown in Table 10. A number of cases were assembled using the corresponding mannequins according to this table (the mannequins with the minimum, average, and maximum joint angles for these 5 activities are introduced in Chapter 3) and categorized according to driving mode (automation level), and are displayed on this page.

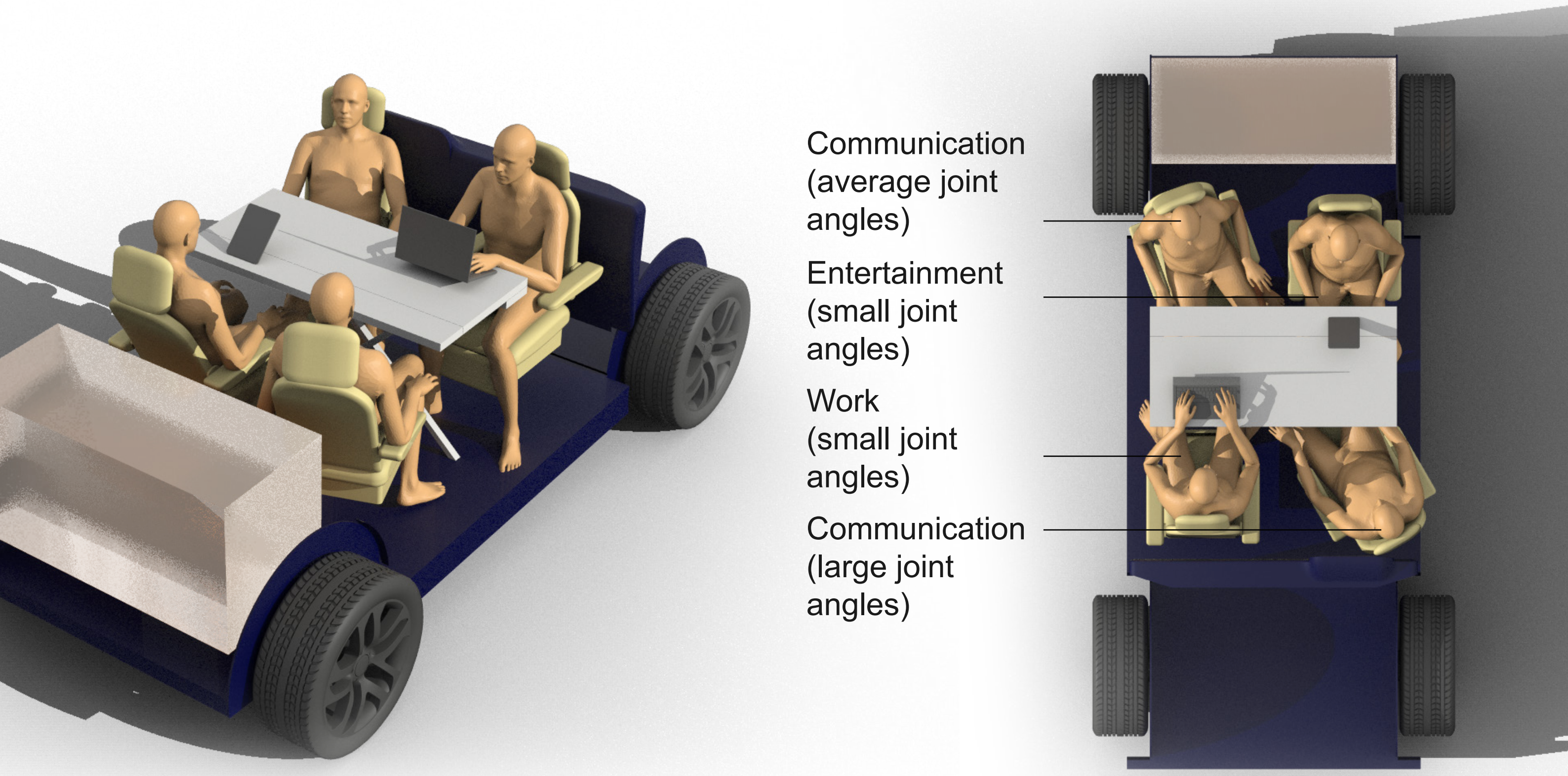
Table 10. Joint angle of activity that can be satisfied in 4 passengers scenario

Small joint angles	Sleeping
	Working (using laptop)
Medium (average) joint angles	Entertainment (watching IPad)
Large joint angles	Talking with passengers
	Looking out of the window







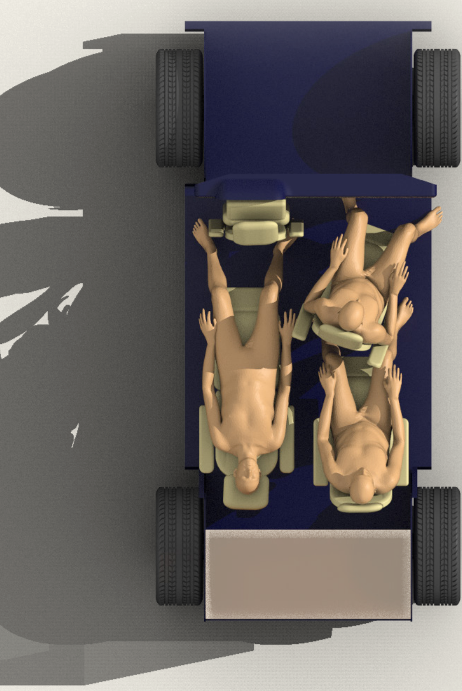


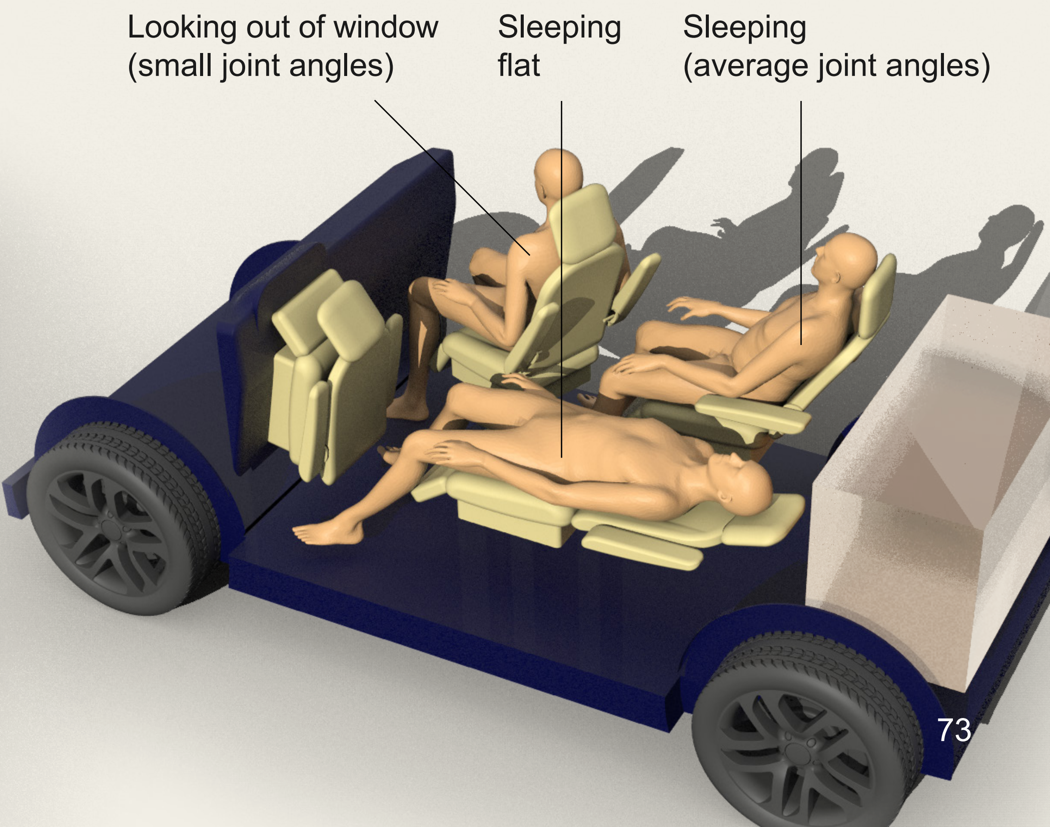
2-3 passengers scenario

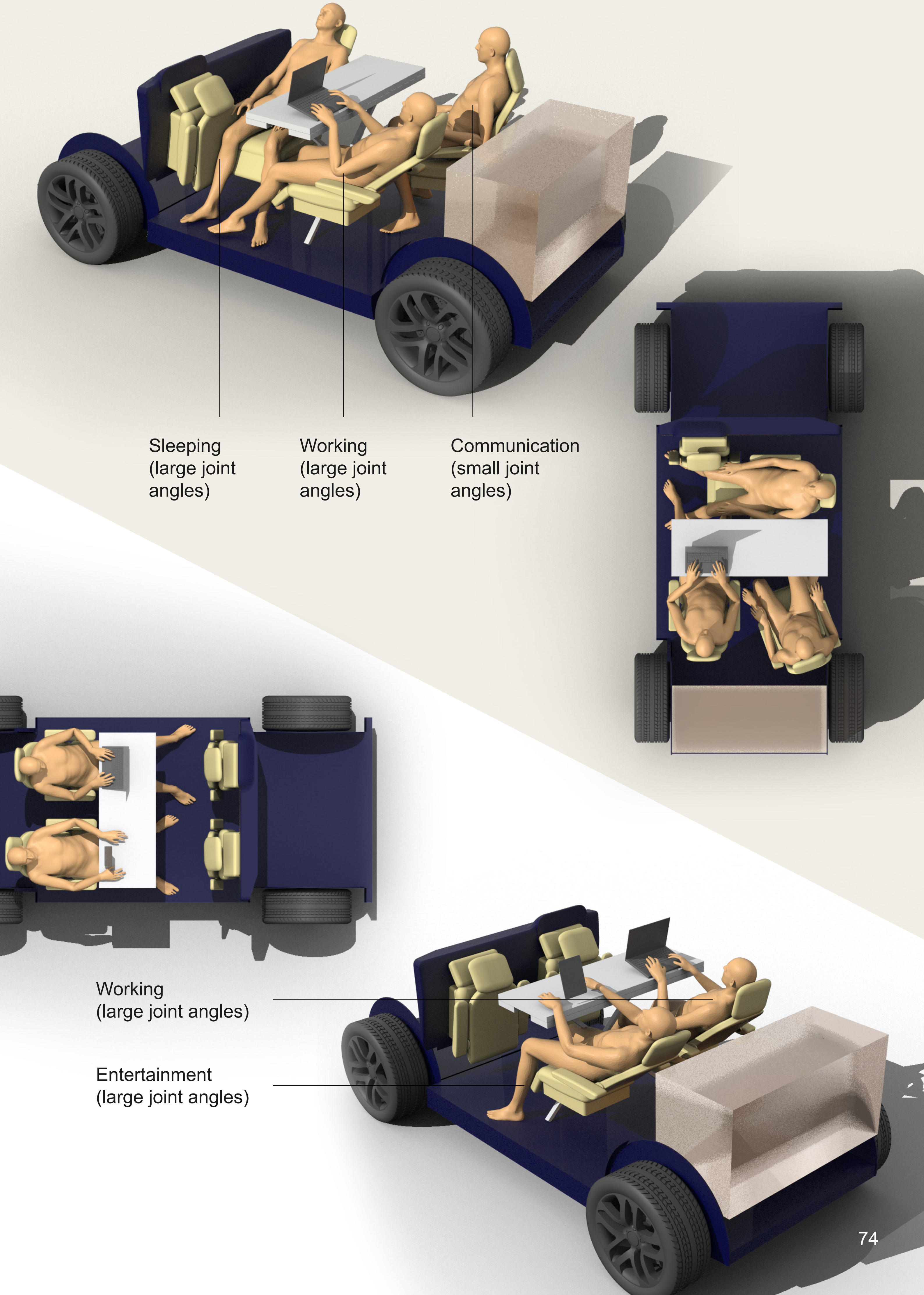
Table 11. Joint angle of activity that can be satisfied in 2-3 passengers scenario

Large joint angles	Talking with passengers
	Looking out of the window
	Entertainment (watching IPad)
	Working (using laptop)
	Sleeping (include sleeping flat)

The joint angles for each activity that can be supported in a 2- or 3-passenger scenario are shown in Table 11. As before, a number of cases were assembled using the corresponding mannequins according to the table, and are displayed on this page.







Sleeping
(large joint
angles)
Working
(large joint
angles)
Communication
(small joint
angles)
Working
(large joint angles)
Entertainment
(large joint angles)

Chapter 7. Discussion

7.1 Reflection

Design Process

This project underwent several stages: an extensive literature review, an exploratory experiment phase, a model-based exploration phase, and a design phase. The entire process followed the Double Diamond model, starting from a basic question, and going through four stages: discover, define, develop, and deliver, with numerous divergences and convergences, eventually culminating in a design vision for future automated vehicle interiors. This allowed me to gain a deeper understanding not only of vehicle interior design but also of design methodology.

During the literature review phase, I realized that clarifying research objectives, defining eligibility criteria, and selecting the right search strategies and information sources were even more critical than quickly obtaining answers to questions. Due to incomplete search strategies, I conducted two literature screenings, each involving 2000+ documents. Hence, without proper groundwork, one might have to invest more effort to compensate for this oversight. The second difficulty I encountered in this phase was the unclear definition of clustering principles for activities, which made meta-analysis challenging. To obtain more accurate results, the clustering principles could be redefined in the future, and a meta-analysis of the collected data could be performed.

In the exploratory experiment phase, the most significant challenge was deciding what tools and methods to use for the experiment, what kind of experimental data I needed to collect, and how to utilize these data. Initially, I was inclined to use motion capture technology to test more subjects, but due to time constraints and accuracy issues with the device, I opted for the more traditional but efficient method of directly measuring joint angles with a goniometer for six participants. The primary reason for shelving the motion capture technology was its location drift issue and higher technical difficulty. In the future, if more accurate joint angle data of users performing activities are needed, more precise measurement methods can be used for broader participant ergonomics experiments.

