FRAMING THE OPPORTUNITIES OF ROBOTICS IN MEANINGFUL AUTONOMOUS VEHICLE EXPERIENCES

An exploration of fundamental needs,
AI-systems, and user interfaces

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MASTER THESIS

Framing the opportunities of robotics in meaningful autonomous vehicle experiences

An exploration of fundamental needs, AI-systems and user interfaces

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PREFACE

This graduation thesis is the end project of a fascinating two-year journey in the MSc Strategic Product Design program. I cannot be more grateful for the opportunity I had in going through these studies and learning from very enriching experiences, both from a professional and personal perspective. In these two years, I understood that design is a fundamental element in innovation and strategic challenges, not only because of its unique human-centric approach, but also due to the capability it has to propose new meanings that create value and transform how products, services, and systems are created and experienced. From now on, I would like to continue to progress in this direction.

ACKNOWLEDGEMENTS.

I would like to extend my gratitude to my supervisory team, who have guided me closely and with dedication in all the stages of this project. Thanks, prof. Euiyoung Kim and Willem van der Maden, I am looking forward to continuing to collaborate with you.

I am also grateful for the participants who have contributed to this research; it is thanks to your input that I can present my results in this report. To the end users that participated in the workshops, thank you for your time and enthusiasm. To the experts that were engaged in the validation sessions, thank you for sharing your valuable insights with me, that really brought in complementary perspectives and helped me give shape to the conclusions of the research.

Finally, to the readers, might you have any comments, questions, or discussions, I will be happy to share a talk on the topic of user experience design and future autonomous contexts. Enjoy the reading!

Etxekoei, bihotzez.

EXECUTIVE SUMMARY

Vehicle automation will increasingly release car drivers from driving tasks, allowing them to engage in previously inconceivable activities. Experiential components are therefore expected to become central in human automotive mobility. In this context, the design of future in-vehicle experiences is a research gap to still discover, that concerns both academia and industry alike.

This graduation project explored the opportunities of using robotics and AI technology for the provision of meaningful autonomous in-vehicle experiences. In that aim, different user interfaces (UIs) were analyzed, as a way to visualize and study different user-technology interactions. The outcomes of the research comprise recommendations about promising scenarios that could be included in autonomous vehicles as well as insights into how different UIs shape user experiences differently.

The project first reviewed prior academic work on the topics of fundamental needs (from positive design), vehicle automation, user experience design, robotics, AI, and user interfaces. A research approach was proposed based on that analysis; because robotics and AI present ample capabilities, in-vehicle scenarios should be designed first, to later define (through UIs) the role that technology should have in those scenarios. These are the research questions that were proposed:

1. What in-vehicle scenarios can be designed to support fundamental needs?
    - How do different user interfaces enable those use cases?
    - How do different types of user interfaces affect the in-vehicle user experiences?
2. What are the most promising scenario and user interface combinations?

To answer those questions, a co-creative workshop was designed, with the aim of collecting user needs and perceptions as data. The participants were asked to envision future needs in AVs, based on the typology of 13 fundamental needs, as well as to design meaningful scenarios that would fulfill them. Through a questionnaire, they voted for the most promising scenarios (i.e., most attractive and most innovative scenarios). The workshop was conducted three times and a total of 18 participants were recruited.

The preliminary results from the workshop were 13 meaningful scenarios, each of them aimed at fulfilling one fundamental need; additionally, those scenarios were adapted to ambient, graphical, and tangible UIs. Besides, promising UI and scenario combinations were identified, according to the participant's perspective. Finally, insights were clustered on how different UIs shape the in-vehicle user experience. Those outcomes were contrasted and enriched in validation sessions, where a total of six field experts contributed. The experts brought in insights from the HCI, future mobility, and positive design fields.

This research aims to contribute to both industrial and academic practices. First, fundamental needs and sub-needs have been explored in the context of autonomous vehicles. Second, design directions and examples are offered for the development of meaningful in-vehicle experiences. Additionally, conclusions on how users perceive tangible, graphical, and ambient UIs are given, which could be used as guidelines for designing interactions. Finally, insights are offered about how end-users perceived innovations, as well as how innovative and attractive solutions are differently framed.

Finally, additional research paths were revealed through the study, that future research may consider. For instance, activity-based fundamental need hierarchies could vary across different demographic groups. Apart from that, further work could be done in the classification of the UIs, as well as in mapping out the interactions that they enabled. Finally, in-vehicle scenarios could be related to the concept of 'innovation adoption' to study what solutions to develop further in the coming years.

CONTENT

ABBREVIATIONS

ADS, Automated Driving System

AI, Artificial Intelligence

AV, Autonomous Vehicle

DDT, Dynamic Driving Task

FAV, Fully Autonomous Vehicle

HCD, Human-Centered Design

HCI, Human-Computer Interaction

HRI, Human-Robot Interaction

LORA, Levels of Robot Autonomy

NDRA, non-driving-related activity (from 617)

SAE, International Society of Automotive Engineers

UI, User Interface

Chapter 1 -

INTRODUCTION

In this introductory chapter, the 'raison d'être' of the project and its main stages will be presented. This includes the background context of the research, the research gaps that were initially found, the project assignment, and the approach taken, with an overview of the methods that have been used in every stage. Finally, an overview of the main contributions will be given, in an attempt to clarify how the initial goals were addressed.

1.1 CONTEXT

The spread of autonomous vehicles (AVs) (Figures 1, 2, 3), whose technology is becoming more accessible and ordinary [Trubia et al., 2020], opens new paradigms and opportunities to the mobility industry. [Khayyam et al., 2020] mention the "releasing of driver time and business opportunities" and "new potential market opportunities" among the benefits that AVs bring. In that respect, it is envisioned that primary driving tasks "will become obsolete" as automation levels increase in automated driving [Pfleging and Schmidt, 2015, Krome et al., 2015]. As claimed by [Tang et al., 2020] "Automation will release drivers from the task of driving and allow them to undertake new activities that would not be possible in vehicles controlled manually" (p. 1), resulting in the "transformation of human mobility into a purely experiential phenomenon" [Floridi, 2019] (p. 571).

In this context, three main elements emerge that are relevant for the current research. First, meaningful experiences gain a central role in future mobility [Riener et al., 2022], and thus, finding the potentials for a "great user experience" (p. 215) and understanding the underlying human needs is necessary. Following that aim, this project will take "the typology of thirteen fundamental needs" [Desmet and Fokkinga, 2020b] as a base framework. Second, the latest research directions in the field of robotics show a shift in application areas, from industrial environments to social contexts, where robots would be designed to assist and give service to humans [Garcia et al., 2007]. Exploring how robotics technology could be used to enhance future experiences in autonomous vehicles will be our aim throughout this project. Third, user interfaces will be regarded closely, as they are the elements users interact with, and thus shape how users experience the technologies and also how those ultimately fulfill their needs.

Figure 1. Zoox autonomous vehicle concept. [Zoox, nd]

Figure 2. Zoox autonomous vehicle concept. [Zoox, nd]

Figure 3. Experiential components are central in future mobility. [Zoox, nd]

1.2 RESEARCH GAP & ASSIGNMENT

To date, research around the user experience in autonomous vehicles has mainly focused on improving the driving task performance and reducing safety concerns [Meschtscherjakov et al., 2015], such as the system take-over in the third automation level [Kim et al., 2015]. Driver trust and information support systems [Riener et al., 2022] have also been widely analyzed.

Many authors claim the need for understanding the factors that influence user experience in autonomous vehicles [Alpers et al., 2020], seek to elicit user needs and design requirements [Lee et al., 2022], and highlight that automobile manufacturers could offer "new technologies for functions that go beyond traditional needs" (e.g. journey and performance-related needs, Figure 4) [Filev et al., 2013]. Nevertheless, even if the relevance of the topic seems to be widely claimed, it is still understudied in the literature.

The ultimate goal of this research is to give recommendations on how to provide meaningful autonomous experiences for future drivers and passengers, and to explore how could this be done by implementing technologies from the fields of robotics and artificial intelligence.

Therefore, the following preliminary research questions and sub-questions are proposed as a starting point for the research:

- RQ: What are the most relevant fundamental needs and sub-needs for the future user experience in autonomous vehicles?
- SQ1: What opportunities do robotics present for fulfilling those needs?
- SQ2: Based on that, what functionalities can be implemented in autonomous vehicles to enhance the future user experience?

Note that this research project is part of a larger research and development initiative that TU Delft is working on together with an automotive manufacturer (anonymous) on the concept of in-vehicle sub-robots. The current research aims to set a common ground for the later concept development stages; the most relevant theoretical concepts and technological developments will be mapped first, to later propose, based on empirical arguments, what design directions could be taken to provide users with meaningful user experiences.

The ultimate goal of this research is to give recommendations on how to provide meaningful autonomous experiences.

We will explore how could this be done with technologies from the fields of robotics and AI.

^
Figure 4. Passenger relaxing in a car. [Pexelx, nd]

1.3 APPROACH

The approach followed in this project mixes traits from design research [Cash, 2018] and scientific research, meaning that methods from qualitative scientific research have been used to gather data, analyze it and generate knowledge on design-related topics. Therefore, the method is both scientifically coherent and instrumental for design engineering (by "generating knowledge about design and for design", as [Blessing, 2003] claim).

The following timeline shows the main stages that were followed in the research, as well as the rational and methods that were used in each of them.

- **Literature review (Chapter 2):** an extensive analysis of the literature was carried out in order to compile the emerging user needs in autonomous vehicles and to identify theoretical frameworks that would allow us to ground those needs. The opportunities and trends in the fields of automation, AI and robotics were also analyzed from a technical perspective.

- **Redefine research approach (Chapter 3):** the literature review showed that the opportunities of AI systems and robotics were very broad to serve as a research boundary; the research focus was narrowed down by taking future in-vehicle scenarios and user interfaces as a constraint.

- **Co-creative workshops with end-users (Chapter 4):** participatory design sessions were carried out with end users, where they were involved in scenario design tasks. Discussions about user interfaces were favoured as part of the data collection for the research.

- **Analysis of the preliminary results:** the outcomes of the workshops were analyzed, and questions emerged about the various results that the participants proposed, which served as an input for the expert validation sessions.

- **Validation sessions with experts (Chapter 4):** experts in the various fields that are related to this research were recruited to participate in one-to-one interviews. The experts were asked to react to various aspects of the preliminary results.

- **Analysis of the validation sessions:** the data that was generated in the expert interviews (in the form of audio recordings) was analyzed by the main researcher and used to iterate on the preliminary results.

- **Final results (Chapter 5):** final results include the comments of the experts on the preliminary outcomes.
- **Discussion (Chapter 6):** the rational behind the results that were obtained is discussed, including arguments from the literature and the comments from the experts. A reflection on the research limitations, contributions and themes for future research is included.
- **Project reflection (Chapters 7):** the project is concluded with a summary.

1.4 MAIN CONTRIBUTIONS

The outcomes of this study may contribute to both academic and industrial practice in the field of autonomous vehicles, on the topic of in-vehicle experience design. Answering the initial goal of the research, the report explores how meaningful experiences can be provided for future passengers, who will no longer need to be fully engaged in driving-related tasks. AI-systems, robotics, and different types of user interfaces were analyzed as possible technological and interaction elements for the provision of those experiences.

The results from the workshops, which were later validated by field experts, comprise both examples of meaningful in-vehicle scenarios and adaptations of those scenarios to different user interfaces. The most promising scenario and UI combinations were identified, and conclusions were made on how different UI manifestations affect in-vehicle experiences.

In short, practitioners in the automotive and experience design fields may find these outcomes useful in two ways. First, design directions are suggested for future in-vehicle experiences. Examples of meaningful scenarios are given, as well as a context-dependent hierarchy of fundamental needs. Future practice could aim to fulfill a selection of those prominent fundamental needs. Apart from that, conclusions on how users perceive tangible, graphical, and ambient UIs are given, which could be used as guidelines when designing interactions. Second, practitioners might also reflect on their own design process, mainly on designing for meaningfulness. The design rationale followed in this work could also be replicated (i.e., starting from designing scenarios, think what user interfaces should be used to convey those, to later considering how different technologies should be used as an enabler).

Regarding theory, many authors claim the need for understanding the factors that influence user experience in autonomous vehicles and this work further contributes in that direction. Fundamental needs and sub-needs have been explored in the context of autonomous vehicles. Additionally, the concept of interface is analyzed, as well as the implications it has in user roles and interface roles in in-vehicle experiences. Apart from that, insights are offered about how end-users perceive innovations, as well as how innovative and attractive solutions are differently perceived.

Chapter 2

LITERATURE REVIEW

Almost before we knew it, we had left the ground. A peep at some distant orb has power to raise and purify our thoughts like a strain of sacred music, or a noble picture, or a passage from the grander poets. It always does one good.

2.1 INTRODUCTION

This section discusses the state-of-the-art literature in the following academic fields: user needs in autonomous vehicles, future implications of the levels of automation, meaningful user experiences, capabilities of AI and robotics, and the concept of user interface. The procedure followed for the literature analysis was inspired by the rationale by [Kim et al., 2018], that state that, to address the current VUCA challenges (short for volatility, uncertainty, complexity, and ambiguity [Bennett and Lemoine, 2014]) and rapid technological advances, innovation processes should be anchored both in a deep understanding of user needs and the development of a clear user experience vision.

Based on the steps of the design road-mapping process that they propose, user experience in autonomous vehicles has been explored first in this study; the implications of the gradually evolving automation levels, emerging user needs, and factors for a meaningful user experience have been identified. Second, the technological boundaries and core features of AI-systems and robotics have been studied, in an attempt to envision what capabilities could serve the identified needs. Finally, the concept of interface has been introduced, as it is a crucial element in the interplay between user needs and technological capabilities.

2.2 USER EXPERIENCE IN AVs

With the increase in driving automation levels, drivers will be allowed to spend their time in new, non-driving-related activities, that will bring new user needs into play. The opportunity to design those non-driving related experiences is addressed in the following section from the point of view of meaningful user experience design.

EVOLUTION OF IN-VEHICLE TASKS

The dynamic driving task (DDT) concept refers to "all of the real-time operational and tactical functions required to operate a vehicle in on-road traffic, excluding the strategic functions such as trip scheduling and selection of destinations" [SAE, 2021], (p. 9). Automated vehicles are those in which part of the dynamic driving task occurs without direct driver input [NHTSA, nd]. Therefore, driver-car interactions within autonomous vehicles are directly related to the level of autonomy in which the vehicle operates [Rödel et al., 2014, Meschtscherjakov et al., 2015, Tang et al., 2020].

Levels of automation. Different classifications can be found in the literature to describe the autonomy level of on-road motor vehicles, being the "SAE Levels of Driving Automation", defined by the International Society of Automotive Engineers (SAE), the most extended one [Coppola and Silvestri, 2019]. According to that taxonomy, there are six (discrete and mutually exclusive) levels of automation if the role division and the expected performance of both the human driver and the system are taken into account ("who does what and when" approach) [Coppola and Silvestri, 2019]. The levels are explained below (in Table 1), as well as in Figure 5, as defined in the "Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles" [SAE, 2021], (p. 30-32). Note that an additional column has been included in Table 1, where the definitions from [Coppola and Silvestri, 2019] have been included; these last are more colloquial as they use everyday language.

ODD: Operational Design Domain
Operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics. [SAE, 2021]

ADS: Automated Driving System
The hardware and software that are collectively capable of performing the entire DDT on a sustained basis, regardless of whether it is limited to a specific operational design domain (ODD); this term is used specifically to describe a Level 3, 4, or 5 driving automation system. [SAE, 2021]

OEDR: Object and Event Detection and Response
The subtasks of the DDT that include monitoring the driving environment (detecting, recognizing, and classifying objects and events and preparing to respond as needed) and executing an appropriate response to such objects and events (i.e., as needed to complete the DDT and/or DDT fallback). [SAE, 2021]

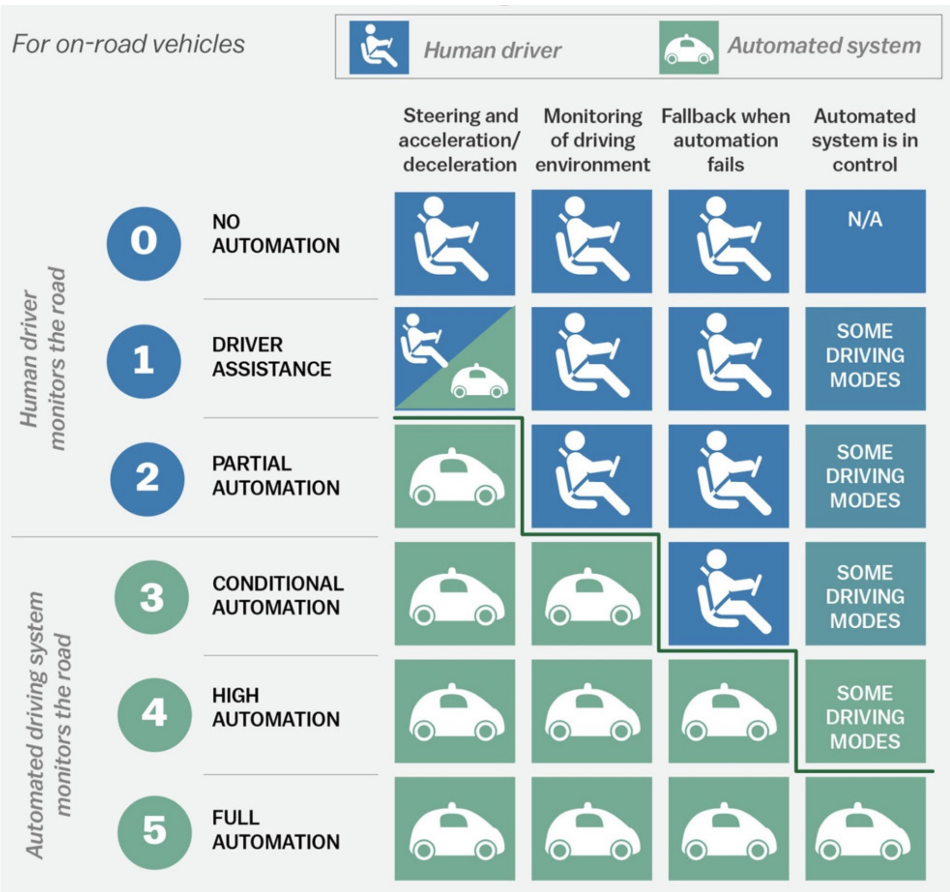
SAE LEVEL OF DRIVING AUTOMATION	[SAE, 2021]	[Coppola and Silvestri, 2019]
Level 0 – No Driving Automation	The performance by the driver of the entire DDT, even when enhanced by active safety systems.	The driver performs all driving tasks.
Level 1 – Driver Assistance	The sustained and ODD-specific execution by a driving automation system of either the lateral or the longitudinal vehicle motion control subtask of the DDT (but not both simultaneously) with the expectation that the driver performs the remainder of the DDT.	Vehicle is guided by driver, but some driving-assist features may be included in the vehicle.
Level 2 – Partial Driving Automation	The sustained and ODD-specific execution by a driving automation system of both the lateral and longitudinal vehicle motion control subtasks of the DDT with the expectation that the driver completes the OEDR subtask and supervises the driving automation system.	Vehicle has combined automated functions, like acceleration and steering, but the driver must maintain control of all driving tasks and monitor the environment at all times.
Level 3 – Conditional Driving Automation	The sustained and ODD-specific performance by an ADS of the entire DDT under routine/normal operation with the expectation that the DDT fallback-ready user is receptive to ADS-issued requests to intervene, as well as to DDT performance-relevant system failures in other vehicle systems, and will respond appropriately.	Vehicle can run autonomously, but the driver must be ready to take control of the vehicle at all times with notice.
Level 4 – High Driving Automation	The sustained and ODD-specific performance by an ADS of the entire DDT and DDT fallback.	Vehicle is capable of performing all driving functions under certain conditions, but the driver has the option to take control of vehicle.
Level 5 – Full Driving Automation	The sustained and unconditional (i.e., not ODD-specific) performance by an ADS of the entire DDT and DDT fallback.	Vehicle is capable of performing all driving functions under all conditions, but the driver may have the option to control the vehicle.

Table 1. Definitions of SAE Levels of automation according to SAE and Coppola and Silvestri (2019)

The automation level of a vehicle is determined by the driving automation features that are engaged in a given instance of on-road operation, meaning that, for the same vehicle, its driving automation system could deliver automation features that belong to different levels in different moments of a journey [SAE, 2021].