During the model-based exploration phase, my first major challenge was to create a human body model that truly reflects user comfort postures, using the data I obtained from the exploratory experiment. My initial idea was to randomly select some postures and apply them to various human models to explore whether the space of the Range Rover Evoque could meet their activity space requirements. This yielded some results, but due to the significant variety of human models selected and the impact of the seat models used on the results, I found the final conclusions had some flaws after evaluation. However, it was these very flaws that prompted me to modify the model and further explore in AR, contributing useful insights to my final solution. This is the design process, continuous iterations, modifications, and further iterations.

Final concept

The final concept of this project is fundamentally based on the major Non-Driving-Related activities (NDRAs) that users might engage in within automated vehicles. The space occupation is analyzed based on the comfortable joint angles of the users while performing these activities, further designing the vehicle's interior space. Overall, the entire process is well-grounded, with the final design being backed by both theory and practice.

However, the final concept is still in its early stages, having only undergone two iterations. Due to time constraints, user evaluations of the outcomes were not conducted. This might have left some room for oversights and missed opportunities for refining the design based on user feedback. Considering the scope of the project, the research primarily focused on user activities and comfort, without taking into account other socio-cultural or commercial factors. While this focus enabled a deeper understanding of space requirements for NDRAs, it might have excluded potential influences or considerations from a broader context for example user experience, feasibility, or commercial viability of the design. Additionally, more in-depth research on future technology trends was not extensively carried out, potentially limiting the concept's feasibility.

Grow and improve

In terms of time management, although the initial literature review faced challenges due to the overwhelming volume of tasks, overall, all tasks were successfully completed according to plan. A crucial strategy utilized was multitasking, where research, experiment, and design were conducted concurrently. This approach had the advantage of allowing continual adjustments to tasks based on feedback from other tasks, ensuring a dynamic and responsive design process.

Mentally, I've grown to understand that the design process is a series of failures leading to continual improvements. I initially sought perfection from the beginning but gradually realized the importance of swift initiation followed by continuous iterations and refinements. There is no ultimate perfection in design; rather, it's about persistent reflection and improvements after each process to strive for better outcomes. I also realized that "failure" doesn't necessarily denote uselessness. Looking at the process from a different perspective could lead to new insights. Therefore, one should not hastily discard the outcomes of each attempt.

As a designer, this was my first experience starting with a literature review, integrating exploratory experiments, models, and other practical methods to achieve the final design. This process of merging theory and practice, where each complements the other, was enlightening. The use of experimental data offered me a unique understanding of the role experiments play in design, and the application of 3D models made me realize the significance of prototypes. Moving forward, I need to persist in this combined approach of theory and practice and learn to utilize technologies such as 3D models and AR more effectively to gain further insights.

7.2
Future Recommendations

Persistence

The most significant outcome of this project is its methodology. This project has successfully explored the combination of theory and practice. During the research phase, the literature review provided a clear and reliable set of Non-Driving-Related activities (NDRAs) that users might engage in while in automated vehicles, which laid a solid foundation for further exploration. Moreover, the project utilized the ergonomic experiment and statistical tools to support the theories, and it used computer-aided technology for design and iteration during the design and rapid validation phase. This methodology or design process is feasible, and it can be used in the future to research a broader range of NDRAs or different user groups to design car interiors that meet specific activities or user needs.

Improvement

Firstly, there are many aspects of the entire process that can be improved. For example, in the literature review, a meta-analysis can be conducted to achieve more accurate results. In the ergonomics experiment, a broader range of subjects can be included, more precise measurement tools can be utilized, and the experiment design itself can be improved. During the design iteration phase, more accurate car and seat models can be used, and user evaluations can be integrated into the iterative design.

Secondly, the entire project mainly focuses on designing car interiors from the perspectives of activities, space, and comfort. In the future, it will be necessary to combine other aspects such as user preferences, business, manufacturing constraints, and socio-cultural factors to integrate and develop a more feasible car interior design.

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Administration, N. H. T. S. (2004). Federal Register :: Federal Motor Vehicle Safety Standards; Seat Belt Assemblies. Communications in Computer and Information Science, 1498 CCIS, 521–526. doi:10.1007/978-3-030-90176-9_67/FIGURES/2

Appendix

Appendix A:
Project brief

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT
Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Cai
initials: Y   given name: Yujing
student number:
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): ★ IPD   ◯ DfI   ◯ SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: ◯ Honours Programme Master
specialisation / annotation: ◯ Medisign
◯ Tech. in Sustainable Design
◯ Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Wolf Song   dept. / section: SDE
** mentor: Gerbera Vledder   dept. / section: SDE
2nd mentor:
organisation:
city: country:

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

TUDelft

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Wolf Song date 08 - 03 - 2023 signature Yu (Wolf) Song Digitally signed by Yu (Wolf) Song Date: 2023.03.16 08:43:06 +01'00'

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: ______ EC

Of which, taking the conditional requirements into account, can be part of the exam programme ______ EC

List of electives obtained before the third semester without approval of the BoE

YES all 1st year master courses passed

NO missing 1st year master courses are:

name ______ date - - signature ______

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

comments

name ______ date - - signature ______

Initials & Name Y Cai Student number 5592410

Title of Project Autonomous car interior layout design based on user activities

Autonomous car interior layout design based on user activities

project title

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

start date 28 - 02 - 2023

14 - 07 - 2023 end date

INTRODUCTION **

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

Over the past decade, self-driving cars have attracted increasing societal attention. Governments, car manufactures, technology companies, component suppliers, and other stakeholders have flocked to this field.

SAE classifies autonomous driving into five levels. In highly autonomous driving (L3, L4 and L5), the driver does not need to continuously control speed and steering. However, they still have to occasionally regain manual control when the autonomous driving solution reaches its limits or malfunctions, mainly in L3.

The changed responsibilities of passengers/drivers lead to new types of activities as well as possible new layouts in L3, L4 and L5 vehicles, for instance, the difference between drivers and passengers is smaller, and HMI devices for drivers might be rearranged to adapt to the new scenarios.

space available for images / figures on next page

introduction (continued): space for images

TO PLACE YOUR IMAGE IN THIS AREA:
- SAVE THIS DOCUMENT TO YOUR COMPUTER AND OPEN IT IN ADOBE READER
- CLICK AREA TO PLACE IMAGE / FIGURE

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- IMAGE WILL SCALE TO FIT AUTOMATICALLY
- NATIVE IMAGE RATIO IS 16:10
- IF YOU EXPERIENCE PROBLEMS IN UPLOADING, COVERT IMAGE TO PDF AND TRY AGAIN

image / figure 1:

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image / figure 2:

PROBLEM DEFINITION **

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

As vehicles gain more and more agency through automation, a new social relationship will emerge. There have been studies of human-vehicle relationships such as the H-metaphor, the "personal driver" relationship, and so on. So in this study, we focus on answering the following questions:

1. What are the future relationship among humans in the vehicles and between humans and vehicle?

2. What are the types and the intensity of human-vehicle cooperation?

3. How can we design a new cabin layout and new seat(s) to support those activities in a comfortable manner?

ASSIGNMENT **

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

In this assignment, we aim at designing the layout and seats in the cabin of L3, L4, and/.or L5 vehicles based on new roles and new activities of drivers/passengers.

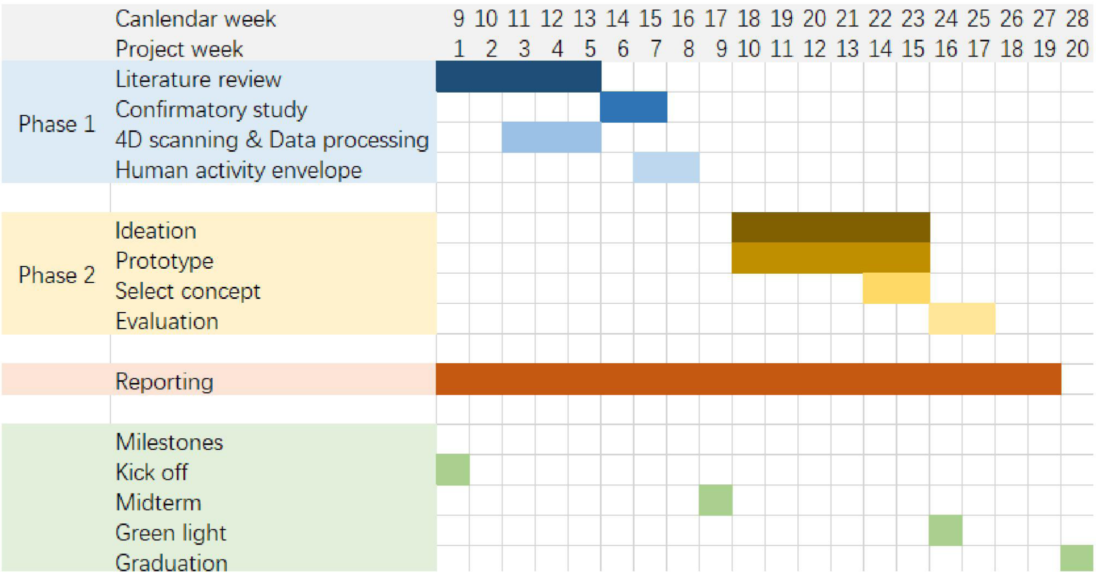
Extensive literature study will be conducted first to collect information on: 1) Type of users in L3, L4 and L5 vehicles; 2) Possible activities/tasks of different users in the vehicles. Based on the research outcomes, we will identify the difference among the user activities regarding different levels of automation. Focused group study will be launched on the selected activities, maybe in a particular level of automation, to affirm the discoveries and propose new activities/tasks.

A user experiment will be launched to identify the envelope for performing those activities in a comfortable manner using 4D scanning techniques. Using those human envelopes, new cabin layouts will be ideated and designed. The selected concept will be modeled and tested with mock-ups, or in XR environments as virtual prototypes. Different types of users will evaluate the prototype while performing different activities. The collected feedback will be used to iteratively improve the design.

PLANNING AND APPROACH **

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

start date 28 - 2 - 2023 | 14 - 7 - 2023 end date



The planning for graduation project is divided into two phase. In phase 1, Literature review and confirmatory study will be done to identify activities, and 4D scanning will be conducted to come out the human activity envelope. Based on these results, I will work on design a new cabin layout and evaluate it in phase 2. In the end, a mock-up or a model in XR environment of the designed cabin will be created and evaluated.

MOTIVATION AND PERSONAL AMBITIONS

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

From the ACD project design, I learned how to integrate the insights and define the design frame, and became interested in how to define the future-oriented design vision. From the AED project, I have gained some experience in comfort-related design and hope to continue to improve my prototyping and user testing skills. So I hope to explore the future of self-driving car interior design in my graduation project.
In this project, I hope to achieve:
- Gain an understanding of the automated driving and get some insights into the human-vehicle relationship.
- Try to learn Unity to build test environment.
- Try to get user feedback using a rapid prototyping approach.

FINAL COMMENTS

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

Appendix B
Time Horizon & Car Dimensions

Time Horizon

Setting a time horizon for designing the interior layout of a self-driving car is critical to aligning the design with the rapidly evolving technology landscape, market trends, and consumer needs.

In light of the prevailing uncertainties in the automotive industry, McKinsey has formulated three scenarios for autonomous passenger car sales, considering different levels of technological accessibility, customer acceptance, and regulatory backing. In the base scenario, car manufacturers release AVs punctually, and consumers adopt them at a typical rate. Under these circumstances, it is projected that by 2030, 12% of new passenger cars sold will be equipped with L3+ AD features, rising to 37% by 2035 (Deichmann et al., 2023b). In addition, Bansal & Kockelman (2017) summarized the predictions for the long-term adoption of CAV technology through a literature review. It summarized three types of studies that have forecasted: (a) future-year shares of self-driving vehicles, (b) future sales of AVs, and (c) vehicle miles traveled by self-driving cars, shown in Table 12.

It can be found that different scholars and institutions predict the future development of self-driving cars very differently. It is difficult to give an accurate timeline because of the uncertainties in many aspects such as future technology development, designation of laws and regulations, etc. But most of the results show that some level 4 self-driving cars will reach the market in 2035. Therefore, in this project, I choose to specify the time horizon of my project to be around 2035.

Source	AV ownership & access forecasts
Litman (2015)	30% and 50% of U.S. vehicle fleet to have Level 4 automation in 2040 and 2050, respectively
Lux research (Laslau et al., 2014)	92% and 8% of world vehicles to have Level 2 and 3 automation in 2030
Morgan Stanley (2013)	Nearly 100% of U.S. light-duty vehicles are Level 3 and 4 vehicles by 2030 and 2055, respectively
Fehr & Peers (Bierstedt et al., 2014)	25% of U.S. vehicle fleet to be autonomous by 2035
IHS Automotive (2014)	Entire global fleet is expected to be to be fully-autonomous by 2050
IDTechEx (Harrop and Das, 2015)	The number of self-driving capable cars to reach 8.5 million by 2035 in the U.S.
Rowe (2015)	100% of U.S. vehicles are Level 4 AVs by 2060
(Bansal & Kockelman, 2017)	Predict 24% (pessimistic) to 87% (optimistic) Level 4 U.S. vehicle fleet by 2045.
	Sales & cost forecasts
Litman (2015)	50% and 90% of U.S. vehicle sales will have Level 4 automation in 2040 and 2050, respectively
Lux research (Laslau et al. 2014)	Year 2030 revenues from Level 2 plus Level 3 sales: $21B for the U.S. and $20B for Europe
Morgan Stanley (2013)	Cost to add Level 3 automation is forecasted to be $6000 per vehicle by 2030 and $10,000 for Level 4 by 2045
ABI Research (2013)	50% of all new vehicle sales to be Level 4 AVs by 2032
BCG (Mosquet et al., 2015)	U.S. sales of Level 4 AVs will reach about 10% of all new light-vehicle sales by 2035
Citi GPS (2014)	Global market for Level 4 AVs could reach $40 billion by 2025
Alexander and Gartner (2014)	U.S. AV sales to reach around 18 million (or 75% of all light-duty vehicles) by 2035
	VMT & use forecasts
Litman (2015)	40% and 65% of U.S. vehicle travel will be in Level 4 AVs in 2040 and 2050, respectively
Hars (2014)	90% of all person-trips in U.S. will be in Level 4 AVs by 2030, and car ownership will decline by 20% decline by 2030

Table 12. Summary of forecasts by Bansal & Kockelman (2017)

Car Dimensions

The explanation of the dimensions of the Range Rover compact SUV Evoque were shown in the picture below (from book *H POINT: the fundamentals of car design & packaging*). The car dimensions are from Range Rover Evoque website.