Four main elements define the boundaries between the SAE levels of driving automation: the execution of the steering and acceleration and deceleration functions, the monitoring of the driving environment, the fallback performance of the dynamic driving task, and the system's capability in relation to the driving modes [Coppola and Silvestri, 2019]. The lower two levels (levels 1 and 2) are labeled as ”driver support” modes, as the human driver still performs part of the DDT. The upper three levels of driving automation (levels 3 to 5) comprise cases in which the entire DDT is performed by the automated driving system and thus are referred to as ”automated driving” features [SAE, 2021]. The third automation level is special, as it entails complex interactions between the system and the human driver [Tang et al., 2020]. Drivers are not expected to monitor the system, but they need to take control of the vehicle in fallback situations, in conditions not supported by the system.

The ongoing automation of safety-critical driving functions will gradually relieve the driver from cognitive load [SAE, 2021] and will open a new paradigm in in-vehicle tasks (for instance, by allowing drivers to perform activities that they currently cannot be involved in or by allowing non-driving passengers to travel on their own).



<Figure 5. SAE Levels of Automation illustrated [SAE, 2021]

Terminology for driving tasks. In the past, in the context of non-automated cars, the concept of "driving task" was used as a reference to all tasks and activities a driver could perform [Pfleging and Schmidt, 2015], which were classified as "primary driving tasks" (needed for vehicle maneuver), "secondary driving tasks" (intended at increasing driving performance or safety, e.g. activating wipers) and "tertiary driving tasks" (used to describe all other tasks; for instance, operating the heating system).

Nevertheless, as the automation level increases in automated driving, primary driving tasks "will become obsolete" according to the same authors, and the relevance of the former tertiary task category will increase. Therefore, a new classification is proposed, by dividing "driving-related activities" and "non-driving-related activities" [Pfleging and Schmidt, 2015]. Driving-related activities include all activities necessary to control the vehicle safely and to enhance driving performance or safety. In contrast, non-driving-related activities will describe activities that are not related to driving, such as communicating with other passengers, eating or drinking, as well as new activities that will become possible in the autonomous vehicle experience. This proposed terminology update is visualized in Table 2.

Driving tasks in manual cars	Updated terminology
primary driving task	driving-related activities
secondary driving task	
tertiary driving task	non-driving-relaed activities

Table 2. Terminology update regarding driving taks.

SETTING THE SCOPE IN NON-DRIVING-RELATED ACTIVITIES

To date, research around the user experience in autonomous vehicles has mainly focused on improving the driving task performance and reducing safety concerns [Meschtscherjakov et al., 2015]; thus, driving-related activities in the automation context have been widely analyzed, as well as the interactions between the human driver and the automated driving system. For instance, the system take-over in the third automation level [Wright et al., 2017, Large et al., 2019, Yang et al., 2020] and driver trust and information support systems [Azevedo-Sa et al., 2021, Helldin et al., 2013] are some often addressed challenges.

Scope. In contrast to those more established study fields, there is an emerging trend in research that analyses the new role of autonomous vehicles by focusing on the non-driving-related activities that passengers and drivers will carry [Kim et al., 2015, Pfleging and Schmidt, 2015]. It is envisioned that ”automation will release drivers from the task of driving and allow them to undertake new activities that would not be possible in vehicles controlled manually” [Tang et al., 2020], (p. 1), resulting in a “transformation of human mobility into a purely experiential phenomenon”, as claimed by [Floridi, 2019] (p. 571). The scope of this research will be set in the non-driving tasks, as our ultimate goal is to give recommendations on how to provide meaningful autonomous experiences for future drivers and passengers, where the shift from a ‘joy of driving’ to a ‘joy while driving’ (i.e. joy while being driven) [Meschtscherjakov et al., 2015] is envisaged as a major challenge.

As far as automation levels are concerned, the focus on non-driving activities limits the scope of the research to the third to fifth SAE levels of automation, as drivers will only have room for non-driving activities in instances when the entire DDT is performed by the automated driving system. [Meschtscherjakov et al., 2015] claim that ”higher levels provide the potential for new immersive interactions and advanced services”.

An additional constraint of level 3 of driving automation is that drivers need to be ready to take control of the vehicle at all times, and, as such, certain activities may be limited (e.g., playing games) or even not be feasible (e.g., sleeping) to favor smooth and safe control transitions, as they could reduce the drivers’ situational awareness [Yang et al., 2020]. Nevertheless, this inherent constraint to the SAE level 3 will initially not be taken into account in the current research and will be relegated to a later implementation stage. The aim here is to explore the field for the first time, and thus these constraints might be too detailed for that initial goal.

USER NEEDS IN AUTONOMOUS VEHICLES

As a consequence of this task evolution, autonomous vehicles are expected to completely change user behavior [Kim et al., 2015] and experience [Lee et al., 2022]. The “releasing of driver time and business opportunities” is mentioned by [Khayyam et al., 2020] among the benefits of autonomous vehicles, as drivers will now be free to spend their travel time in non-driving-related activities [Lee et al., 2022, Giraldi, 2020]. Therefore, the focus moves towards creating and radically re-thinking experiences that are facilitated by vehicle interiors [Meschtscherjakov et al., 2015], being the relevance of exterior design and horsepower secondary [Riener et al., 2022]. [Filev et al., 2013], for instance, highlight that automobile manufacturers could offer "new technologies for functions that go beyond traditional needs." (p. 1)

Relevance. Identifying the user needs and related in-vehicle use cases that will emerge in the future autonomous experience is essential if new solutions are to be designed. Human-centered design (also referred to as "user-centered design") is "a creative approach to problem-solving" [Ong et al., 2019] (p. 374) that begins with the understanding of users and employs the insights gathered as relevant guidance in every stage of the design process [Tang et al., 2020, Giacomin, 2014a]. This approach ensures that the final solution is not only feasible but also coherent with what different user profiles value and tacitly necessitate in a certain context. This is also recognized in the prior work, as many authors claim the need for understanding the factors that influence user experience in autonomous vehicles [Alpers et al., 2020], seek to elicit user needs and design requirements [Tang et al., 2020, Lee et al., 2022] or state that "vehicle development requires human centered-approaches" [Riener et al., 2022].

Prior work regarding user needs in AVs. Those inquiries (i.e., understanding the user needs, design requirements, and relevant factors in the context of AVs) have been addressed by various authors. Some of them identify, describe and categorize the future activities that users would want to do in autonomous vehicles, for different automation levels. For instance, [Kim et al., 2015] and [Tang et al., 2020] analyzed detailed non-driving-related activities for level 3 of automation; the former had the goal to explore novel functionalities of a full-windshield display concept, while the latter was concerned with the required information and functions to support in-vehicle activities. [Lee et al., 2022] and [Pfleging et al., 2016] also compile non-driving-related activities in AVs, but this time with a focus on fully autonomous vehicles (FAVs, SAE level 5 of automation).

Some studies were also concerned with the needs of future users [Lee et al., 2022] or with potentially unmet needs [Sivak and Schoettle, 2016]. [Lee et al., 2022] found 12 user needs that will emerge in FAVs, and created a design taxonomy accordingly, whereas [Sivak and Schoettle, 2016] focus on three envisioned obstacles that should be overcome so that passengers can enjoy increased productivity in self-driving vehicles, and thus can also be categorized as user needs. [Kim et al., 2020] also identified user needs, but in this case, the context was an autonomous taxi service design.

Finally, research has also been carried out around the user experience and acceptance factors within autonomous vehicles, where [Rödel et al., 2014] analyzed how those factors vary with regard to the level of system autonomy.

We have compiled the findings from that previous work in Table 3, in an attempt to have an initial overview of the user needs that will emerge in the future autonomous experience, concerning non-driving tasks. Every need, activity, or requirement has been clustered according to the fundamental need that it would primarily address, following the "Typology of Thirteen Fundamental Needs" introduced by [Desmet and Fokkinga, 2020a] (note that fundamental needs will be covered in the next subsection, as well as the insights that we derive from the table).

Limitations of prior work. The studies that have been analyzed and used as a theoretical ground for the current research have two limitations that could be discussed further. First, regarding how user needs were obtained, many of the authors mention that the field of autonomous vehicles entails an added research difficulty, as users are required to shift their focus to picture currently unavailable technology [Kim et al., 2015, Tang et al., 2020] when using user-centered design methods. Methods were selected accordingly to bridge the identified challenge. For instance, [Kim et al., 2015] used four convergent participatory design sessions with users, [Kim et al., 2020] created a prototype through the wizard of oz method (i.e., a method where researchers act as puppeteers of a prototype, which allows participants to try future interactions of yet non-existing products [Riek, 2012]), and [Tang et al., 2020] applied a combined method of simulator study and user enactment. The approach by [Lee et al., 2022] might seem the most suitable one for "going beyond a faster horse," as user insights are complemented with input from experts, which have a more elaborate vision of the technology that is being proposed.

Second, user needs are not completely independent from the social context where they are unfolded and evolve together with socioeconomic changes. For example, ”working while commuting” is a recurrently identified in-vehicle activity for autonomous vehicles. But, what if the future of work is mostly remote and offices no longer have on-site work spaces by the time autonomous vehicles reach the upper automation levels? Then, the user need would no longer be valid in that future context. Although the proposed example is an overly exaggerated one, as a recommendation for future work, research might first look at the potential future socioeconomic contexts, to later identify user needs that are coherent with those envisioned scenarios.

MEANINGFUL USER EXPERIENCE

The ultimate goal of this study is to analyze how meaningful user experiences can be provided for future drivers and passengers within autonomous vehicles. As claimed by [Riener et al., 2022], “fascinating positive experiences will be the core of future premium mobility (p. 209),” and thus, to find the potentials for a “great user experience (p. 215),” understanding the underlying human needs is necessary.

Related to that, [Geiser and Kim, 2021] claim that ”events and activities that help fulfill our fundamental needs are meaningful to us (p. 1);” fundamental needs are framed by the typology of thirteen fundamental needs, which is therefore taken as the theoretical base of this study. Note that [Human and Watkins, 2022] highlight that there is still little agreement in the literature about a common definition for the “needs” concept; choosing the framework by [Desmet and Fokkinga, 2020a] for the current study will be of help to align all understandings.

The typology of thirteen fundamental needs is a ”design-focused typology of psychological human needs” [Desmet and Fokkinga, 2020a], meaning that it was conceived as a practical resource for informing human-centered design and research. The typology distinguishes 13 fundamental needs and includes 4 sub-needs per fundamental need (i.e. 52 sub-needs in total).

Five criteria are used by [Desmet and Fokkinga, 2020a] to define a fundamental need; as such, a need is fundamental when all the following are met:

1. ”it is universal” (p.8), in other words, equal for all humans, no matter their culture or demographics;
2. it is not originated in another need;
3. it directly contributes to our wellbeing (both psychological and physical), while not satisfying it leads to pathology;
4. it is not linked to a specific situation or circumstance;
5. it ”affects a wide and diverse assortment of behaviors” (p.8).

In contrast to Maslow’s Hierarchy of Needs [Maslow, 1943], all thirteen fundamental needs are categorized as equally important, as neglecting any of them would entail considerable negative consequences [Desmet and Fokkinga, 2020b]. See the 13 fundamental needs and their definitions in Table 3, as defined by [Desmet and Fokkinga, 2020a].

Sub-needs. Regarding sub-needs, they are particular manifestations of the fundamental needs, that is, goals and desires that emerge in concrete contexts or from specific individuals [Geiser and Kim, 2021, Desmet and Fokkinga, 2020a]. As [Geiser and Kim, 2021] explain, in our daily life ”we operationalize the fundamental needs (...) in a multitude of sub-needs” (p. 1). As an example, the fundamental need for ”recognition” could be fulfilled as ”popularity” in the context of social media, while it could be described by the sub-need ”appreciation” if we are talking about a family environment. The sub-needs fail to meet the first and second criteria that were mentioned previously in this section as necessary characteristics of a fundamental need. Namely, they are not universal (criteria 1) and they could be derived from another need (criteria 2) [Desmet and Fokkinga, 2020a].

As its authors state, the typology of thirteen fundamental needs ”can function as an inclusive framework to cluster and make sense of the hundreds of context-specific needs captured in a study” [Desmet and Fokkinga, 2020a] (p. 17). This is relevant for the current project, as it can serve as a guideline to analyze user needs in the context of autonomous cars. Previous work can

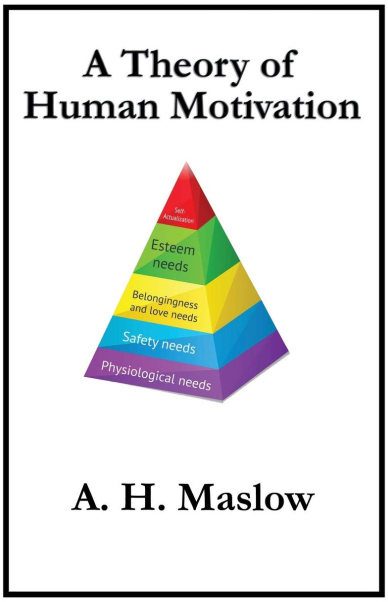


Figure 6. Maslow's Theory of Human Motivation

Fundamental need and its definition [Desmet & Fokkinga, 2020]		User needs in AVs (derived from the literature)
Autonomy	Being the cause of your actions and feeling that you can do things your own way, rather than feeling as though external conditions and other people determine your actions.	Work [29], preparing food or drink [50], space needs [57], prepare meals [617]
Beauty	Feeling that the world is a place of elegance, coherence and harmony, rather than feeling that the world is disharmonious, unappealing or ugly.	
Comfort	Having an easy, simple, relaxing life, rather than experiencing strain, difficulty or overstimulation.	Relax, changing clothes, looking around [22], Perceived Ease of Use (PEU), trust [28], looking outside (the vehicle) [50, 617]
Community	Being part of and accepted by a social group or entity that is important to you, rather than feeling you do not belong anywhere and have no social structure to rely on.	Social networking, caregiving [22]
Competence	Having control over your environment and being able to exercise your skills to master challenges, rather than feeling that you are incompetent or ineffective.	Manage schedule, ofice work [22], Perceived Behavioural Control (PBC) [28], office tasks, learn languages, knitting, play instruments [617]
Fitness	Having and using a body that is strong, healthy, and full of energy, rather than having a body that feels ill, weak, or listless.	Fitness, meal, sleep, make up, washing, clean up [22], sleep, addressing the inherent motion-sickness problem [29], sleep\rest, Personal hygiene, applying makeup, changing clothes, doing simple sports [50], health needs [57], eating & drinking, sleeping, smoking, cosmetics, fitness [617]
Impact	Seeing that your actions or ideas have an impact on the world and contribute to something, rather than seeing that you have no influence and do not contribute to anything.	
Morality	Feeling that the world is a moral place and being able to act in line with your personal values, rather than feeling that the world is immoral and your actions conflict with your values.	
Purpose	Having a clear sense of what makes your life meaningful and valuable, instead of lacking direction, significance or meaning in your life.	Attitude Towards using the system (ATT) [28]
Recognition	Getting appreciation for what you do and respect for who you are, instead of being disrespected, underappreciated or ignored.	Personalization & Customization [57]
Relatedness	Having warm, mutual, trusting relationships with people who you care about, rather than feeling isolated or unable to make personal connections.	Video telephone, phone call [22], text or talk with friends/family [29], making audio\video calls [50], social needs [57], talk to passengers, texting, calling, social media, interact with passengers [617]
Security	Feeling that your conditions and environment keep you safe from harm and threats, rather than feeling that the world is dangerous, risky or a place of uncertainty.	Watch the road even though I would not be driving, an increased confidence of occupants in selfdriving vehicles, solving occupant-protection issues [29], monitoring the driving [50], safety and security [57]
Stimulation	Being mentally and physically stimulated by novel, varied, and relevant impulses and stimuli, rather than feeling bored, indifferent or apathetic.	Multimedia, reading, web surfing, game, taking a picture, shopping, drinking, singing, talking [22], fun [28], read, watch movies / TV, play games [29], listening to music [50], watching films and videos, playing on the mobile phones, playing video games, playing board games, taking selfies [50], music/ radio, internet, reading, watch movies, (video) games, take pictures, [617]

Table 3. User needs, activities and requirements according to the literature and linked to the 13 fundamental needs.

be found related to that; for instance, [Geiser and Kim, 2021] explored what shape fundamental needs take in the domain of mobility, and [Desmet, 2020] portrayed what fundamental needs were fulfilled by different alarm clock designs.

Link to the literature. Inspired by the steps that are proposed by [Geiser and Kim, 2021] for identifying and clustering sub-needs, we connected the insights from the literature to the thirteen fundamental needs. The outcome can be found in Table 3, where the first and second columns respectively introduce the fundamental needs and their definitions by [Desmet and Fokkinga, 2020a]. The third column collects, from the previous work, the user needs that are specific to the autonomous driving context (i.e. sub-needs), as well as the non-driving-related in-vehicle activities, according to the fundamental need that they would fulfill. Note that the user needs that were identified by more than one article have been only written once.

Limitations. There are certain limitations regarding the clustering process that was followed here. First, the user needs were always linked to the main fundamental need that they would fulfill, even if some of them could be related to two or even three fundamental needs. A more flexible clustering process could have been conducted as an alternative, but the end results might have been more blurry in that case. Second, the interpretive validity of the outcome might have been compromised, as a single researcher is in charge of the current research. Triangulation techniques (i.e. investigator triangulation) would have been suitable to address this limitation [Ravitch and Carl, 2015].

Insights from Table 3. After that initial clustering process some fundamental needs stood out from the rest, since the majority of the needs and activities that were collected from the literature belonged to them. The categories ”stimulation” and ”fitness” were the most repeated ones. Following them, we have ”relatedness”, ”comfort”, ”security”, ”autonomy”, ”competence", ”community”, ”purpose” and ”recognition”. In contrast to those, some other fundamental needs turned out to be uncovered by the papers analyzed; namely, the categories ”Beauty”, ”Impact” and ”Morality”.

These insights could have different interpretations. While the more prominent fundamental needs could be seen as the most promising or urgent needs to cover within autonomous vehicles, the empty categories might also represent novel and currently uncovered opportunities. Besides, categories such as ”fitness” or ”stimulation” represent activities that are often carried out in manually driven cars or other public transport means (e.g. trains), whereas the least covered fundamental needs are all intangible categories, which might have been harder to elicit when users were asked.

Key takeaways:

- As the automation level increases in automated driving, the primary driving tasks ”will become obsolete”, meaning that extra time will emerge for other activities.
- The focus of the current research is on non-driving-related tasks (SAE levels 3 to 5).
- New user needs will emerge in the future autonomous vehicle experience as a consequence of the evolution in driver tasks. In Table 3, we have compiled the user needs and activities that have been identified in prior work and connected them to the 13 fundamental needs.
- Meaningful user experiences are provided when fundamental needs (i.e., basic, universal needs that lead to wellbeing) are met.

2.3 TECHNOLOGY OPPORTUNITIES

After analyzing the user needs that will emerge in future, autonomous, in-vehicle contexts as a consequence of increased automation levels, the current chapter is aimed at understanding the problem from a technological perspective.

Based on emerging trends, automotive manufacturers are concerned with how the implementation of robotics could benefit the user experience in autonomous vehicles. As such, the chapter dives deeper into the topic. In order to analyze the technological opportunities from a wider perspective, not only the capabilities and limitations of robotics are reviewed, but also those related to AI-systems.

ROBOTICS TECHNOLOGY IN AV CONTEXTS

Robots are defined by [Russell and Norvig, 2022] as ”physical agents that perform tasks by manipulating the physical world” (p. 925). Many different types of robots can be mapped [Garcia et al., 2007], having all of them two core elements in common: sensors (e.g. cameras, radars, lasers, microphones, etc.) and effectors (e.g. arms, wheels, joints, or grippers), which allow them to both perceive their environment and state, and to act on it to accomplish their tasks. [Russell and Norvig, 2022] claim that robotics problems are nondeterministic, partially observable, and multiagent, which means that predictions will be required to act in an environment where many other (unpredictable) stakeholders also take part (e.g. other robots, humans, objects, etc.) and that the sensors are only able to provide information about certain parts of the environment (e.g. a camera cannot see around the corner).

Sub-robots. The initial brief of this research project referred to the concept of ”sub-robots” (see Appendix A). Very few references to the term have been found in the prior work, which suggests that it is a new concept. [Meschtscherjakov et al., 2015] mention that autonomous cars have been studied as autonomous robots by the human-robots interaction community; based on that, our assumption is that the concept of sub-robot would then be related to a smaller and scoped-down robot concept within the bigger autonomous car robotic system and that the concept probably refers to a broader technological agency. Sub-robots would be physical agents through which users would experience AI-driven systems, and therefore, after studying robots and robotic applications, the following sections will also cover the field of artificial intelligence and user interfaces.

This section will dive deeper into robotics by discussing some of the elements and themes that are related to the field, to approach the opportunities that they could present for future in-vehicle scenarios. Types of robots and autonomy levels will be discussed, to set a base to understand human-robot relationships. Finally, the trends in robotic applications will be listed to highlight the options and challenges in the context of autonomous vehicles.