Pictures from book *H POINT: the fundamentals of car design & packaging*

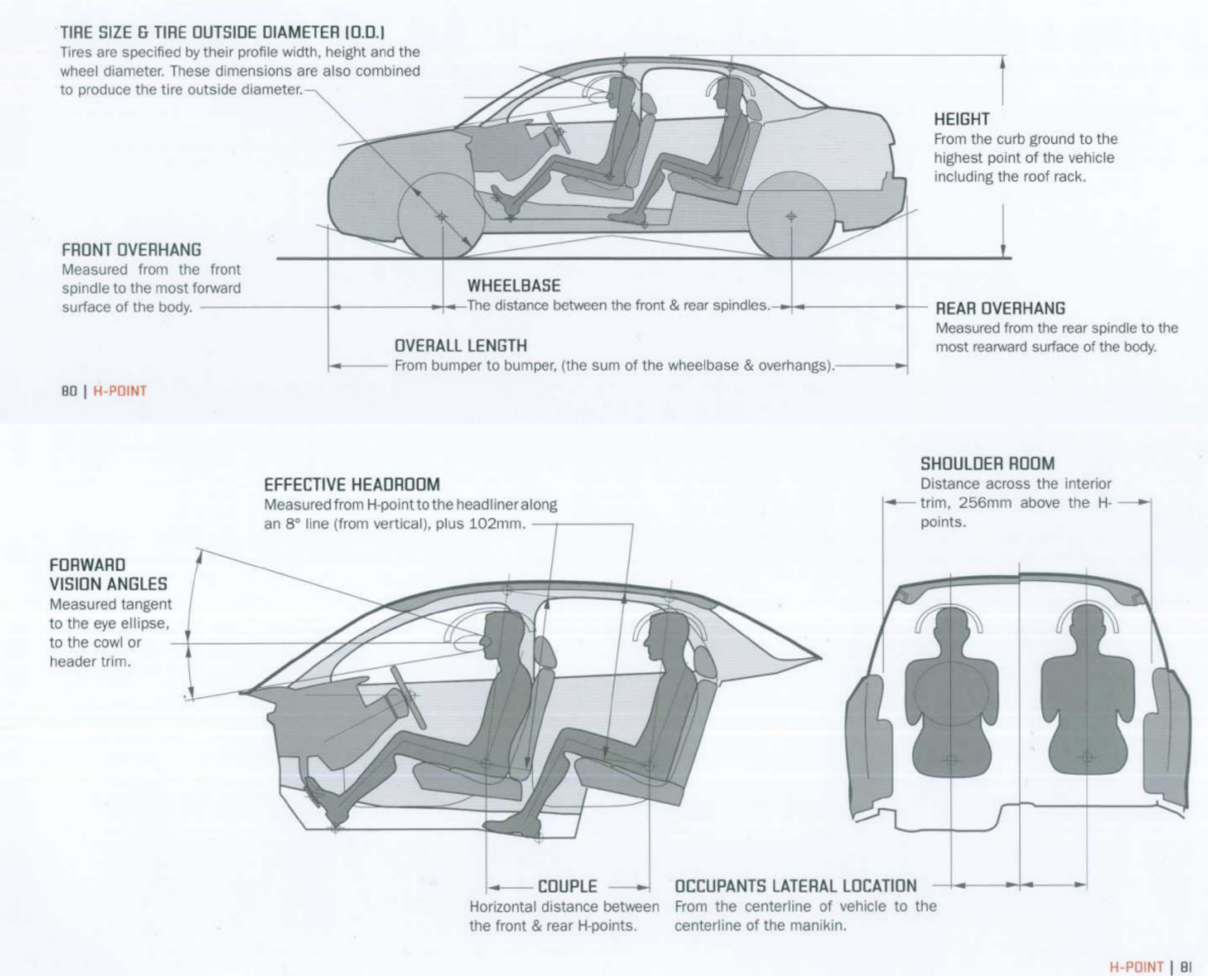


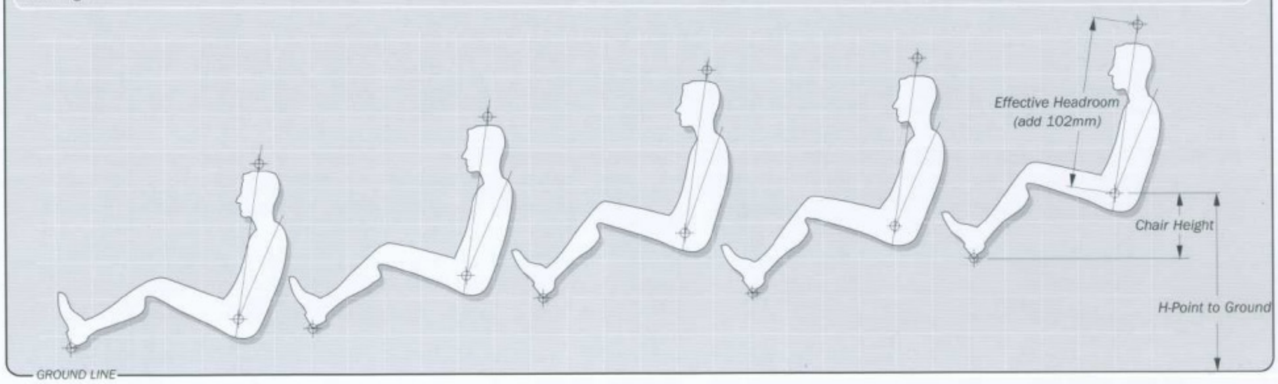
Table 8. Range Rover Evoque

Wheelbase	268.22cm
Length, Overall	437.13cm
Height, Overall	164.85cm
Front	
Leg Room	101.6cm
Shoulder Room	143.76cm
Head Room	98.81cm
Second	
Leg Room	85.85cm
Shoulder Room	140.72cm
Head Room	97.28cm

		DRIVER & FRONT PASSENGER										REAR OCCUPANTS						
		Heel to Ground (Ref)	Chair Height H30	H point to ground H5	Back Angle A40	Effective Head Room H61	Upward Vision Angle A60	Downw'd Vision Angle A61	Shoulder Room W3	Hip Room W5	Lateral Location W20	Couple L50	Chair Height H30-2	Back Angle A40-2	Effective Head Room H61-2	Shoulder Room W3-2	Hip Room W5-2	Lateral Location W20-2
CARS	NEV	325	400	725	15.0	1075	11.0	10.0	-	-	275	-	-	-	-	-	-	-
	SPORTS CAR	175	150	325	28.0	950	8.0	5.0	1350	1275	325/400	-	-	-	-	-	-	-
	MICRO CAR	350	275	625	21.0	1000	14.0	11.0	1200	1150	300	-	-	-	-	-	-	-
	SMALL ELECTRIC CAR	450	250	700	24.0	975	15.0	9.0	1325	1325	350	750	275	26.0	950	1325	1325	325
	SMALL CAR	225	250	475	24.0	975	15.0	7.0	1350	1325	350	750	275	27.0	950	1350	1325	325
	MEDIUM CAR	250	250	500	24.0	975	14.0	7.0	1475	1400	350	850	275	27.0	950	1475	1400	325
	MEDIUM COUPE	250	175	425	24.0	950	13.0	5.0	1375	1325	350	750	200	27.0	875	1375	1325	325
	LARGE CAR	275	250	525	24.0	975	14.0	6.0	1500	1450	375	900	275	27.0	975	1500	1450	400
	LARGE LUXURY CAR	275	275	550	22.0	975	15.0	7.0	1550	1500	400	975	300	28.0	975	1550	1450	375
TRUCKS	MINIVAN	425	350	775	20.0	1010	19.0	11.0	1575	1525	425	850	375	22.0	1000	1575	1525	400
	SMALL SUV	400	350	750	22.0	1010	15.0	9.0	1425	1400	400	800	375	24.0	1000	1425	1375	375
	MEDIUM SUV	450	300	750	22.0	1010	14.0	6.0	1500	1450	400	825	325	24.0	1000	1500	1450	425
	LARGE SUV	450	325	775	22.0	1025	14.0	7.0	1650	1600	375	875	350	24.0	1025	1650	1600	375
	SMALL TRUCK	400	300	700	22.0	1010	14.0	7.0	1475	1450	375	625	325	18.0	950	1475	1425	400
	LARGE 4x4 TRUCK	600	350	950	22.0	1025	15.0	8.0	1700	1650	475	950	375	18.0	1025	1700	1650	475
	COMMERCIAL VAN	725	350	1075	22.0	1010	10.0	10.0	1675	1625	525	900	425	19.0	1000	1675	1625	500

VARIOUS DRIVER HEIGHTS FROM GROUND AND POSTURES

H-Point to Ground	300 - 350*	400 - 500	700 - 750	700 - 800	700 - 950
Chair Height	135 - 180	200 - 250	300 - 350	300 - 350	300 - 350
Effective Headroom	950 - 960	970 - 1000	990 - 1010	1010 - 1020	1010 - 1020
Back Angle	28° - 30°	22° - 25°	22° - 24°	22° - 24°	22° - 24°



SPORTS CARS

The driver height is kept as low as possible to lower the center of gravity and reduce drag. Getting in and out of the car may be difficult but that is a compromise sports car owners will accept.

PASSENGER CARS

Most passenger car H-points are set up for a combination of easy ingress/egress and low center of gravity. Although not as extreme as most sports cars, they are relatively low.

MINIVANS

Usually set up quite high to provide a sense of security and good visibility. The tall chair height also helps to create an efficient package and provides excellent ingress and egress.

SUVs

A combination of high ground clearance and a durable underbody structure push the heel height up. The chair height is also tall to help the driver see over the engine, which is usually mounted high above the front axle.

LARGE OFF-ROAD TRUCKS

Similar to SUVs, the occupants often sit very high because of the ground clearance and the separate frame that the body sits on. Because the engines are usually very large and mounted high, the driver's eye point may end up in a very high position.

*All measurements in millimeters unless otherwise noted.

Appendix C Data extraction form

Article	Source	Country or area	Autopilot level	Study design	Participant		Activity 1	Activity 2	Activity 3	Activity 4	Activity 5	Activity 6	Activity 7	Activity 8	Activity 9	Activity 10	Activity 11	Activity 12	Activity 13	Activity 14	Activity 15	Activity 16	Activity 17	Activity 18	Activity 19	Activity 20	Activity 21	Activity 22	Activity 23	Activity 24	Activity 25	Activity 26	Activity 27	Activity 28	Activity 29	Activity 30	Activity 31	Activity 32	Activity 33	Activity 34	Activity 35	Activity 36	Activity 37	Activity 38	Activity 39	Activity 40	Activity 41	Activity 42	Activity 43	Activity 44	Activity 45	Activity 46	Activity 47	Activity 48	Activity 49	Activity 50
					Total	Other characteristics																																																			
The Value of Time-Potential for user-centered services offered by autonomous driving*	(Fraunhofer IAO & Horváth & Partners, 2016)	3 countries: Germany, Japan, and the U.S. (California)	L3 (highly automated driving in German Association of the Automotive Industry (VDA), L3 in SAE)	An online user survey (the relevance of the service groups for all countries)	1500 (500 German, 500 U.S. (California), and 500 Japanese)	Each holding a passenger car driving license, representative distribution of sociodemographic characteristics	Private communication (74%)				Eating/drinking (64%)	Online information search (60%)			Social networks/interest groups (39%)		Work (48%)	Sleep (46%)	Passive entertainment (58%)	Games (29%)		Training (36%)	Washing/cleaning (28%)	Beauty (41%)					Fitness (34%)	Changing clothes (33%)			Surrounding\route information (64%)		Shopping for daily requirements (56%)	Organization (49%)	Wellness (47%)	Product information (44%)	Health (39%)	Consultations (35%)		Artistic activities (22%)														
Public opinion on automated driving: Results of an international questionnaire among 5000 respondents	(Kyriakidis et al., 2015)	109 countries	BASt highly automated driving (L3 in SAE)	A 63-question Internet-based survey	4886 responses from 109 countries (40 countries with at least 25 respondents)	The mean age was 32.46, 69.2% males, 52.2% had heard of the Google Driverless Car before		Listen to music\radio (54.5%)	Observing the scenery (42.5%)		Eating/drinking (40.5%)	Checking emails\surfing on the Internet (38.2%)	Using mobile phone for texting and making phone calls (39.4%)	Reading a book, newspaper, magazine (23.8%)		Interaction with other passengers (44%)		Rest/sleep (16%)	Watching movies (23.1%)																																					Doing nothing at all (13.2%)	
Multitasking while driving: A time use study of commuting knowledge workers to assess current and future uses	(Teodorovicz et al., 2022)	U.S.	L3 (SAE)	An online time-use study adapted from the Daily Reconstruction Method survey (add up the percentages of 'personal activities' and 'work-related activities')	400	Knowledge workers who commute-by-driving, 51.5% females	In-person meeting (0.8%)	Listening to podcast/audio book/lecture/music (11.2%)				Reading and replying emails (23.3%)	Phone calls (4.5%)	Reading (7.8%)	Browsing/social media/messaging (14.3%)			Relaxing/resting/sleeping (5.9%)	watching videos/tv (5.8%)										Exercising (0.5%)		Video conference (1.5%)\Conference call (with two people or more) (1.2%)						Praying/mediating/worshiping (0.3%)								Programming (3.7%)			Planning (3.4%)\ Analyzing (2.5%)\ Thinking and reflecting (5.6%)\Preparing (1.5%)			Making a to-do list (3%)\ Writing and editing (1%)					
Understanding Driver Preferences for Secondary Tasks in Highly Autonomous Vehicles	(Li et al., 2023)	China	L3 (SAE)	An online questionnaire	214	18-61 (mean = 30.13), 101 female and 113 male, 188 had driving licenses, and 100 had experience in driving AV	Talking to the passengers (65%)	Listening to music (67%)	Enjoying the scenery outside windows (58%)	Typing or chatting on a phone (30%)	Drinking water or eating (52%)		Making a call (51%)	Reading (14%)				Sleeping (8%)	Watching videos on a phone (28%) or onboard devices (21%)	Playing video games on a smartphone (12%)				Making up (10%)	Smoking (15%)						Attending an online meeting (16%)		Using onboard navigation system (29%)											iPad for entertainment or work (12%)	Computer for entertainment or work (18%)											
Using the UTAUT2 model to explain public acceptance of conditionally automated (L3) cars: A questionnaire study among 9,118 car drivers from eight European countries*	(Nordhoff et al., 2020)	8 countries (EU)	L3 (SAE)	Questionnaires	3771 (only agree and strongly agree using the time for other activities were allowed to respond to questions)	41.37% 40-49, 50.74% male	Talking to my fellow travellers (44.76%)		Observing the landscape (41.70%)		Eating and drinking (28.90%)	Surfing the internet, watching videos or TV shows (44%)		Reading a book (14.68%)		Socialising with friends or family (e.g., write messages, make phone calls, use social media) (26.37%)	Working (17.06%)			Playing games (e.g., video or board games) (10.11%)												Relaxing and resting (34.42%)																					Taking care of children (13.37%)				
L3Pilot Deliverable 7.2: L3-L4 long-term study about user experiences*	(Metz et al., 2021)	Federal Highway Research Institute (BASt)	L3 (SAE)	An online survey with a video (one of nine videos) (add up the percentages of 'often' and 'very often')	147	38.1% female, M = 43.9 years, all have driving licence			Watching environment (83%)	Texting (53%)	Drinking (53%)\eating (34%)		Phone calling (46%)				Office work (18%)		Watch a movie (12%)	Gaming on smartphone/tablet (18%)																							App usage (48%)													
What Do You Do? An Analysis of Non-driving Related Activities During a 60 Minutes Conditionally Automated Highway Drive	(Hecht, Feldhütter, et al., 2020)	German	L3 (conditionally automated driving, SAE)	Video data from one-hour driving simulator study	20 (in the natural load group)	Two age groups (young: 23-38 years; old: 60-77 years), 6 female, 12 participants had taken part in a driving simulator study before		Music (tablet) (35%)\Music (phone) (10%)\Audio books (35%)\Changing the volume			Drinking		Phone calls (5%)	Reading (60%)				Sleeping (5%)	Videos (tablet) (45%)	Games (tablet) (15%)													Surroundings (100%)										Use smartphone (75%)	Browsing the tablet (50%)	Laptop usage (15%)	Scratching one's head										
Shaping driver-vehicle interaction in autonomous vehicles: How the new in-vehicle systems match the human needs	(Sun et al., 2021)	Ningbo (China)	L3 (SAE)	User enactment and interviews in AV simulator	44 drivers	Random sample, at least one year's driving experience, 68.2% 30-50, 3 have experience with autonomous vehicles	Talk to each other (13.6%)	Listen to music (50%)	Look out (22.7%)		Eat\drink (40.9%)	Listen to\read news (11.4%)	Phone calls\video calls (34.1%)	Read a book (6.8%)			Work\study (36.4%)	Sleep\rest (43.2%)	Watch film\video (34.1%)	Play video games (15.9%)\ play board games (11.4%)	Take selfie (2.3%)		Personal hygiene (9.1%)	Make up (4.5%)			Prepare food or drink (13.6%)		Simple sports (11.4%)	Change cloths (2.3%)			Monitor the driving (54.5%)		Online shopping (18.2%)								Play smartphone (18.2%)						Communicate with other vehicles (9.1%)	Trade stocks (2.3%)						
				Two 10-min periods of video recording in AV simulator			Talking (11%)		Look around (3%)		Drinking/eating, writing, etc. (7%)							Resting (54%)																									Play on a mobile phone (25%)													
Investigating user activities and the corresponding requirements for information and functions in autonomous vehicles of the future	(Tang et al., 2020)	Ningbo (China)	L3 (SAE)	User enactment and interviews in AV simulator	16 drivers (driving-alone driver (DAD) group)	At least one year's driving experience, 21 males, 3 have experience with autonomous vehicles	Talk to each other (0%)	Listen to music (74%)	Look outside the vehicle (25%)		Eat\drink (58%)	Listen to\read news (20%)	Make audio\video calls (69%)	Read a book (6%)			Work\study (44%)	Sleep\rest (50%)	Watch film\video (50%)	Play video games (25%)\ play board game (5%)	Take selfies (5%)		Personal hygiene (5%)	Make up (5%)			Preparing food or drink (12%)		Simple sports (20%)	Change cloths (5%)			Monitor the driving (88%)		Online shopping (12%)								Play on a mobile phone (38%)						Communicate with other vehicles (13%)	Trade stocks (5%)						
				Two 10-min periods of video recording in AV simulator			Talking (21%)		Look around (4%)		Drinking/eating, writing, etc. (9%)							Resting (55%)																									Play on a mobile phone (32%)													
				User enactment and interviews in AV simulator	14 drivers (driving-with-a-passenger driver (DPD) group)		Talk to each other (42%)	Listen to music (71%)	Look outside the vehicle (42%)		Eat\drink (64%)	Listen to\read news (15%)	Make audio\video calls (29%)	Read a book (15%)			Work\study (65%)	Sleep\rest (79%)	Watch film\video (50%)	Play video games (36%)\ play board game (29%)	Take selfies (0%)		Personal hygiene (21%)	Make up (6%)			Preparing food or drink (30%)		Simple sports (15%)				Monitor the driving (71%)		Online shopping (43%)								Play on a mobile phone (14%)						Communicate with other vehicles (15%)	Trade stocks (0%)						
				Two 10-min periods of video recording in AV simulator					Look around (3%)		Drinking/eating, writing, etc. (4%)							Resting (53%)																									Play on a mobile phone (19%)													
Age differences in the takeover of vehicle control and engagement in non-driving-related activities in simulated driving with conditional automation	(Clark & Feng, 2017)	North Carolina State, USA	L3 (SAE)	A driving simulation (counts & time)	35	18 older participants (mean age: 70.4 years, 11 men), 17 younger participants (mean age: 19.9 years, 11 men)	Talking to others\ Talking to self	Music	Eyes off road															Grooming								Horseplay											Electronic Device			Reaching										
Investigation of older drivers' requirements of the human-machine interaction in highly automated vehicles	(S. Li et al., 2019)	U.S.	L3 (SAE)	A driving simulator, and an interview after that (data from thematic analysis of the interview)	24	Older drivers, M = 71.5 years, 12 female	Talking to others (4/24)	Listening to radio (8/24)	Looking at scenery (7/24)		Eating and drinking (8/24)\meal (1/24)			Reading (16/24)			Working (2/24)		Watching TV and films (2/24)	Doing crosswords (2/24)									Doing exercise (1/24)			Relaxing not demanding tasks (10/24)	Monitoring driving (12/24)				Meditation and breathing (1/24)						Using mobile phone (3/24)					Thinking (2/24)								
A Longitudinal Simulator Study to Explore Drivers' Behaviour in Level 3 Automated Vehicles	(Large et al., 2019)	UK, the University of Nottingham	L3 (SAE)	A medium-fidelity, fixed-base driving simulator ('device' level)	49	27 male, M = 32 years, 21-64								Book				Sleeping						Cosmetics									Roadway (decrease with the days)										Phone (increase with the days)	Tablet	PC											
Setting the stage for autonomous cars: A pilot study of future autonomous driving experiences	(Pettersson & Karlsson, 2015)	Copenhagen shopping mall	L3 (NHTSA, L3 in SAE)	Participatory Design methodology (drawing, collaging, interviews, act)	9	6 males	Socialising				Eating and drinking alcohol			Reading	Using social media		Working	Sleeping	Video entertainment	Games												Relaxation																					Tending to children				
Deriving future user experiences in autonomous vehicle	(Kim et al., 2015)	Yonsei University, Korea	L3 (NHTSA, L3 in SAE)	Focused Group Interview	24	16 male, 8 female, M = 28	Talking		Look around		Drinking\meal\snack	Web surfing	Phone call	Reading	SNS (social networking service)		Office work	Sleep		Game	Taking a picture		Washing	Make up					Fitness	Changing clothes	Video telephone	Relax			Shopping	Clean up (work)							Multimedia	Multimedia	Multimedia			Manage schedule				Caregiving		Singing		
Non-Driving-Related Tasks During Level 3 Automated Driving Phases—Measuring What Users Will Be Likely to Do*	(Shi & Frey, 2021)	German motorways	L3 (SAE)	A Wizard-of-Oz vehicle with a questionnaire	39	20 female, M = 51 years	Making conversation (4.73%)		Taking a look at the environment (7.43%)	Reading and writing messages (8.11%)	Eating (8.78%) \ Drinking (6.08%)		Making phone calls (10.14%)	Reading (15.54%)				Sleeping (3.38%)														Relaxing (2.07%)											Using smartphone (8.78%)													
		German test track with an oval course of 2.1 km		A Wizard-of-Oz vehicle with a questionnaire (1. Engagement rate, 2. Total duration rate of engagements)	18	8 female, M = 45 years	Not allowed talking due to EEG measurement		Steady gaze to the outside (38.89%; 5.9%)		Eating/drinking (1.39%; 0.22%)			Magazines (16.67%; 23.54%) \ Book (5.56%; 8.79%) \ ebook (6.94%; 3.37%)												Knitting needles (1.39%; 5.59%)																	Smartphone (without phone calls) (25%; 45.13%)								Writing using a pen (4.17%; 7.52%)					
L3Pilot Deliverable D7.3: Pilot evaluation results	(Weber et al., 2021)	7 European countries: Belgium, France, Germany, Italy, Luxembourg, Sweden, and the UK	L3 (SAE)	Pilot site and simulators with the questionnaire (add up the percentages of 'frequently' and 'very frequently')	58 (motorway professional driver tested at the Pilot site)	Tested 70 vehicles		Music, radio, audiobooks (64%)		Texting (40%)	Eating or drinking (26%)	Browsing the Internet (45%)	Calling (37%)		Social media (14%)	Interacting with a passenger (57%)	Office/work tasks (17%)	Sleep (12%)	Watching movies (22%)				Personal hygiene/cosmetics (12%)		Smoking (36%)								Navigation (63%)										Smartphone apps (17%)												None (18%)	
					236 (motorway ordinary driver tested at the Pilot site)			Music, radio, audiobooks (94%)		Texting (68%)	Eating or drinking (52%)	Browsing the Internet (67%)	Calling (69%)		Social media (52%)	Interacting with a passenger (97%)	Office/work tasks (45%)	Sleep (14%)	Watching movies (35%)				Personal hygiene/cosmetics (7%)		Smoking (5%)								Navigation (65%)										Smartphone apps (70%)												None (13%)	
					60 (motorway ordinary driver tested at the simulator)			Music, radio, audiobooks (93%)		Texting (78%)	Eating or drinking (60%)	Browsing the Internet (72%)	Calling (50%)		Social media (50%)	Interacting with a passenger (92%)	Office/work tasks (34%)	Sleep (15%)	Watching movies (18%)				Personal hygiene/cosmetics (7%)		Smoking (4%)								Navigation (62%)										Smartphone apps (67%)													
					175 (urban driver tested at the Pilot site)			Music, radio, audiobooks (91%)		Texting (39%)	Eating or drinking (61%)	Browsing the Internet (45%)	Calling (65%)		Social media (43%)	Interacting with a passenger (87%)	Office/work tasks (35%)	Sleep (14%)	Watching movies (26%)				Personal hygiene/cosmetics (12%)		Smoking (7%)								Navigation (57%)										Smartphone apps (42%)												None (5%)	
Non-Driving Related tasks and journey types for future autonomous vehicle owners	(Wilson et al., 2022)	United Kingdom (42.7%), the United States (41.1%), Canada (3.6%) and Australia (2%)	L4 (SAE)	A 42-question online survey (add up the percentages of 'strongly agree' and 'agree')	566 (the more likely to own an AV population, total n = 1378)	Purposive sampling, 59% males, have driving licence, 37% 18-30	Socialise (e.g., socialise and play games with friends and family) (70%)										Work with a colleague (e.g., have a meeting, work collaboratively) (42%)	Rest and sleep (e.g., rest, meditate or sleep) (75%)		Leisure activity ((e.g., read something, watch something, play a game, exercise) (88%)			Morning routine (e.g., eat breakfast, do my make-up, shave) (46%)										Remain in the driving position (52%)															Be productive (e.g., admin tasks, send emails, dial into an early meeting, learn something new) (64%)								
Understanding Driver Preferences for Secondary Tasks in Highly Autonomous Vehicles	(Li et al., 2023)	China	L4 (SAE)	An online questionnaire	214	18-61 (mean = 30.13), 101 female and 113 male, 188 had driving licenses, and 101 had experience in driving AV	Talking to the passengers (64%)	Listening to music (69%)	Enjoying the scenery outside windows (64%)	Typing or chatting on a phone (50%)	Drinking water or eating (54%)		Making a call (59%)	Reading (24%)				Sleeping (15%)	Watching videos on a phone (45%)or onboard devices (33%)	Playing video games on a smartphone (25%)				Making up (20%)	Smoking (19%)						Attending an online meeting (24%)		Using onboard navigation system (40%)											iPad for entertainment or work (24%)	Computer for entertainment or work (26%)											
Design Implications of Drivers' Engagement with Secondary Activities During Highly-Automated Driving – A Longitudinal Simulator Study	(Large et al., 2017)	UK, the University of Nottingham	L4 (SAE)	A medium-fidelity, fixed-based driving simulator	6	29-55 years, all have UK driving licences				Mobile phone texting/conversations	Eating/drinking	Web-browsing		Reading an article or magazine (using either published or paper copies, or from a tablet)	Social networking activities using a mobile device				Watching programmes/films on a laptop or iPad					Personal grooming activities																																
How the initial level of trust in automated driving impacts drivers ' behaviour and early trust construction	(Manchon et al., 2022)	USA	L4 (SAE)	A static driving simulator (percentage refers to the percentage of time spent)	38 (Removal of 2 trustful participants)	20 females, M = 38 years old, all had a driver's license for a min of three years (M = 18.5) and drove regularly		Listening to the radio (3.75%).						Reading magazines or other documents (14.2%)																			Monitor the driving environment (21.9%)										Mobile for texting, calling, playing or web browsing (33.6%)	Tablet for games and web browsing (17%)												Other (e.g., grooming, drinking water, putting glasses on) (9.15%)
A Wizard of Oz Field Study to Understand Non-Driving-Related Activities, Trust, and Acceptance of Automated Vehicles	(Detjen et al., 2020)	Urban areas of Bremen and Essen in Germany	L4 (SAE)	A Wizard of Oz automated car in a real-world driving experiment (percentage is frequency)	8 (4 persons stated that they had noticed the deception, total n = 12)	6 females, 24-33 years (M = 28.67), had a regular daily commuting/travel time of short to medium-length (M = 19.63 min)	Talking to passengers (4.17%)	Listen to Music/Radio/Audiobooks (6.25%)	Watch out of window (95.83%)	Smartphone Typing/Texting (37.5%)	Eat\drink (18.75%)		Calling (8.33%)	Reading a Book (12.5%)			Office tasks (14.58%)	Sleeping (2.08%)			Take pictures (14.58%)			Cosmetics (4.17%)																			Smartphone Use/Internet/Social Media (66.67%)								Writing (56.25%)					
The Value of Time-Potential for user-centered services offered by autonomous driving*	(Fraunhofer IAO & Horváth & Partners, 2016)	3 countries: Germany, Japan, and the U.S. (California)	L5 (driverless driving (VDA), no drivers)	An online user survey (the relevance of the service groups for all countries)	1500 (500 German, 500 U.S. (California), and 500 Japanese)	Each holding a passenger car driving license, representative distribution of sociodemographic characteristics	Private communication (68%)				Eating/drinking (57%)				Social networks/interest groups (42%)		Work (47%)	Sleep (52%)	Passive entertainment (53%)	Games (31%)		Training (41%)	Washing/cleaning (29%)	Beauty (37%)					Fitness (37%)	Changing clothes (35%)			Surrounding\route information (59%)		Shopping for daily requirements (57%)	Organization (47%)	Wellness (46%)	Product information (45%)	Health (43%)	Consultations (39%)		Artistic activities (30%)														
Non-driving Related Activities in Automated Driving – An Online Survey Investigating User Needs	(Hecht, Darlagiannis, et al., 2020)	German	Train setting, automated driving (should be L5 in SAE)	An online survey	200	The average age was 33.83 years, from 18 to 70 years, 58% females, 49% students		Voice messages		Text messages	Eating and drinking		Phone call	Reading			Working	Sleeping														Relaxing											Smartphone	Laptop/tablet												
Public opinion about automated vehicles in Australia: Results from a large-scale national survey*	(Cunningham et al., 2019)	Australia	L5 (SAE)	An online survey (add up the percentages of 'somewhat likely' and 'very likely')	5089	M = 45.39 years, 45.9% males, 90.6% have driving licence			Observing the scenery (69.6%)		Eating/drinking (58.2%)			Reading a book, newspaper, magazine (37.2%)		Interaction with other passenger (68.2%)	Doing work (31.9%)	Sleep (23.4%)\rest (45%)						Grooming (e.g. makeup) (28.5%)																			Using personal devices (e.g. mobile phone, iPad) (53.3%)	Using personal devices (e.g. mobile phone, iPad) (53.3%)											Doing nothing (42.7%)	
Seating configuration and position preferences in fully automated vehicles	(Koppel et al., 2019)	Australia (40.9%), Spain (16.5%), Sweden (15.6%), or Lebanon (19.4%)	L5 (SAE)	An online survey (self)	552	50.5% males, mean = 36.6 years		Listen to music/radio/podcast (15%)	Look out window at scenery (8%)					Read (25%)																		Relax\rest\sleep (10%)	Watch vehicle/road/traffic (12%)										Check/use phone (7%)													Other (24%)
				An online survey (with partner/spouse/children)			Talk (45%)	Listen to music/radio/podcast (10%)	Look out window at scenery (4%)					Read (17%)																		Relax\rest\sleep (2%)	Watch vehicle/road/traffic (7%)										Check/use phone (4%)													Other (16%)
				An online survey (with older relatives)			Talk (55%)	Listen to music/radio/podcast (13%)	Look out window at scenery (6%)					Read (5%)																		Relax\rest\sleep (2%)	Watch vehicle/road/traffic (9%)										Check/use phone (3%)													Other (7%)
				An online survey (with stranger)			Talk (31%)	Listen to music/radio/podcast (12%)	Look out window at scenery (10%)					Read (20%)																		Relax\rest\sleep (4%)	Watch vehicle/road/traffic (3%)										Check/use phone (6%)													Other (17%)
Understanding Driver Preferences for Secondary Tasks in Highly Autonomous Vehicles	(Li et al., 2024)	China	L5 (SAE)	An online questionnaire	214	18-61 (mean = 30.13), 101 female and 113 male, 188 had driving licenses, and 102 had experience in driving AV	Talking to the passengers (66%)	Listening to music (68%)	Enjoying the scenery outside windows (69%)	Typing or chatting on a phone (65%)	Drinking water or eating (66%)		Making a call (64%)	Reading (41%)				Sleeping (40%)	Watching videos on a phone (61%) or onboard devices (47%)	Playing video games on a smartphone (43%)				Making up (33%)	Smoking (21%)						Attending an online meeting (38%)		Using onboard navigation system (45%)											iPad for entertainment or work (38%)	Computer for entertainment or work (49%)											
A day in the life with an automated vehicle: Empirical analysis of data from an interactive stated activity-travel survey	(Pudāne et al., 2021)	Netherlands	AV partial\AV ideal (L5 SAE, both do not have any control over the car, but AV partial can limit certain activities or cause motion sickness)	Interactive stated activity-travel survey, and they designed their current daily schedule (percentage refers to the share of mode users, AV partial and AV ideal)	496 (509 complete responses, 13 were excluded)	63% male, 18-64, 91% worker, 50% short commute time (10–30 min), 40% medium (30–60 min)					Meal (9.5%; 12%)						Work (17%; 17.5%)															Leisure (13%; 13.8%)																Get ready (6.5%; 5.5%)							Do nothing (e.g., watching out, thinking, and listening to music) (most-selected, missing data)	Other (sleep, shop, service, household, other) (2.5%; 7%)
Seating positions and activities in highly automated cars–a qualitative study of future automated driving scenarios	(Jorlöv et al., 2017)	Sweden	L5 (SAE)	A questionnaire and a structured interview	18 (shorter drive, 52 total)	18-65			Look out (5/18)		Eat (2/18)	Surf (5/18)	Talk on the phone (3/18)	Read (3/18)			Work (3/18)	Sleep (5/18)	Watch movies (1/18)									Play guitar (1/18)				Rest (4/18)																								
					11 (longer drive, 52 total)	<18	Socializing (2/11)		Look out (1/11)		Eat (3/11)								Watch movies (9/11)	Playing video games (8/11)\play board games (4/11)												Reat (1/11)																								
					20 (longer drive, 52 total)	18-65	Socializing (7/20)		Lookout (2/20)		Eat (4/20)	Surf (5/20)	Talk on the phone	Read (4/20)			Work (2/20)		Watch movies (9/20)	Playing board games (9/20)																																				
Behavioral impact of drivers' roles in automated driving	(Reimer et al., 2016)	USA	Fully autonomous (the vehicle was in full control, including steering, speed, and lane change, L5 SAE)	A full cab fixed-base driving simulator (mean percent of the time participants held on to each type of distractor)	32 (36 complete, 4 were excluded)	20-29 or 55-69, having a driver's license for over three years, and driving on average at least one day a week					Food (2%)			Reading (6%)																													Phone (36%)												No item (26%)	Other (1%)
How will automated vehicles shape users' daily activities? Insights from focus groups with commuters in the Netherlands	(Pudāne et al., 2019)	Netherlands	L5 (SAE)	Five focus groups	27	Commuters, each group consisted of 4–7 participants, 15 males, 11 (30-39)	Talk with travel companions (current optional activities)	Listen to music/radio/audio book/podcasts (current optional activities)	Observe landscape (current optional activities)		Eat or snacks (e.g., have breakfast or coffee) (current high-priority activities)	Browse Internet (current optional activities)	Phone call (current optional activities)	Read news/read a book or newspaper (current optional activities)		Spend time with friends (new optional activities)	Work (e.g., plan the day, write emails, arrange appointments, prepare for a presentation) (current or new high-priority activities)	Sleep (new high-priority activities)	Watch movies (new optional activities)	Play board games or computer games (new optional activities)		Study (current high-priority activities)	Wash oneself\brush teeth (new high-priority activities)	Make up (current high-priority activities)	Smoke (current optional activities)	Sew (new optional activities)	Prepare dinner (new high-priority activities)		Exercise (new optional activities)		Video call (new optional activities)	Relax\unwind from work (current optional activities)				Do administration (new high-priority activities)					Use a massage chair (new optional activities)		Check phone (current optional activities)					Play day in head/contemplate (current optional activities)				Attend to children (new high-priority activities)	Business (beauty salon in car) (new high-priority activities)	Singing karaoke (new optional activities)		
Demands Exploration of Future Interior Layout in Shared Mobility Using Design Fiction	(Yang et al., 2021)	China	Carpooling for 6 scenarios (L5 SAE)	Design Fiction and User Enactments questionnaires (workshop)	10	Graduate students, 6 male, and 4 female, 24–26	Chatting				Eating & drinking						Working	Sleeping & relaxing	Watch film	Playing video games				Make up							Meeting						Meditation																	Karaoke		
Exploring user needs and design requirements in fully automated vehicles	(Lee et al., 2020)	USA	L5 (SAE)	Workshop	Can't tell	Researchers, internal workshop					Eating meals (daily activities)	Information & Notification				Youth Interaction	Office work	Sleeping (daily activities)	Watching Movie & TV shows	Games		Study											External UI		Shopping & parking		Accessibility		Healthcare																	
Using Time and Space Efficiently in Driverless Cars: Findings of a Co-Design Study	(Stevens et al., 2019)	The UK	Driverless cars (should be L5)	Co-design sessions (semi-structured interviews and inspiration cards workshops)	14	Diversity of people regarding age, gender, job, and time and mobility management			Enjoy the view (with additional information) (second most preferred)		Restaurant or Café (eating snacks and drinking, social) (a common, but secondary satisfying issue)						Office (reading up on topics, reading messages, writing e-mails, creating presentations, sorting documents, and talking with employees) (most frequently selected favorite)	Sleeping place (take a nap) (mostly associated with relaxation)		Entertainment (television, community game for social) (Less often)									Sport (car maybe not be perceived as the right space)			Relaxation (related to other categories such as eating and drinking, a place to sleep, or a pleasant view while driving) (a prominent issue, not first)		Kindergarten (car maybe not be perceived as the right																						
Approximation of the user behaviour in a fully automated vehicle referring to a stationary prototype-based research study	(Fitzen et al., 2019)	Can't tell	L5 (SAE)	Stationary prototype-based research (a concept vehicle containing an innovative seat concept) (percentage about test persons that selected activities, and a linear weighting of their prioritised 5 activities)	30	9 female, from different departments, mainly under 40	Talking to other passengers (97%; 52%)	Listen to music (80%; 56%)	Enjoy the scenery (50%; 28%)	Texting	Drinking (77%; 30%)\eating	Surfing the internet (90%; 60%)\writing emails\reading the news	Making a call (93%; 40%)	Reading (83%; 40%)	Using social media (80%; 32%)		Working		Watch a movie (57%; 34%)	Playing board games											Business meeting	Relaxing (93%; 99%)					brain callisthenics					Painting														
A Wizard of Oz Study on Passengers' Experiences of a Robo-Taxi Service in Real-Life Settings	(Meurer et al., 2020)	Germany	Shared autonomous vehicle services (SAVs) (L5 SAE)	A Wizard of Oz automated car in a real-world driving experiment for one week	10	5 female, 22-80	Talking with companions	Listen to music, radio and podcasts	Look out of window		Eating	Writing & checking emails\surfing	Phone calls	Read			Working	Sleeping	Watch a movie													Relaxing	Check Google maps															Arrange some stuff & write massages			Make to-do lists					
The Effects of a Predictive HMI and Different Transition Frequencies on Acceptance, Workload, Usability, and Gaze Behavior during Urban	(Hecht, Kratzert, et al., 2020)	Germany	L3 & L4 (SAE)	A dynamical driving simulator	33	18 in the predictive, 15 in the baseline condition, M = 28.55 years, all have driving license, 15 have taken part in other	Talking		Window gazing		Drinking			Reading magazines					Tablet videos	Tablet gaming																							Phone use	Tablet browing												
Automated Driving on the Motorway: A Users' Perspective on Conditional Versus High Automation	(Wörle et al., 2020)	Can't tell	L3 & L4 (SAE)	A high-fidelity moving-base driving simulator	61 (L3 with 31, L4 with 30)	29 female, M = 38 years, SD = 12 years		Listening to music, radio or audiobook (the most frequent)		Writing text messages (the most frequent)	Eat and drink			Reading magazines or newspapers\Reading books\Reading an eBook		Interact with a passenger (the most frequent)	Work	Sleeping (more frequently than L3)	Watch movies (more frequently than L3)				Hygiene and cosmetics																				Smartphone\Other technical devices	Smartphone\Other technical devices	Smartphone\Other technical devices											Others
Supervising the self-driving car: Situation awareness and fatigue during highly automated driving	(McKerral et al., 2023)	Australia	Highly automated driving (should be L3 & L4 in SAE)	A driving simulation	26 (54 complete, 27 monitoring, and 27 NDRT, but one didn't engage in any NDRT)	18-60, M = 24.15 years, 67% female, have valid driver licences		Music (7/26)\Podcasts (1/26)			Food (7/26)			Book (5/26)			Work – written (3/26)			Gaming device (1/26)																							Mobile phone (26/26)	Tablet (2/26)	Laptop (5/26)									Singing (1/26)		
From partial and high automation to manual driving: Relationship between non-driving related tasks, drowsiness and take-over performance	(Naujoks et al., 2018)	Würzburg Institute for Traffic Sciences (WIVW GmbH)	Highly automated driving (should be L3 & L4 in SAE)	A moving-base driving simulator (collected activities during the last 15s before the onset of the target event)	32 (64 complete, 32 in partially automated, 32 in highly automated)	From the test driver panel, 34 male, M = 33 years				Smartphone texting (1/32)			Smartphone phoning (1/32)	Smartphone reading (9/32)\magazine (5/32)	Smartphone social media (1/32)				Smartphone video (2/32)	Smartphone gaming (2/32)																																			No NDRT (9/32)	
Behavioral impact of drivers' roles in automated driving	(Reimer et al., 2016)	USA	Semi-autonomous (able to change lanes, but unable to brake, steer, or resume full control of the vehicle, could be L3 & L4 SAE)	A full cab fixed-base driving simulator (mean percent of the time participants held on to each type of distractor)	32 (36 complete, 4 were excluded)	20-29 or 55-69, having a driver's license for over three years, and driving on average at least one day a week					Food (2%)			Reading (12%)																													Phone (24%)												No item (51%)	Other (1%)