Types of robots. Many types of robots can be distinguished; [Russell and Norvig, 2022] classify them according to their hardware. Manipulators and mobile robots are pointed to as the "most common types of robots" (p. 974). Manipulators are robot arms (i.e. "a serial chain of rigid limbs designed to perform a task with its end effector", [Garcia et al., 2007], p. 91), that are especially relevant in the fields of industrial robotics, medical robotics (e.g. surgical robots) and rehabilitation robotics [Garcia et al., 2007]. Next to those, mobile robots can move in space; as such, they require locomotive elements (e.g. wheels, legs, rotors, etc.) that change depending on the environment of the robot (e.g. aquatic, aerial or terrestrial). [Garcia et al., 2007] add a third category, by also considering biologically inspired robots, which use adaptive locomotive systems that are inspired by biology. Walking robots and humanoid robots are the most extended ones within this group. Finally, other kinds of robots would include prostheses, exoskeletons, robots with wings, swarms, or intelligent environments (i.e. the robot fills the whole room) [Russell and Norvig, 2022].

Autonomy. Additionally, robots can also be classified by their level of autonomy. Autonomy, as related to robots, is defined by [Beer et al., 2014] as: "The extent to which a robot can sense the environment, plan based on that environment, and act upon that environment, with the intent of reaching some goal (either given to or created by the robot) without external control" (p. 3). [Gruver, 1994] claimed that intelligent robots are different from "early pre-programmed robots" [Bekey, 1998] in that they "can operate in partially structured and unstructured environments by the use of advanced sensory feedback mechanisms, and make decisions using learning and reasoning algorithms" (p. 4).

Defining the levels of robot autonomy (LORA) within the context of HRI might be relevant according to [Beer et al., 2014], taking into account that they highly influence the interactions between humans and robots. In that respect, the authors provide a framework "for examining levels of robot autonomy and its effect on human-robot interaction" (p. 6), in which ten different LORA levels are specified. Every task can be divided into the subcomponents 'sense', 'plan', and 'act', which can have a higher or lower robot autonomy allocated. The lowest level would be related to a low robotic autonomy (Level 1: Manual Teleoperation, where all sense, act, and plan are allocated to the human), whereas the highest level would indicate full autonomy of the robotic agent (Level 10: Full Autonomy, being sense, plan and act allocated to the robot).

Service robotics. As far as the latest applications of robotics technology are concerned, [Garcia et al., 2007] identified the historical milestones of the robotics research, and stated that a shift in application areas is currently happening. Nowadays, as the authors claim, "new services are being demanded that are shifting how we think of robots from the industrial viewpoint to the social and personal viewpoint" (p. 2). As such, society could benefit from new robots, designed to provide human beings with assistance (p. 2). This application area is denominated "service robotics", and it includes subfields like domestic robots, security robots, surveillance robots, construction robots, and tour guides. This area would also be in line with the approach of our research, where we aim to explore how robotics technology could be used to favor passengers and to create meaningful in-vehicle experiences.

Challenges. Those current applications in robotics, where giving service to the human being stands out, bring in new challenges that both society and researcher communities should not disregard. In that respect, [Royakkers and van Est, 2015] investigated the societal, ethical, and regulatory issues raised by the new robotics, where privacy, cyber-security, excessive anthropomorphism, decision-making capabilities of robots, and required human skills for robot teleoperation were some of the emerging themes.

To conclude, to understand the capabilities that robots could bring to the in-vehicle environments in autonomous cars, taking a wider perspective might be beneficial, by also considering the current opportunities of AI-systems. As we have seen in this section, intelligence is a characteristic that could be embedded in robotic agents, which will be enabled by AI.

OPPORTUNITIES OF AI-SYSTEMS

Artificial intelligence (AI) is a very broad domain [Razavian et al., 2020, Russell and Norvig, 2022]. The definition of the concept is highly influenced by how the term 'intelligence' is approached [Kaplan and Haenlein, 2019]. Related to this, [Russell and Norvig, 2022] explain that two relevant dimensions should be specified first. On the one hand, intelligence can be defined either as "fidelity to human performance" or as "rationality". On the other hand, it can be seen as an internal thought process or as an external behavior instead. From the combination of those two dimensions ("human vs. rational" and "thought vs. behavior" [Russell and Norvig, 2022]), four possible perspectives emerge that research has used as study approaches in the field of artificial intelligence.

Nevertheless, this might be a too deep and out-of-the-scope debate for the current graduation thesis; therefore, we propose to adopt a common definition that [Jazdi et al., 2020] have used in industrial practice, which claims that "AI is the technical transformation of aspects of intelligence – namely observing or perceiving, analyzing, reasoning and action – into a software with the goal of realizing a problem-solving automat" [Jazdi et al., 2020], (p. 397).

The core of artificial intelligence is concerned with the successful achievement of goals [Beardow et al., 2020]. Due to their computational nature, AI agents particularly excel in collecting datasets and developing algorithms, capabilities that they use to perceive, assess, and respond to changing environments.

Machine learning. Currently, machine learning is the primary approach to AI and its base underlying principle is "learning from data" [Razavian et al., 2020] (p. 1), as it comprises

”methods that help computers learn without being explicitly programmed” [Kaplan and Haenlein, 2019] (p. 17). Machine learning models have inputs and outputs (i.e. what they receive and what they predict) and, through various iterations in which they adjust their parameters, the quality of the model is enhanced, which means that it can make better output predictions, given the training input data.

Various learning paradigms can be found within machine learning, among which the most commonly used are unsupervised learning, supervised learning, and reinforcement learning [Razavian et al., 2020]. Another relevant learning model within machine learning are neural networks, which are studied by the ’deep learning' subfield. The deep learning models can work with a large number of parameters and capacity to learn complex tasks, which makes them suitable for many state-of-the-art applications (e.g. computer vision or natural language processing) [Razavian et al., 2020].

Capabilities of AI. Based on those methods and technical paradigms, many capabilities can be derived from artificial intelligence. For instance, IBM characterized AI as having four main qualities; AI understands (i.e., through data, AI understands its context in depth), reasons (i.e., AI ”has the ability to form hypotheses by making considered arguments and prioritized recommendations”), learns (i.e., the systems get better over time by learning through experience) and interacts (i.e., ”AI interacts naturally with people and systems”) [IBM, 2019].

The approach by the AIxDesign community is also interesting. In 2021, they published a toolkit, the ’AI-ideation cards', that is aimed at designers to help them in their ideation sessions when AI is involved. Apart from that, they claim that the deck can also be used to learn about AI capabilities (”use the deck as an educational tool to learn and teach about current AI capabilities and real-life examples of how they're applied across industries”). Seven categories are mentioned as capabilities of AI systems:

- Deep personalization - adapt to the individual: ”a system can continuously learn from its interactions to best serve user needs”.
- Context awareness - adapt to surroundings: ”the system

can understand the system's current surroundings, both spatially and socially, and adapt accordingly".

- Simulated presence - seeing and sensing physical space: "new capabilities like sensors and computer vision now enable computers to see, sense, and respond to their environment".
- Intelligent interfaces - post-pixel interactions: this is related to new ways of mediation between the technology and our bodies. "AI enables new ways of interacting with digital technologies through speech, gestures, and expressions".
- Autonomous action - act in anticipation: performing a task for the user before they make a request.
- Uncovering insight - insights from (big) data: "the ability to process big amounts of data and uncover new insights from it".
- Advanced automation - outsourcing tasks to machines: "technological advancements are enabling increasingly complex and affordable large-scale automation".

Applications. Those capabilities are currently the enablers for many real-life projects and applications. For instance, speech recognition (used, for example, in online virtual agents), computer vision (e.g., in apps that identify types of plants and trees), recommendation engines (e.g., weekly job recommendations on Linkedin), object recognition, sentiment analysis, etc. As such, they could also be the enablers of new experiences within autonomous vehicles, and we could use them to enhance the passenger journey into a meaningful one.

Challenges. Finally, besides the technological capabilities that AI can provide us with, there are also some limitations and challenges that should be taken into account when considering its implementation. On the one hand, technological limitations can be found. [Russell and Norvig, 2022] mention the argument from informality (meaning that human behavior is far too complex to be captured by any formal set of rules), the argument from disability (i.e., argument that states that machines can never do certain things that are attributed to humans, such as being resourceful or having initiative) and the mathematical objection (i.e., ”Certain mathematical questions are in principle unanswerable by particular formal systems”).

Additionally, AI brings in new ethical issues to consider [Coeckelbergh, 2019], for example, lack of privacy, lack of transparency, attribution of responsibility, the problem of explainability, the problem of bias, etc.

Key takeaways:

- This chapter analyzed the current project from a technological perspective, by studying robotics and AI technologies more closely.
- Coherently with the aim of our study, the robotics field is currently experiencing a shift towards service robotic applications, that aim to provide humans with assistance.
- Very few references to the concept ”sub-robot” have been found in the prior work, which suggests that it is a new term.
- Intelligent robots make decisions using learning and reasoning algorithms, and thus benefit from the capabilities of artificial intelligence.
- Capabilities of AI systems include deep personalization, context awareness, simulated presence, intelligent interfaces, autonomous action, managing big data, and advanced automation.
- Those capabilities are technological enablers to take into account in the current project for the provision of meaningful user experiences.

2.4 USER INTERFACES

So far, we have depicted a future context around autonomous vehicles where, as a consequence of evolution in driving automation levels, user tasks concerning non-driving-related activities will become increasingly relevant. New user needs that will emerge have been identified and described (see Section 2.2), as well as the technological paradigms in the robotics and AI fields that could contribute to the fulfillment of those needs in a meaningful way (Section 2.3). This chapter would like to add further nuance to the interplay between user needs and available technologies, by diving deeper into the concept of user interfaces, which could be described as an in-between layer that frames their relationship.

Definition. In his study about the term, [Hookway, 2014] provided a theoretical framework for the concept of interface and its implications. First defined in the field of fluid dynamics, the concept of interface has been used across many disciplines to describe the boundary between two (or more) different entities. A general definition of the term is presented:

> *"The interface is a form of relation that obtains between two or more distinct entities, conditions, or states such that it only comes into being as these distinct entities enter into an active relation with one another; such that it actively maintains (...) the separation that renders these entities as distinct at the same time as it selectively allows (...) communication (...) from one entity to the other; and such that its overall activity brings about the production of a unified condition or system that is mutually defined through the regulated and specified interrelations of these distinct entities"*
> *[Hookway, 2014] (p. 4)*

In the present research, Hookways's approach concerning human-machine interfaces will be taken into account, where the bounding entities are the human and the machine and the operation would be delimited as acts of transaction and translation between these two entities.