Investigating User Needs for Non-Driving-Related Activities During Automated Driving	(Pfleging et al., 2016)	European / German (The whole system was set up in German)	L4 & L5 (SAE)	Online survey 2015 (add up the percentages of 'very frequent' and 'frequent' activities + other activities without percentage)	300	21-30 (60.7%); 156 females (52.0%), 134 males (44.7%); all owned a driver license	Talking to passengers (90.3%)	Listening to music/radio etc. (87.7%)	Watching out of the window (81.7%)	Write (any type of) text message (71.3%)	Eating and drinking (63.7%)	Surf on the Internet (61.3%)	Make phone calls (54.3%)	Reading (52.7%)	Social media (47.7%)	Interact with passengers (e.g., play games) (45.3%)	Perform office tasks (34%)	Sleeping (32.7%)	Watch movies (26.3%)	Play (video) games (17.3%)	Take pictures (15.7%)	Learn languages (12.3%)	Cosmetics (Personal hygiene) (10.3%)		Smoking (6%)	Knitting (5%)	Prepare meals (7.5%)	Play instruments (3%)	Fitness (2.5%)		(video) telephony like Skype																									
Travel time evaluation for automated driving: a use-case-driven study*	(Cyganski et al., 2015)	German	L4 & L5 (SAE)	Online survey 2014 (add up the percentages of 'absolutely true', 'predominantly true' and 'rather true' activities)	250	56% females; 30-49 (34%); 90% have driving license (whole survey)	Talk to my companions (65%)		Enjoy the trip and the landscape (72%)			Surf the Internet (38%)			Social networking (via social media, SMS, mail, or phone) (40%)		Work (33%)		Watch movie (32%)													Relax and maybe to sleep (44%)																								
A Survey of Public Opinion about Autonomous and Self-Driving Vehicles in the U.S., the U.K., and Australia*	(Schoettle & Sivak, 2014)	The U.S., the U.K., and Australia	L4 (NHTSA) (Completely self-driving vehicle, L4 & L5 in SAE)	Online survey 2014 (total percentage, equal weighting of each country)	1533 (501 for the U.S., 527 for the U.K., 505 for Australia)	18 years and older; 18-29 (26.5%); 52.2% females							Text or talk with friends/ family (7.7%)	Read (8.3%)			Work (4.9%)	Sleep (7%)	Watch movies/TV (5.3%)	Play games (2%)													Watch the road even though I would not be driving (41%)																							
Enabling the Value of Time Implications for the interior design of autonomous vehicles*	(Fraunhofer IAO et al., 2018)	5 countries: China, the USA, Japan, Germany, and France	Based on the scenario whereby vehicles can drive autonomously (should be L4 & L5 in SAE)	An online survey (acceptance values for different usage types)	2500 (500 users from the five countries)	Covered a representative distribution of demographic characteristics; average age is 46.3 years; almost 90% have their own car					Eating and drinking (covers the consumption of small snacks and beverages as well as complete meals that can be cooled or warmed up in the vehicle) (38.2%)						Working and being productive (covers private and occupational office work, e. g., writing documents, deadline planning or activities related to continuing education and training, such as a language course) (36.4%)	Sleeping and relaxing (covers any type of rest – from switching off in a seated position to falling fast asleep in a lying position) (46.6%)		Entertainment (covers a range of activities, including watching television, playing video games, listening to music, reading books, or playing board games) (39.8%)			Beauty, wellness and fitness (covers activities such as personal care or applying make-up, as well as activities related to wellness and fitness such as fitness exercises) (23.2%)																																		
Are we ready to embrace connected and self-driving vehicles? A case study of Texans*	(Bansal & Kockelman, 2018)	In or around Texas' biggest cities	L4 (NHTSA) (Completely self-driving vehicle, L4 & L5 in SAE)	An online survey	1088	The mean age was 44.56, 49% males	Talk to others in a car (59.5%)		Look out the window (59.4%)		Eat or drink (56%)	Surf the internet (33.3%)	Text, or talk on phone (46.2%)	Read (24.5%)			Work (17.4%)	Sleep (18.1%)	Watch movies or play games (27.3%)										Exercise (7.8%)																		Maintenance activity (17.5%)									
Public opinion on automated driving: Results of an international questionnaire among 5000 respondents	(Kyriakidis et al., 2015)	109 countries	BASt fully automated driving (L4 & L5 in SAE)	A 63-question Internet-based survey	4886 responses from 109 countries (40 countries with at least 25 respondents)	The mean age was 32.46, 69.2% males, 52.2% had heard of the Google Driverless Car before		Listen to music\radio (56.5%)	Observing the scenery (47.4%)		Eating/drinking (48.2%)	Checking emails\surfing on the Internet (44.3%)	Using mobile phone for texting and making phone calls (47.3%)	Reading a book, newspaper, magazine (39.2%)		Interacting with other passengers (47.8%)		Rest/sleep (38.5%)	Watching movies (39.4%)																																							Doing nothing at all (15.8%)	
Fully automated vehicles: The use of travel time and its association with intention to use	(Wadud & Huda, 2021)	Bangladesh, the UK, USA, Other countries	Fully automated vehicles (L4 & L5 in SAE)	An online questionnaire survey	621	Snowballing, 61% 25 to 40, 36.1% females	Talking to other passengers (Out: 27.5%; In: 28%)	Listening to music/radio (Out: 38.6%; In: 39.7%)	Window gazing/people watching (Out: 31.9%; In: 31.9%)		Eating/drinking (Out: 16.8%; In: 16.1%)	Emailing/browsing internet (Out: 28.1%; In: 27.1%)	Phone calls/messaging (Out: 28.1%; In: 28.9%)	Reading for leisure (Out: 20.5%; In: 20.7%)	Online social media (Out: 28.1%; In: 29.5%)		Working/studying (Out: 21.8%; In: 17.3%)	Sleeping/snoozing (Out: 16.7%; In: 21.6%)	Watching video/playing games (Out: 7.7%; In: 8%)														Still watching roadway (Out: 46.2%; In: 43.5%)															Thinking/planning (Out: 43.4%; In: 38.6%)								
Spatial components guidelines in a face-to-face seating arrangement for flexible layout of autonomous vehicles	(Kwon & Ju, 2021)	Korea	L4 & L5 (SAE)	Ethnographic observation, using mock-ups, observational surveys, and the think-aloud research method (Ratio of frequency and time duration)	3	Aware of the changing concept of AV, with more than one year of experience in future mobility research	Face-to-face conversation (listening/speaking) (36%; 20%)				Eating snacks (14.5%; 2.5%)						Table-use activities (work) (5.5%; 1.5%)	Sleeping and reclining (28%; 46%)	Watching videos (2%; 21%)																								Using cell phone (4%; 6.5%)													Other postures (inaction-basic sitting posture and posture change) (9%; 2.5%)
"Don't make me turn this seat around!" Driver and passenger activities and positions in autonomous cars	(Ive et al., 2015)	Outside of Stanford 's Automotive Innovation Lab	Did not have any operator controls (should be L4 & L5 in SAE)	Visualization and think-loud exercises, and situation interviews within an simulated autonomous car	17	Undergraduate and graduate students, 14 males, age M = 22.76, 15 have driving licence								Reading a book		Interacting with other car occupants (1)		Sleep																									Phone usage (often for reading) (2)	Tablet usage												
An International Survey on Automated and Electric Vehicles: Austria, Germany, South Korea, and USA	(Jeon et al., 2018)	Austria (383), Germany (78), South Korea (81), and USA (324)	AVs (not clear, should be L3-L5 in SAE)	An online survey	866	M = 27.9 years, 59.6% males					Eat (50%)		Phone call (41%)		Social networking (27%)		Office work (50%)	Sleep (50%)	Watch TV (28%)														Monitoring vehicle operation (49%)																							Other (8%)
Perceptions related to engaging in non-driving activities in an automated vehicle while commuting: A text mining approach	(Xing et al., 2023)	US (96.5%), 21 NA's, and 5 from other counties such as France and India	AVs (not clear, should be L3-L5 in SAE)	An online questionnaire survey	752	Commuting knowledge workers, 346 are female and 406 are male, 18 to 79 with an average of 38.02		Listen to music/radio/podcast/audio book				Emails		Read			Work	Sleep															Relax																Planning for their day (making to-do lists, preparing, getting ready for the day)								
How Will the driver sit in an automated vehicle? - The qualitative and quantitative descriptions of non-driving postures (NDPs) when non-driving-related-tasks (NDRTs) are conducted	(Y. Yang et al., 2019)	In the social media and university	AVs (not clear, should be L3-L5 in SAE)	An online survey (13 activities mentioned significantly ($\alpha < 0.05$) more frequently in HAD, are denoted by the '*')	122	18-79, M = 42, SD = 18, 64.75% male	Talking to the passenger on the front seat (99%); talking to the passenger on the back seat (97%)	Listen to music, radio and audiobook, etc. (98%)	Looking at the landscape (99%)		Eating & drinking (90%)		*Telephoning with a hand-free system (97%)*Telephoning without a hand-free system (75%)	*Reading newspaper, books, etc. (72%)			*Working and studying (63%)	*Sleeping (53%)	*Watching movies (61%)	*Playing video games (40%)				*Body care (make up, etc.) (36%)	Smoking (8%)							*Doing nothing, day-dreaming or relaxing (88%)	*Using infotainment and navigation (98%)\watching the traffic (97%)										*Using a smartphone (84%)	*Using a tablet or a laptop (68%)	*Using a tablet or a laptop (68%)			Thinking deeply about something (94%)				*Taking care of children (61%)				
Approximation of the user behaviour in a fully automated vehicle referring to a stationary prototype-based research study	(Fitzen et al., 2018)	Can't tell	No differentiation was made regarding target groups, target markets, or automation levels	Meta-analysis	17 research studies (over 50,000 study participants)	Concerned with secondary activities in automated vehicles or **other means of transportation**			Enjoying the scenery (54.2%)	Texting (39.2%)	Drinking (59.5%); Eating (47.7%)	Surfing the internet (37.2%)	Making a call (40.5%)	Reading (43.1%)	Using social media (41.2%)												Preparing food (51.8%)				Having videoconferences/virtual meetings (69.6%)																									

Appendix D CASP checklist evaluation

Study	Section A: Are the results valid?						Section B: What are the results?			Section C: Will the results help locally?	Yes 1, can't tell 0, no -1
	Was there a clear statement of the aims of the research?	Is a qualitative methodology appropriate?	Was the research design appropriate to address the aims of the research?	Was the recruitment strategy appropriate to the aims of the research?	Was the data collected in a way that addressed the research issue?	Has the relationship between researcher and participants been adequately considered?	Have ethical issues been taken into consideration?	Was the data analysis sufficiently rigorous?	Is there a clear statement of findings?	How valuable is the research?	Value
(Pfleging et al., 2016)	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	Yes	Yes	Yes	8
(Cyganski et al., 2015)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	10
(Schoettle & Sivak, 2014)	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
(Stevens et al., 2019)	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	9
(Fraunhofer IAO & Horváth & Partners, 2016)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	10
(Fraunhofer IAO et al., 2018)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	10
(Hecht et al., 2020)	No	Yes	Can't tell	Can't tell	Can't tell	Can't tell	Yes	Yes	Yes	Yes	6
(Hecht, Feldhütter, et al., 2020)	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	Yes	Yes	Yes	8
(Kyriakidis et al., 2015)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	10
(Bansal & Kockelman, 2018)	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
(Wadud & Huda, 2021)	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	Yes	Yes	Yes	8
(Large et al., 2017)	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	Yes	Yes	Yes	8
(Sun et al., 2021)	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	Yes	Yes	Yes	8
(Tang et al., 2020)	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	Yes	Yes	Yes	8
(Detjen et al., 2020)	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	9
(Wilson et al., 2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	10
(Cunningham et al., 2019)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	10
(Ive et al., 2015)	Yes	Yes	Yes	Can't tell	Can't tell	Can't tell	Yes	Yes	Yes	Yes	7
(Pettersson & Karlsson, 2015)	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	Can't tell	Yes	Yes	7
(Hecht, Kratzert, et al., 2020)	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	Yes	Yes	Yes	8
(Teodorovicz et al., 2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	10
(Clark & Feng, 2017)	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	9
(Pudāne et al., 2019)	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	Yes	Yes	Yes	8
(Koppel et al., 2019)	Yes	Yes	Can't tell	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	8
(Jeon et al., 2018)	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	9
(Kim et al., 2015)	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	Yes	Yes	Yes	8
(Large et al., 2019)	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Can't tell	Yes	Yes	8
(Shi & Frey, 2021)	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	9
(Jorlöv et al., 2017)	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	No	Yes	Yes	6
(Nordhoff et al., 2020)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	10
(Metz et al., 2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yez	Yes	Yes	Yes	10
(Weber et al., 2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	10
(Xing et al., 2023)	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Can't tell	Yes	Yes	8
(Li et al., 2023)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	10
(Manchon et al., 2022)	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
(Pudāne et al., 2021)	Yes	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Yes	9
(Reimer et al., 2016)	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Can't tell	Yes	Yes	8
(Kwon & Ju, 2021)	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	9
(Yang et al., 2021)	Yes	Yes	Can't tell	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	8
(Meurer et al., 2020)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	8
(Lee et al., 2020)	Yes	Yes	Can't tell	Can't tell	Yes	Yes	Yes	Can't tell	Yes	Yes	7
(Fitzen et al., 2018)	Yes	Yes	Can't tell	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	8
(Y. Yang et al., 2019)	Yes	Yes	Can't tell	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	8
(Wörle et al., 2020)	Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	No	Yes	Yes	6
(McKerral et al., 2023)	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Can't tell	Yes	Yes	8
(S. Li et al., 2019)	Yes	Yes	Can't tell	Yes.	Yes	Yes	Yes	Yes	Yes	Yes	9
(Naujoks et al., 2018)	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Can't tell	Yes	Yes	8