Types of UIs. User interfaces (UI) have experienced a fast evolution [Iizuka et al., 2014]. Many classifications and types of user interfaces can currently be found in the user interaction field (e.g., gesture interfaces, intelligent user interfaces, multimedia UIs, multimodal UIs, etc.), most of them combinable with each other.

Selection. Since we could not cover all and every user interface in the current research, three interfaces are selected, that represented three different manifestations of the technology. Therefore, our choice is not relevant because of the specific interfaces chosen, but rather because of the level of interaction they provide users with. The interfaces are described below:

- **Ambient user interface:** the word 'ambient' refers to the entire setting that can be found around a user. As such, ambient interfaces "use the whole environment of the user as a medium for the interaction between the user and the system" [Gross, 2003], (p. 2). The information is presented subtly by form changes, motion, sound, smell, color, temperature, light, etc. [Gross, 2003].
- **Graphical user interface - GUI:** A GUI is a visuospatial representation of the state and control of a computer program. Presented on a display, it allows for interaction through a pointer; through these interactions, users are conveyed the program state as well as allowed to change it. Currently, GUIs are considered to be the main user interface type in human-computer interactions [Oulasvirta et al., 2020].
- **Tangible user interface - TUI:** defined as "devices that give physical form to digital information, employing physical artifacts as representations and controls of the computational data" [Xu, 2005], (p. 2). The physical elements of tangible interfaces are referred to as 'Tangibles' and can take the form of augmented physical surfaces (e.g., ceiling), graspable objects (e.g., instruments), and ambient media (e.g., airflow), always within a physical setting. [Xu, 2005]

To conclude, user interfaces are described as relevant elements in the relationships between technology and user needs, which will shape how users experience the technologies and also how they ultimately fulfill their needs. This has been exemplified by defining three different UIs, that differ in the means and nature of the interactions that they enable.

Key takeaways:

- The concept of interface has been used across many disciplines to describe the boundary between two (or more) different entities.
- In this study, we will take human-machine interfaces into account (we refer to them as UIs) to visualize the relationships between technology and AV passengers.
- Many types of UIs can be found; we select three of them as it would be impossible to cover all kinds of interfaces.
- We will work with ambient, graphical, and tangible UIs, as they represent three different manifestations of technology.

Chapter 3

RESEARCH APPROACH

The current project stage is a suitable moment to choose a more concrete research scope. In this chapter, a direction will be given to the research stage that follows, by reflecting on the outcomes of the literature review and proposing relevant research questions.

3.1 CONCLUSIONS FROM LITERATURE

The analysis of prior work has been conducted from various perspectives, in order to cover not only the human side of autonomous vehicle experiences but also the technological enablers and interaction elements that will affect future automation scenarios.

First, from the scientific papers analyzed, the user needs and activities that are envisioned for future autonomous rides have been compiled, by exclusively focusing on non-driving-related tasks. Those needs and activities were later linked to the main fundamental need that they would fulfill. Therefore, specific examples of how the thirteen fundamental needs manifest themselves in context-specific sub-needs are given. By fulfilling and supporting those sub-needs, meaningful user experiences can be created [Desmet and Fokkinga, 2020a].

Second, as far as the technology perspective is concerned, the opportunities and limitations of both AI-systems and robotics have been analyzed, concluding that the possibilities that they both present are very extensive, and are even expected to grow in the near future; [Russell and Norvig, 2022] state that "the intellectual frontiers of AI are wide open" and "AI still has many openings for full-time masterminds" (p.1). As a consequence, technology capabilities might be too broad design boundaries for the current study.

Third, user interfaces have been introduced as a relevant element that will shape the interactions between technology and users in the in-vehicle contexts that are being analyzed. User interfaces can have different materializations, shapes, and interaction means.

3.2 FOCUS: SCENARIOS AND UIs

As mentioned at the beginning of this report, the initial goal of the current study was to explore the possibility of using robotics technology for enhancing future autonomous in-vehicle experiences into meaningful ones; a systematic and theoretical approach was expected to be taken for the discovery of opportunities.

The fact that robotics and AI present ample capabilities and possible configurations requires us to set additional boundaries to frame our contributions. Accordingly, future scenarios have been considered as a suitable first approach. Scenarios are described by [Gujónsdóttir and Lindquist, 2008] as effective design tools to communicate information regarding the users' context and to "understand why the system has to behave in a certain way" (p. 1). Therefore, we consider them a useful tool for the current project stage.

In line with human-centered design approaches, that state that "HCD is not consistent with the well-known paradigm of 'technology push'" [Giacomin, 2014b] (p. 617), it might be appropriate to first consider what scenarios could be created to support user needs, without taking technology into account or as a constraint. Later, in a further stage, considerations would be done about how technology could be used to enable the envisioned scenarios [Riener et al., 2022], by analyzing how all the possible technical elements should be combined to create a solution.

In our case, after defining the scenarios that would fit the identified context-specific fundamental needs (i.e. sub-needs in the autonomous vehicle environment), we will be in the position to introduce the technology perspective to the study. Regarding AI and robotics, something to beware of is the fact that users find it hard to visualize these technologies, as they usually work based on abstract principles, where only inputs and outputs are seen; this is an important issue if participatory methods or user-centered tools are to be used in the research. Analyzing how those technologies are experienced in their boundary with the user (i.e. human-machine interface or user interface, [Hookway, 2014]) may be a useful way to navigate this difficulty. As such, user interfaces are an important element to look into.

Once user scenarios and technology-user interfaces are defined, in a later stage it would be beneficial to contact experts, to see how those could be implemented with the technology analyzed (i.e., AI-systems and robotics). This is something that the current research will not cover, as time and expertise constraints would not allow doing so.

All in all, this section claims the need to zoom in into the previously described user-technology-vehicle system; the approach will enable us to first see how the compiled user needs could be supported, to later analyze what the role of technology could be in those scenarios. User interfaces are chosen as the relevant elements to analyze, as they will bring insights into how users experience AI-systems and robotics.

3.3 RESEARCH QUESTIONS

Once the scope is set, these are the research questions and sub-questions that will possibly contribute to the initial goal of the study, analyzing how robotics and AI-systems can contribute to the provision of meaningful autonomous experiences.

We expect these research questions to bring insights into the scenarios that end-users expect for the future autonomous vehicle experiences, as well as about what the role of user interfaces will be in those envisioned scenarios:

1. What in-vehicle scenarios can be designed to support fundamental needs?
   - How do different user interfaces enable those use cases?
   - How do different types of user interfaces affect the in-vehicle user experiences?
2. What are the most promising scenario and user interface combinations?

SELECTED UIs: THREE LEVELS OF TECHNOLOGY MANIFESTATIONS

Note that the sub-questions refer to "different types of user interfaces". As explained in the review of the prior work, many different types of user interfaces can currently be found both in design theory and real-life applications. As such, in order to gather different technology manifestations, ambient, graphical and tangible user interfaces are selected as a representative yet manageable sample to work with in the current study. (See their definitions in Section 2.4).

MOST PROMISING COMBINATIONS

Note that, as described in research question 2, something that we would like to discover with the current research is what the most promising (i.e., interesting) scenario and UI combinations could be, in order to see if recommendations could be given to potential manufacturers or designers in what development lines to take.

In that respect, defining ’promising’ more precisely may be beneficial, which in our case we do by proposing two complementary terms: ’innovative’ and ’attractive’. Both terms are going to be used in the data collection stage of the research and thus are explained in the following lines.

Innovative (scenario and UI combinations): ’innovation’ is defined by [Garcia and Calantone, 2002] as ”an iterative process initiated by the perception of a new market and/or new service opportunity for a technology-based invention which leads to development, production, and marketing tasks striving for the commercial success of the invention”. Technology inventions, new market opportunities, and ongoing iteration are emphasized in this definition.

On the other hand, we would have the concept of ’innovativeness’, which describes the degree of ’newness’ of an innovation [Garcia and Calantone, 2002]. Therefore, highly innovative and low innovative products would be seen as products with high and low levels of newness.

For the current research, we will refer to innovative scenario and UI combinations from this second perspective, where the degree of discontinuity of a concept with the previous context will be considered to identify promising design directions.

Attractive (scenario and UI combinations): Following the rational of human-centered design, user preferences should be considered central when deciding what concepts to develop further. As an example of this criticality, [Giacomin, 2014b] states that ”70% to 80% of new product development that fails does so not for lack of advanced technology but because of a failure to understand users’ needs.” As such, attractiveness will be used in this study to describe user wishes and perceptions (i.e., ’what users would like to have’ or ’what users prefer’).

Chapter 4 -

METHOD

To address the aim of this study, a qualitative co-creative workshop was designed. After various iterations, and by theorizing from the data collected, preliminary insights were gathered. Those outcomes were shared with experts in validation sessions, and feedback was collected on how to improve the proposed results.

The following chapter covers the rationale behind the design of both the workshop and the expert validation session, as well as the details of the data collection and data analysis.

4.1 CO-CREATIVE WORKSHOP

In order to discover meaningful scenarios and explore future in-vehicle interactions, a co-creative workshop was designed. By using participatory design methods, participants (who were end-users) were guided through different creative activities where they would reflect on autonomous in-vehicle experiences, fundamental needs, and user interfaces.

RESEARCH DESIGN

Goal of the workshop. The workshop had two specific goals; first, to analyze how the 13 fundamental needs could be addressed in the context of AVs, by identifying sub-needs and creating a scenarios for fulfilling them. Second, to understand how those scenarios are differently shaped when different UIs are implemented for the in-vehicle interactions.

Workshops with end-users are useful to "reveal deeper levels of understanding," since "both tacit and latent knowledge" (p. 75) can be accessed when participants are engaged in 'making' activities [Sanders and Stappers, 2020]. Previous work also used workshops in the context of autonomous vehicles and experience design [Kim et al., 2015, Lee et al., 2022].

Participants. Snowball sampling techniques [Patton, 2015] were used to recruit potential end-users for the workshops. The participants were reached using personal and professional contacts; as a consequence, they were mainly master students with technical study backgrounds. The only selection criteria used was their willingness to participate and no incentive was provided for the participation.