Appendix E
Whole activity clusters

● Observation and Monitoring (n=37)	Observing the landscape/looking out of the window (n=22)
	Monitoring the driving/watching vehicle or road (n=15)
	Communicate with other vehicles (n=0)
● Sleep and Relaxation (n=45)	Relax/rest (n=15)
	Sleep (n=25)
	Use a massage chair (n=1)
	Wellness/praying/meditating/worshiping (n=4)
● Food and Drink (n=32)	Eating & drinking (n=30)
	Prepare food or drink (n=2)
● Hobby and Leisure (n=11)	Smoking (n=5)
	Scratching (n=0)
	Knitting needles/sew (n=2)
	Play instrument (n=2)
	Artistic activities/painting (n=2)
● Music and singing (n=22)	Listen to music/radio/⋯ (n=19)
	Singing (n=3)
● Entertainment and Online Activities (n=99)	Emailing/surfing the Internet (n=13)
	Play games (video games/board games/⋯) (n=18)
	Take selfie (n=2)
	Social media (n=8)
	Watch video/movie/⋯ (n=24)
	Use smartphone (n=17)
	Laptop usage (n=10)
	Browsing the tablet (n=5)
	Trade stocks (n=0)
	Shopping (n=2)
● Interpersonal Communication and Interaction (n=60)	Texting (n=9)
	Video conference (n=6)
	Talking to passengers (n=21)
	Phone calls (n=17)
	Interaction with passengers/friends or family (n=7)
● Work and Productivity (n=71)	Work/office task (n=26)
	Study/learn/training (n=4)
	Planning/thinking/analyzing (n=7)
	Making a to-do list/writing (n=2)
	Organization/clean up (n=2)
	Reading (n=30)
● Childcare and Education (n=8)	Kindergarten (n=1)
	Taking care of children (n=2)
● Physical Fitness and Health (n=7)	Fitness/sports (n=5)
	Health (n=2)
● Personal Hygiene, Grooming, and Beauty (n=17)	Washing/cleaning/personal hygiene (n=6)
	Makeup/cosmetics/grooming (n=9)
	Changing clothes (n=1)
	Business (beauty salon) (n=1)
● Information Gathering and Consultation (n=2)	Product Information (n=1)
	Consultation (n=1)
● Vehicle Maintenance (n=1)	Maintenance activity (n=1)

Appendix F
Research on comfort and users view

Comfort
I reviewed the literature on comfort and discomfort models, as well as the book Vehicle seat comfort and Design, and obtained key findings to inform our design process. These insights relate to the joint position, range of motion, body contour, environmental or emotional factors, and sensitive areas that can affect the comfort of the vehicle interior.

Some important insights are listed below.
• Multi-sensory systems are preferred, as they allow users to focus on their main tasks without sensory interference.
• Different activities necessitate varying levels of comfort and support from chairs.
• Different body parts require materials with specific properties to maximize comfort.
• Comfort and discomfort scales can be employed to evaluate physical load.
• Pain can be triggered by various physical loads, such as heavy lifting, repetitive motion, awkward positions, and prolonged sitting.
• The absence of discomfort does not guarantee comfort; one must surpass expectations to feel truly comfortable.
• Maintaining a neutral joint position is preferred for optimal comfort.
• Comfortable reachability of objects within the range of motion is essential.
• Movement helps to prevent discomfort over time.
• Alternating postures and engaging in other activities during long-distance travel is beneficial for health.
• Increased comfort is achieved by better fitting the contours of the body.
• Comfort levels vary with different activities and contours.
• Discomfort is linked to physical environmental factors such as posture, stiffness, and fatigue, whereas comfort is associated with emotions and expectations such as luxury, safety, and refreshment.
• Sensitive areas, including the neck, lateral parts of the shoulder, and areas close to the knees, require special attention and reduced pressure for optimal comfort.

Users view
Autonomous vehicles (AVs) are revolutionizing the automotive industry, promising increased traffic efficiency and reduced accident rates (Bagloee et al., 2016). However, the adoption of AVs depends on consumers' perceptions and preferences. This part aims to provide an overview of the public's views on AVs, including concerns and preferences, and factors that influence these perceptions, and ultimately guiding the design and development of these vehicles to better cater to the needs of diverse consumer segments.

Still lack trust
Despite the potential benefits of AVs, many individuals are hesitant to relinquish control of their vehicles. For example, 62% do not want to hand over complete vehicle operation, and 64% prefer to be a supervisor rather than a passenger in autonomous driving (Cyganski et al., 2015). Furthermore, 41% would still watch the road even with an autonomous vehicle, and 22.4% would rather not drive a fully autonomous vehicle (Schoettle & Sivak, 2014). And there is generally more concern about fully autonomous driving than L3, which offers limited self-driving capabilities (Schoettle & Sivak, 2014). One reason for rejecting self-driving cars is a lack of trust (Zmud et al., 2016). Drivers may not feel fully at ease engaging in NDRAs due to a lack of confidence about the reliability of the system or curiosity to look at how the system behaves.

A good experience can accelerate acceptance
A good experience of using AV would accelerate acceptance and adoption of the tech and users may spend more time on NDRAs. Research suggests that comfort is a potential lever for adoption, with perceived enjoyment and perceived usefulness being strong predictors of intention to use self-driving cars (Delmas et al., 2022; Keszey, 2020). (Fraunhofer IAO et al., 2018) said that the more time spent in the car, the higher the level of acceptance of the concept. (Large et al., 2019) used a driving simulator to explore how drivers' behavior in an L3 autonomous car over a week and found that participants directed less and less visual attention to the road scene and more to their secondary activity as the week progresses. To enhance the experience users have in autonomous vehicles, there is a need to move away from a driver-centered design to a passenger-centered and service-oriented approach (Stevens et al., 2019). Besides this, car manufacturers (e.g., Tesla, Audi, Volvo) and technology companies (e.g., Google, Apple, and Microsoft) need to enhance synergy and focus on driver safety (Hussain & Zeadally, 2019).

Increase the Value of Time

Cyganski et al. (2015) argued that the subjective value of travel time depends on the activities performed during the journey. As the level of autonomous driving increases and users are freed from driving activities, they have more time for Non-Driving-Related activities, which means the value of travel time increases. Furthermore, increasing the value of commuting time could make it more acceptable for people to commute longer distances and live in rural areas (Cyganski et al., 2015).

Savvy Commuters

Savvy Commuters are a distinct group of individuals who are highly satisfied with their commute, value having better physical and mental space during their journey, and actively create positive conditions for their trips. They prefer engaging in a mix of activities during their commute, such as talking, watching video content, and working, and being able to switch between different things is part of the reason they are happy. Half of Savvy Commuters claim to regularly do 3 or more activities during their commute, while 70 percent of the unsatisfied group feel their choice is limited to 2 or fewer activities. Additionally, being in control of their arrival time is more important for them than minimizing travel time. More than 1 in 4 would be willing to add 20 or more minutes of commute to their weekdays if they could improve their experience (consumerlab, 2020).

User preference

Individuals most likely to adopt AVs tend to be young, male, technology adopters, and those who find manually driven highway journeys a waste of time (Wilson et al., 2022). After being informed of the estimated $3,000 market price for self-driving technology, positive responses dropped from 37% to 20% (Power, 2012). This highlights the importance of cost considerations in AV adoption. Besides this, The complexity of NDRAs depends on the level of automation, with suppliers needing to differentiate value-added services based on automation levels (Fraunhofer IAO & Horváth & Partners, 2016). And people prefer to use AVs on highways, scenic areas, less congested streets, and while parked (Bansal & Kockelman, 2018).

Privacy

Privacy, storage options, travel duration, and purpose may affect the attractiveness of certain NRDAs during autonomous driving (Hecht, Darlagiannis, et al., 2020). Activities with high privacy impact, such as making phone calls, voice messages, and sleeping, may be less desirable in shared AV environments. And on short trips, people tend to watch the surroundings and use smartphones, while on longer journeys, they prefer to relax, work, and sleep (Hecht, Darlagiannis, et al., 2020).

In conclusion, the development and adoption of autonomous vehicles depend on various factors, including safety, efficiency, user perceptions, design, trust, and acceptance. A gradual transition towards full autonomy, along with improvements in passenger experience and Non-Driving-Related activities, can help increase user trust and acceptance. Demographic factors, cost considerations, and privacy concerns also play a role in shaping the future of autonomous driving. As technology continues to evolve, understanding user needs and preferences is crucial for the successful integration of autonomous vehicles into society.

Appendix G
List of requirements

General Assignment Requirements:

R.1.1 The interior design is designed for highly automated or fully automated vehicles (specifically, Level 4 or Level 5 as per the SAE automation levels).
R.1.2 The interior is designed to be made for 2035.
R.1.3 The interior design must conform to the spatial dimensions of the Range Rover compact SUV, inclusive of 55.4 inches shoulder room, a 105.6 inches wheelbase (see Appendix B).
W.1.1 The interior design needs to trigger a discussion about user comfort and space usage in the automated vehicle interior design.

Preliminary Requirements for automated vehicle interior:

Space
R.2.1 The car interior should be able to accommodate four rotatable seats with specific dimensions (height 1064mm, width 450mm, see Chapter 3).
R.2.2 The car interior should accommodate the maximum, average, and minimum comfortable joint angles required for five essential activities, including looking out of the window, working, entertainment, sleeping, and talking with other passengers, for P50 users (see Chapter 3).

The definition of looking out of the window in this context is looking out of the window with seat backrest angle between 110 and 130 degrees and seat rotation angle between 0 and 45 degrees.

The definition of working in this context is typing on a computer with seat backrest angle between 90 and 145 degrees and requiring a desk height of 75 cm.

The definition of entertainment in this context is watching movies in an iPad with seatbackrest angle between 110 and 150 degrees and requiring a desk height of 75 cm.

The definition of sleeping in this context is a position of rest with a backrest angle that varies from 110 to 145 degrees.

The definition of talking with other passengers in this context is talking with other passengers with seat backrest angle between 110 and 130 degrees and seat rotation angle between 10 and 45 degrees.

R.2.3 The car interior should accommodate at least one comfortable joint angle required for five essential activities, including looking out of the window, working, entertainment, sleeping, and talking with other passengers, for P95 users (see Chapter 3 for comfort joint angles).
R.2.4 The car interior should enable passengers to rotate the seats smoothly within a range of 0 to 45 degrees without any obstructions or interference.
W.2.1 The car interior can support configurable layout changes from configuration B (traditional seat configuration) to configuration F (face-to-face configuration) (see Chapter 3).
W.2.2 The interior can at least incorporate one seat adjustable to a flat sleeping position, allowing a backrest angle of at least 145 degrees or even up to 180 degrees (see Chapter 3).
W.2.3 The interior can accommodate a table with a height adjustable between 70 and 100 cm for work and entertainment (see Chapter 3).

Seat (see Chapter 3)
R.3.1 The passenger seats should incorporate headrests with additional lateral support.
R.3.2 The passenger seats should feature foldable armrests.
R.3.3 The passenger seats should include adjustable leg supports.
R.3.4 The passenger seats should have a minimum rotational capability of 45 degrees relative to the center axis.
R.3.5 The passenger seats should provide adjustable lumbar support.
R.3.6 The passenger seats should be adjustable to at least 150 degrees of backrest angle.

Safety (Occupant Protection for Vehicles With Automated Driving Systems, (National Highway Traffic Safety Administration, 2022), see Appendix XX)
R.4.1 Each “outboard designated seating position,” including the driver's seat, to have a lap/shoulder (Type 2) seat belt assembly that conforms to FMVSS No. 209, Seat belt assemblies.
R.4.2 The design of front outboard seats, which do not include manually operated driving controls (including those seats that were previously considered as the driver's seat), must adhere to the advanced air bag requirements as specified under FMVSS No. 208.

Appendix H
Federal Register: Occupant Protection for Vehicles With Automated Driving Systems (original text)

FMVSS No. 208, Occupant Crash Protection

Making appropriate amendments to FMVSS No. 208, Occupant crash protection is one of the most important aspects of this rulemaking. Not only is Standard No. 208 a significant 200-Series standard, but it includes several terms that differentiate a “driver's” position from a front “passenger's” seating position. Thus, translating the terms of FMVSS No. 208 to account for vehicles that do not have manually operated steering controls, or vehicles where the manually operated steering controls could be stowed, is central to this final rule.