Involving users in such sessions has trade-offs, as pointed out by [Lee et al., 2022]. Opportunities and challenges can be revealed by observing users. Nevertheless, many authors criticize that users are often more restricted and biased in their creative outcomes, moreover if the topic to be covered is a future environment they are unfamiliar with [Kim et al., 2015]. Therefore, we decided to also include novice designers among the participants, under the assumption that they would favour a suitable creative atmosphere, as out-of-the box ideas were expected to be gathered. 18 participants participated, out of which 8 were designers (% 44).

Pilot. Previous to the workshops, a pilot session was organized, where six extra participants were gathered together. Multiple objectives were covered in this session. For instance, exercises were tested, to see if the amount of time allocated, the trigger materials used, and the explanations given to the participants were suitable. Additionally, the outcomes of the exercises were also analyzed, to see if they were suitable for the research questions that were previously stated. Finally, feedback was received about the participant experience and technical issues (e.g., room size, necessary equipment, etc.) were resolved.

After the pilot a reconfiguration was done on the overall workshop route, in order to ensure that the activities proposed were coherent with the session's objectives and time-constraints. For instance, in order to allocate more time to the discussions the initial context exploration (that was done in the pilot through a group brainstorm) was converted into a previous-to-the-workshop sensitizing exercise, that the participants were asked to do before the session.

Procedure. Before the workshops, a brief sensitizing exercise was sent to the participants, so that they would already start unconsciously thinking about the topic.

For the main session, participants were gathered in a university room and every workshop took 90 minutes to complete. First, they were welcomed and asked to sign a consent form that was previously approved by the HREC committee of the university. Second, exercises were proposed, where participants had to engage in design and discussion activities. A single researcher facilitated the workshop; the facilitator explained the exercises as well as the brief theoretical explanations needed and was responsible to provide participants with materials and to record the last section of the workshop.

Workshop route. The workshop consisted of several individual and group activities, that were organized according to the guidelines proposed by the literature on generative design [Sanders and Stappers, 2020] and creative sessions [van der Meer and Heijne, 2019]:

- 0. Sensitizing: in order to introduce them to the topic, a short

1-minute video about an autonomous concept car (i.e., the Zoox car concept) was sent to the participants before the workshop. They were also asked to think about non-driving-related activities that they currently do in a car, both as a driver or as a passenger.

- 1. Getting into the context and ice breaker: participants were involved in an icebreaker game where, one by one and without repeating others' ideas, they had to say out-of-the-box non-driving-related activities that one can do in a car. The aim of this activity was twofold; apart from introducing the session and warming creativity up, it made all participants speak, which is beneficial to reduce social tension and favor later discussions [van der Meer and Heijne, 2019]. After this first game, basic explanations about driving automation levels and fundamental needs were briefly given.

2. Brainwrite on in-vehicle sub-needs: regarding fundamental needs, participants were asked to think about different sub-needs that can emerge in AVs. This was done in a brainwrite format, meaning that every participant had some time to think about a fundamental need and write their ideas on a paper, that they would later pass on to the next participant. The materials used were white sheets, where a fundamental need and its definition had previously been written. The main goal of this exercise was to familiarize the participants with the fundamental needs and sub-needs so that they could later design scenarios to support them.

- 3. Designing scenarios: participants were divided in two groups. Every group was given two fundamental needs, and was asked to design a scenario for each of them. The sheets that were generated in the previous exercise were used here as a trigger, as they already contained needs the participants could select or be inspired by.

BREAK. After they finished designing both scenarios, participants were given a short break.

- 4. Adapting the scenarios to the user interfaces. In this excercise participants were asked to adapt the two scenarios that they previously had created to the three user interfaces (i.e., ambient, graphical, and tangible) that were chosen for this study. A short explanation about the interfaces was given.

• 5. Presenting and discussing the outcomes. In order to trigger a discussion about how different UIs shaped their scenarios differently, participants were asked to present their scenarios and ideas to the other group. Later, the facilitator used some probing questions to initiate a conversation about different UIs.

• 6. Questionnaire. After all workshops were conducted, a questionnaire was sent to the participants, were they were asked about the most promising scenarios and UIs. Two questions were asked, the first concerning the most attractive scenarios and the second regarding the most innovative scenarios.

Note that participants were first encouraged to think about use cases that would support the fundamental needs, to later think about how the user interfaces would shape those interactions. Similar to the approach taken by [Kim et al., 2015], it allows participants to freely think about their desired design scenarios (divergent mindset) to later fit the technology onto them (convergent mindset) [van der Meer and Heijne, 2019].

DATA COLLECTION AND ANALYSIS

Data was gathered through three workshops that were conducted with a total of 18 participants. Eight novice designers participated among those participants, that were evenly distributed among the sessions (with a minimum of two designers per session). No other demographic or personal data were collected.

On the one hand, the physical outcomes of the exercises were collected and analyzed as data, including the scenarios and the adaptation of those scenarios to the three different UIs. The fourth exercise of the workshop was audio recorded, in order to analyze the discussion. All audio recordings were transcribed, anonymized, cleaned and reviewed by one researcher. Note that the recorder failed to properly work in one of the sessions. Participants were kindly asked to send audio recordings answering the two main questions of the discussion. Those audio recordings were also included in the transcriptions.

All transcribed data were qualitatively analyzed through descriptive coding by dividing and coding the quotes in an excel sheet. 68 codes emerged, that were colour coded depending on the user interface that they were referring to and were finally clustered into seven common themes.

Additionally, note that 14 answers were collected for the questionnaire, that was analyzed as quantitative data. After the workshops, participants were asked to review the generated scenarios and user interfaces, as well as to select the most attractive and innovative combinations. The research aim here was exploratory (rather than statistical), as the goal was to better understand the opinion of the participants of the workshops regarding both concepts and to map that in a visual manner. The gaps and commonalities between the answers to both concepts were analyzed.

4.2 VALIDATION SESSIONS

Once the co-creative sessions were conducted and analyzed, the validation stage was organized. To gather feedback on the outcomes that were derived from the workshops, experts in the related fields of this research were recruited.

Following the approach and rationale by [Lee et al., 2022], experts were considered relevant components in this project to offset the limitations that only including end-users would bring to the study (e.g., exclusively focusing on immediate needs or failing to consider future socioeconomic contexts).

RESEARCH DESIGN

The expert validation sessions were designed with the goal of enriching the preliminary results of the co-creative workshops. In this regard, the sessions were aimed at contrasting the outcomes with academic-level knowledge, identifying and challenging the potential undercovered assumptions, and adding new perspectives to the gathered results.

Participants. Experts in the fields of human-computer interaction, future mobility and positive design (i.e., with knowledge of fundamental needs) were recruited for the sessions, as they comprise the main themes that are covered in the present study. Therefore, a criterion-based participant selection was carried out [Patton, 2015], where the expertise field of the participant was the main selection criteria. Other characteristics such as experience years or location were not considered as relevant, even if those factors were kept balanced in the final sample.

Sampling. Besides, snowball sampling [Patton, 2015] was also followed, meaning that the participants connected the researchers to relevant profiles within their field, who were also contacted in the recruitment process. The participants were reached from personal and professional networks and no incentive was offered for participating, meaning that the experts joined voluntarily, based on their willingness to contribute to the study.

Interview procedure. Participants were invited to individual interviews, where they were asked to participate in two discussion and reflection activities that, led by the facilitator (i.e., the main researcher of the study), were based and triggered by the preliminary results from the workshops with end-users.

The interviews followed a semi-structured outline, meaning that a previously designed question-route was used as guidance, but freedom was given to the facilitator to ask follow-up questions when considered relevant. The session was prepared so that it could be conducted both in an in-person setting or online.

The sessions started with a brief introduction to the research, aiming at providing the participants with some context. The experts were also encouraged to present their expertise area; following that, they were asked to hand in a signed consent form if they agreed to participate in the study. The first discussion exercise was related to the 13 meaningful scenarios that were developed in the workshops. Participants were given a matrix containing all thirteen scenarios, as well as their adaptations to the different UIs. Besides, two tables containing quantitative information about the most promising scenario and UI combinations (i.e., the first, concerning attractiveness and the second, concerning innovativeness) were provided. In this first section, experts were asked to react to the most prominent scenario and UI combinations, as well as to the differences between both quantitative tables.

In the second part, a summary was shown to the participants, regarding the insights gathered on the three user interfaces and their role in the in-vehicle user experiences. The facilitator pointed at one theme at a time, asking the experts to react to the findings. Quotes from the workshops were read when further clarification was needed about what was being explained in the summary. The experts brought in their nuances and pointed out the findings where they did not completely agree.

DATA COLLECTION AND ANALYSIS

Data was gathered through six sessions that were conducted with six experts in the domains that were previously mentioned: Human-Computer Interaction (HCI) (n=2); Human-Robot Interaction (n=1); future mobility (n=2) and fundamental needs (n=1). All participants belonged to academia. Note that equilibrium could be found in the distribution of the expertise fields, as well as in the academic category of the participants.

The sessions were around 45 minutes long (with variations in length from one session to another) and were conducted both online (n=2) and in person (n=4), depending on the participant's location and own preference. Note that time was differently allocated to the two parts of the session with every participant, by considering what their expertise was. The discussions were audio recorded for later analysis and the facilitator also took notes to register relevant moments or quotes.

The validation unfolded smoothly, and rich discussions were favored on the topics that were proposed. The main challenge was to make participants understand the research and its outcomes in such a short time, which sometimes lead to participants perceiving the session as overwhelming.

After the sessions were finished, the audio recordings were transcribed (by using free online tools) and played once again by the main researcher, who also highlighted relevant expert quotes. Those quotes were clustered according to the result section they were related to. The open-ended discussions were taken into consideration for the discussion chapter of this study (see Chapter 6).

Chapter 5 -

RESULTS

In the following section, the results from both consecutive parts of the method are included, by presenting not only the outcomes that the participants brought in at the workshops but also the iteration that they went through thanks to the reflections from the experts at the validation sessions.

5.1 13 MEANINGFUL USE CASES

The co-creative workshops with end-users resulted in the compilation of 13 meaningful scenarios, that is to say, scenarios that would be linked to each of the thirteen fundamental needs. Besides, participants adapted those scenarios to the three user interfaces that were proposed, and they voted for the most attractive and innovative scenario and UI combinations, to see what could the most interesting ideas be. Finally, by analyzing the discussions on the role of the UIs in the in-vehicle user experience, various themes and patterns were found, which could contribute to understanding the role and nature of the UIs better.

Those preliminary results were used as input for the expert validation sessions. The experts added their own perspective, which was valuable for contrasting, refining, and enriching the outcomes.

In the following pages the 13 meaningful scenarios are presented, as well as the adaptation of every case to the three user interfaces that were proposed in the workshops (i.e., ambient, graphical, and tangible user interfaces).