The NPRM discussed proposals for: **Applying FMVSS No. 208's advanced air bag requirements to front outboard seats without manually operated driving controls (including to seats that had been considered a driver's seat); applying the standard's telltale requirements; applying requirements for front outboard seats to seats that are no longer “outboard”; and suppressing vehicle motion when a child restraint system is sensed in a seating position with manually operated steering controls.** The NPRM also proposed amending FMVSS No. 208's bus requirements to account for buses equipped with ADS and that lack manually operated steering controls.

FMVSS No. 208 currently establishes crash protection requirements that are the same for the driver's designated seating position (DSP) as for the right front outboard seating position (commonly referred to as the front passenger seat). The vehicle's compliance with the requirements is assessed in a frontal crash test using adult-sized crash test dummies.

To minimize air bag risks to children and small-statured adults, however, FMVSS No. 208 also establishes “advanced air bag” requirements that, among other things, require the air bags at the right front DSP to either turn off automatically in the presence of detected young children, or deploy in a manner less likely to cause serious or fatal injury to child occupants. Manufacturers may also choose to combine these approaches. Vehicles that disable the passenger air bag utilize weight sensors and/or other means of detecting the presence of young children. To test detection capability, FMVSS No. 208 specifies that child dummies be placed in child restraint systems (child seats) that are, in turn, placed on the passenger seat. It also specifies “out-of-position” tests that are conducted with unrestrained child dummies sitting, kneeling, standing, or lying on the passenger seat. For manufacturers that design their passenger air bags to deploy in a low risk manner, the standard specifies that unbelted child dummies be placed against the instrument panel. The air bag is then deployed. The ability of driver air bags to deploy in a low risk manner is tested by placing the 5th percentile adult female dummy against the steering wheel and then deploying the air bag.

In the NPRM, NHTSA tentatively concluded that the most practical way to maintain occupant protection in ADS-equipped vehicles with no “manually operated driving controls” (and thus, with no driver's seat) would be to treat any seat that does not have immediate access to such controls as a passenger seat under the standard. Thus, all front outboard seats in such vehicles are front outboard passenger seats and would be required to meet FMVSS No. 208's performance requirements that currently apply to the right front outboard passenger seat. For a seat located in the left front outboard position, this would be done by mirroring the test procedures and requirements from the right side. Among other things, to maintain the level of safety currently afforded to right front outboard passengers under FMVSS No. 208, NHTSA proposed requiring that all front outboard “passenger seats” meet advanced air bag requirements.

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a. Advanced Air Bags

As discussed in the proposal, applying advanced air bag requirements to all front outboard seating positions maintains the current levels of safety for ADS-equipped vehicles without manually operated driving controls. Applying the requirements meets the need for safety because an occupant will receive the same crash protection whether they choose to sit in the left or right front outboard seat. In addition, an important benefit of advanced air bags over conventional air bags is the protection of out-of-position occupants, particularly children. In a traditional vehicle, the occupant in the driver's seat is typically an adult. In contrast, occupants of the left front outboard passenger seats in an ADS-equipped vehicle without manually operated driving controls could possibly be children, as there would be no driving control mechanism at any position that may deter occupancy of the seating position by a child. NHTSA tentatively concluded in the NPRM that the most straightforward way to protect children against air bag risks would be to require that any front outboard seat that could potentially be occupied by a child (i.e., a passenger seat) must meet the current advanced air bag requirements. This final rule adopts the provisions of the NPRM that relate to the protection of the left front seat occupant when that DSP meets this final rule's definition of a passenger seating position.

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c. Front Outboard Versus Center or Inboard Seating Position

An “outboard seating position” is defined in 49 CFR 571.3 as “a designated seating position where a longitudinal vertical plane tangent to the outboard side of the seat cushion is less than 12 inches from the innermost point on the inside surface of the vehicle at a height between the design H-point and the shoulder reference point (as shown in fig. 1 of Federal Motor Vehicle Safety Standard No. 210) and longitudinally between the front and rear edges of the seat cushion.” FMVSS No. 208 requires, for most light vehicles (GVWR less than 4,536 kg (10,000 lb.)), each “outboard designated seating position,” including the driver's seat, to have a lap/shoulder (Type 2) seat belt assembly that conforms to FMVSS No. 209, Seat belt assemblies. Moreover, the subset of light vehicles that have a GVWR of less than 3,855 kg (8,500 lb.) and unloaded weight of 2,495 kg (5,500 lb.) are statutorily required to have frontal air bag protection at the driver's and right front DSPs, which are evaluated by FMVSS No. 208's frontal barrier crash tests. Under FMVSS No. 208, any center seating positions in these light vehicles can be equipped with only a lap belt.

In the NPRM, NHTSA acknowledged that future vehicle designs might not have two front outboard seating positions. The agency sought to amend FMVSS No. 208 to be inclusive of and account for ADS-equipped vehicles (particularly those without driving controls) that might not have a front left outboard DSP or, for that matter, any outboard DSP, as those terms are defined in NHTSA's regulations. NHTSA envisioned that one or both of the outboard seating positions on a current vehicle could be moved toward the center of the vehicle and thus fall outside of the outboard seating position definition. NHTSA sought to amend FMVSS No. 208 to provide occupants of an ADS-equipped vehicle with fewer than two front outboard seating positions no degradation in the crash protection now required by the standard for vehicles that are not ADS vehicles. The agency requested comment on including in the final rule air bag (including out-of-position occupant protection) and lap/shoulder (Type 2) seat belt protection to these inboard seating positions if outboard positions were removed. We also requested comment on the implications of such designs upon the statutory obligation for frontal air bags.

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The final rule will implement the following (see Figure 30). First, FMVSS No. 208 currently protects two designated seating positions in the front row of seats with a “full” suite of occupant protection countermeasures: Type 2 (lap/shoulder belt system), and an advanced air bag system. Those protected seats are currently the outboard seating positions. To maintain FMVSS No. 208's protection of two seating positions in the front row—to the extent technically feasible—this final rule continues protecting two designated seating positions in the front row with the full suite of protective countermeasures (Type 2 belt and advanced air bag). Thus, where there is a single inboard seat and one or no outboard seats, the single inboard seat would be required to have lap/shoulder seat belts and advanced air bag protection in that single front row inboard seat, and any one remaining outboard seat will continue to offer the same protection as it does currently in vehicles with driving controls (the full suite of crash protection).

Second, NHTSA considered a front row with multiple inboard seats and one or no outboard seats. As discussed above, this final rule seeks to maintain protecting two designated seating positions in the front row with the full suite of protective countermeasures (Type 2 belt and advanced air bag). Thus, for this situation, the protection required by the vehicle depends on whether there is a remaining single outboard seat or not. If there is a remaining single outboard seat, that outboard DSP will be required to provide the full suite of protection (lap/shoulder seat belts and advanced air bag protection), and one of the inboard seats will be required to offer the same full suite. The manufacturer will have the discretion to determine which of the inboard seats will offer this protection. The other inboard seat (if any) would only require a lap belt (a lap/shoulder belt may be provided at the manufacturers' choice), as this is the requirement now specified for an inboard first row seat under FMVSS No. 208. Thus, the protection offered by this configuration is essentially the same as vehicles with driving controls and three front seats (i.e., two DSPs with full suite of protection and one with lap belt protection).

In the second case, it is possible there is no outboard seat, but multiple inboard seats. For this situation, only a single inboard seat will be required to provide the full suite of protection (lap/shoulder seat belts and advanced air bag protection). The other inboard seat will only be required to offer a lap/shoulder belt. While the agency would like to require the full suite of protections for two DSPs in accordance with our principles above, we are not requiring a full suite of protection for the second DSP because of potential safety risks posed by air bags operating in close proximity to each other (e.g., interaction between the two air bags or between occupants in close proximity when reacting to the air bags), as in the case of two inboard side-by-side seats......

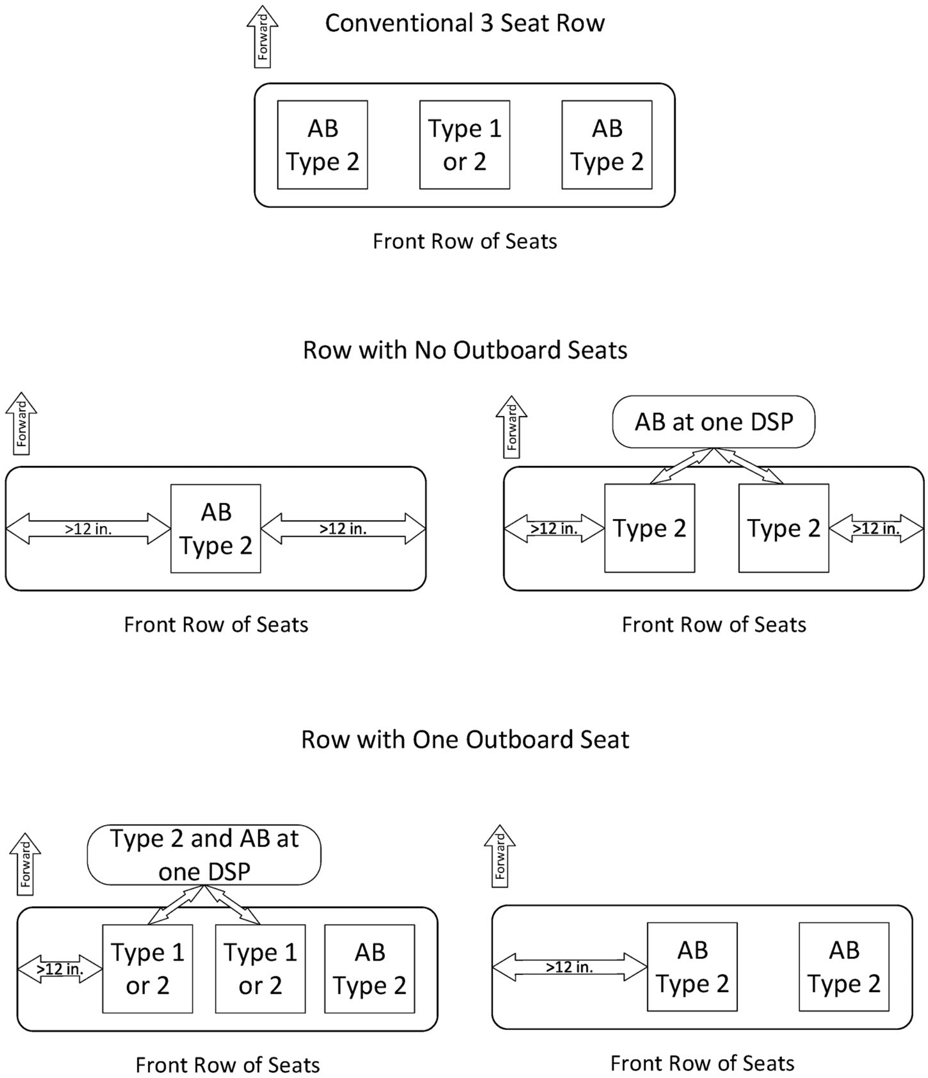

Figure 30. Schematic of air bag (AB) and seat belt protection for vehicles without driving controls and fewer than 2 outboard DSPs

Additions 1: Federal Motor Vehicle Safety Standards, Occupant Crash Protection (FMVSS No. 208)

The advanced air bag requirements as specified under Federal Motor Vehicle Safety Standards (FMVSS) No. 208, Occupant Crash Protection, were designed to optimize the benefits of air bags while minimizing the risks. The main components of the advanced air bag requirements are as follows:

• Low Risk Deployment for Children and Small Adults: This requires that airbags deploy in a manner that is less likely to cause serious or fatal injury to out-of-position small adults and young children. This is evaluated by testing with different sized dummies placed in various positions.

• Automatic Suppression: If a child is detected on the passenger seat, especially a child in a rear-facing child seat, the airbag must automatically turn off.

• Multistage Inflation: Advanced airbags can adapt the deployment force to the severity of the crash, the size and position of the passenger, and whether the seat belts are in use. This helps in providing the necessary protection while reducing the potential for harm to less robust passengers.

• Occupant Sensing: Advanced airbags have sophisticated sensing systems that can identify the size, weight, and position of the occupant, and whether a seat belt is being used. The airbag system uses this information to decide whether, when, and how forcefully to deploy the airbag.

• Out-of-Position Occupant Consideration: Advanced airbags are designed to minimize the risk of injury to occupants who are positioned too close to the airbag at the time of deployment.

• Improved Crash Sensors: Advanced airbags use enhanced crash sensor technology to more accurately detect crashes, including minor crashes where airbag deployment might not be beneficial.

Additions 2: Federal Motor Vehicle Safety Standards; Seat Belt Assemblies (FMVSS No. 209)

The standard encompasses detailed specifications and requirements for all aspects of seat belt design, construction, and performance, which aim to ensure that seat belts provide reliable and efficient occupant restraint in the event of a vehicle crash. The key requirements of FMVSS No. 209 include:

• Webbing: The webbing of the belt should not be easily torn or ripped. It must also maintain its structural integrity under high temperatures and sunlight exposure.

• Hardware: All hardware parts, such as buckles and adjusters, must be durable and operate as intended without malfunctioning.

• Strength: The assembly must be able to withstand specific loads for a given period of time without breaking.

• Performance: The assembly must lock during sudden deceleration or acceleration (as in a crash).

• Labeling: Each belt assembly or retractor must be permanently and legibly labeled with specific information, such as the assembly type, date of manufacture, model, etc.

• Types of Assemblies: FMVSS No. 209 also defines different types of seat belt assemblies - **Type 1 (a lap belt for pelvic restraint), Type 2 (a combination of pelvic and upper torso restraints), and Type 2a (a Type 2 seat belt assembly adjusted by the user, where the upper torso restraint can be detached at one end).**