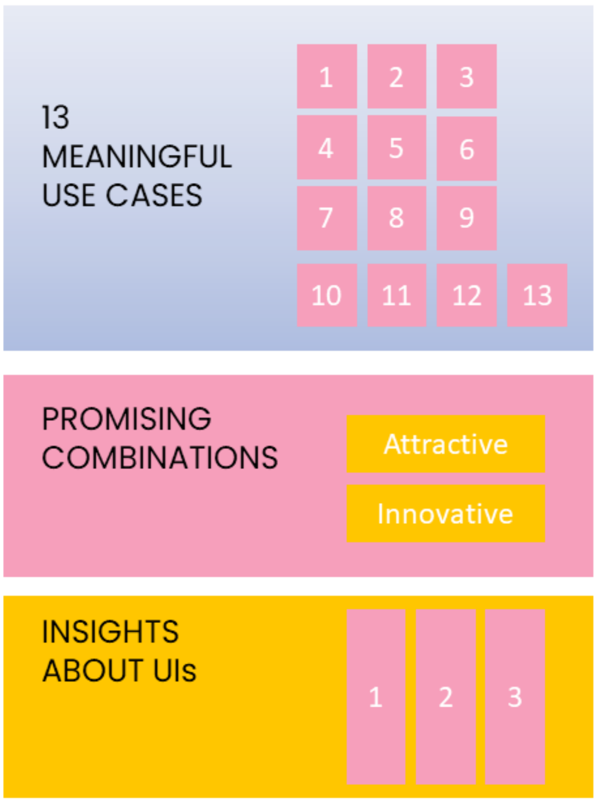


Figure 7. Overview of the results chapter.

1) AUTONOMY:

Participants pointed out that the ability to have car reconfigurations would support users' need for autonomy. As they explained, "the car will change its shape, configuration, considering where it is or where [it] is going" (P9). Various examples were mentioned related to that, "the car can change its shape to a boat", "it can be filled with seawater and used as a bath", "it can be used as camping at the end of the day", etc. The in-vehicle interactions were formulated as follows, according to the user interfaces that were previously proposed:

- **Ambient:** The lights will change to match the surrounding environment (e.g., "if it's beside the beach, the light may be more sunshine[-like]," P9). The volume of the sound will also be regulated to match the in-vehicle activities that take place in every moment ("sound will be kept lower when quiet activities take place", P9).

- **Graphical:** Screens were mentioned as elements of the graphical interaction. Participants suggested that users would be allowed to control the screens; examples were given regarding the change in screen size that the users could make, according to the multiple contexts that their scenario would allow.

- **Tangible:** Related to the adaptive environments and configurations that were initially mentioned, the tangible interactions were pictured as the car being able to bring different equipment to the users, that would match the in-vehicle context at every moment.

2) BEAUTY:

For situations in which outside landscapes are "dull and boring" (P4), the need for beauty could be supported by providing users with "new and exciting" (P4) views instead. This will be possible differently depending on the user interface chosen:

- **Ambient:** Users would experience new scenery through a multi-sensory experience; apart from visuals, where holograms and mixed-reality were suggested as possible technology, smell, and other sensory elements (e.g., wind, temperature, sun rays, or spraying water) should be included too in order to recreate the desired environment.

- **Graphical:** Augmented reality and virtual reality screens should be placed "in the windows, ceiling and all the surrounding" (P4) of the car, to show a new landscape that users could choose. For instance, ideas for alternative landscapes include a ride next to the Coliseum, through Venice, a forest, or even some fantasy worlds such as scenery from Harry Potter.

- **Tangible:** In this case, physical elements would be added to the previously explained outside view. For instance, Greek-style columns would be brought into the vehicle if Greek landscapes are chosen.

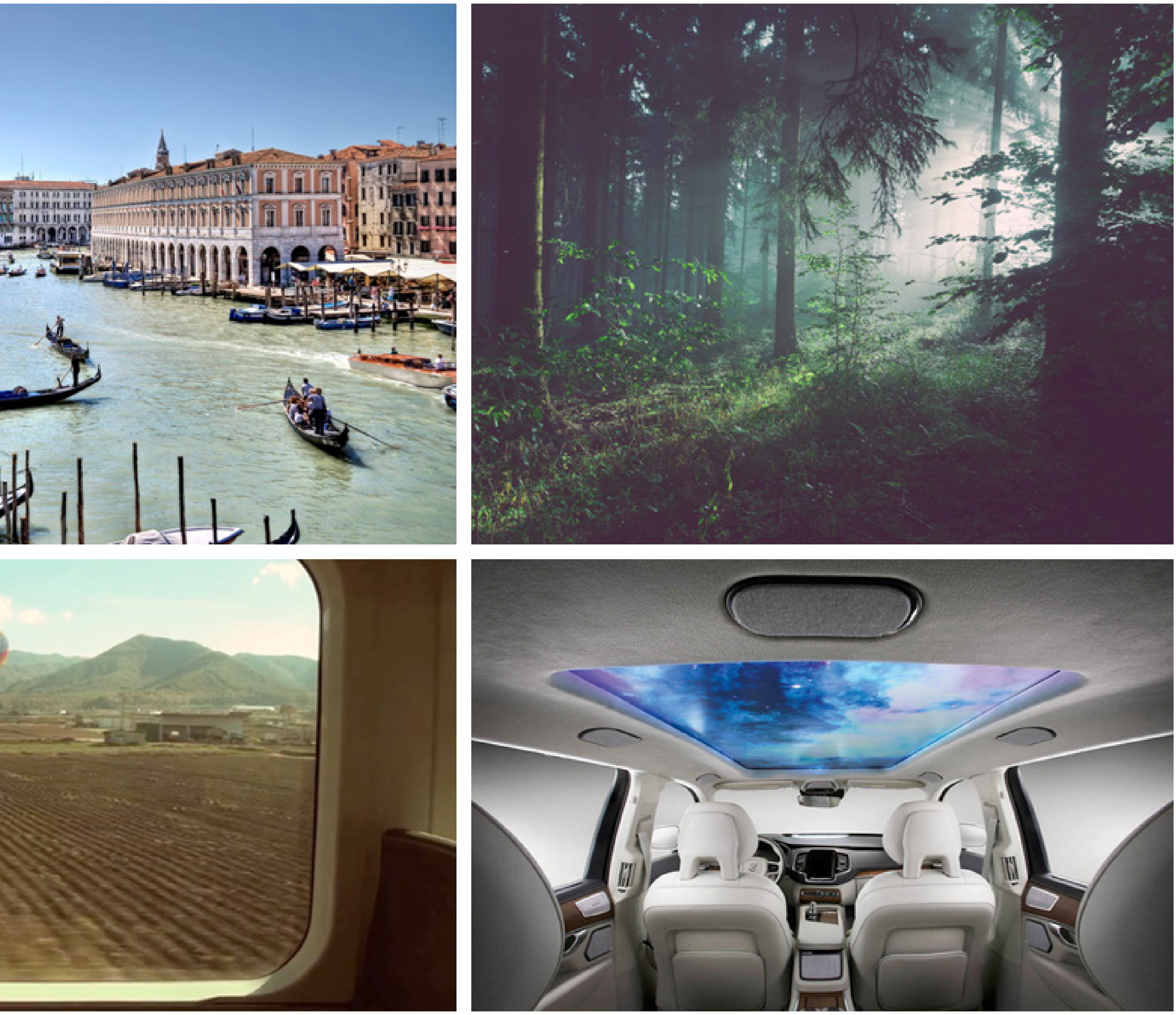


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Figure 8. Moodboard illustrating the ideas for the fundamental need 'Beauty' [Pexelx, nd]

3) COMFORT:

The scenario that would support the fundamental need for comfort was described as a food delivery service; it was approached as a very easy, hassle-free, and simple way for users to receive food when traveling in an autonomous car. It was suggested that even restaurants could be located in some other autonomous vehicles, which would ease delivery processes even more. The three interfaces were framed as follows:

- **Ambient:** Users would order their food by using voice commands. The food delivery time is also communicated by the ambient light, more specifically by its intensity (”let's say it's light green, dark green, and completely yellow when it's completely near you”, P11). Besides, windows were also mentioned to be part of the ambient elements, indicating that they should be opened and closed according to the food delivery. Finally, music and light would be changed when the user is eating.

- **Graphical:** A display would be used to visualize the ordering options available, the delivery map, etc. Voice control was also mentioned as part of this category.

- **Tangible:** An autonomous table was described as a potential tangible interface. Besides, once the users are notified that the food is there, they should be able to remotely or automatically open the window (voice commands may be used for this). At that moment, a robotic arm could go out of the window to pick up the food. Finally, the vehicle could suggest nice locations nearby (e.g., a lake) in case users would like to enjoy their meal there.

4) COMMUNITY:

For this fundamental need, cooking was used as an inspiration that often serves to bring people together. As such, participants raised, for the context of autonomous vehicles, ”how can we make it (cooking) a bit of a community experience?” (P10). Accordingly, in the scenario that they described, users would cook in the autonomous vehicles, to later share their dishes and ingredients with people in other cars. Emphasis was done on the idea of ”sharing”: ”you just end up having a bit of a potluck dinner within your vehicles and you share ingredients or parts” (S10). In terms of the interfaces:

- **Ambient:** The in-vehicle environment would be a changing one, meaning that ”you might not have a cooking car the whole time” (S10); popping-out stoves and tables shall be included. For safety reasons, both the environment changes and the driving style should be smooth. Besides, good lighting will favor manual cooking tasks. Auditory and light notifications could be used to communicate the state of the cooking task (e.g., when users want to share something). Related to that, participants pointed out that the outside of the vehicle could also be used to communicate with other people: ”so maybe it pops up red or green if you want to share something” (P10).

- **Graphical:** A button or touch interface could be used when users ”would like to share or even sell leftovers” (P10) that they have. Voice feedback was envisioned to come from the vehicle, which could also be controlled by the users’ voice commands.

- **Tangible:** It was suggested that the car could take over some of the cooking tasks. A robotic arm was considered a possible solution for this idea.

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Figure 9. Moodboard illustrating the ideas for the fundamental need 'Community' [Pexelx, nd]

5) COMPETENCE:

Participants suggested that, to fulfill the need for competence, the car could train users in their driving skills, which will be reduced when higher automation levels are reached. As participant 3 expressed: "the car could be kind of a trainer for the times that we are going to drive, because if it is just autonomous vehicles, then we lose that ability". The car would still be operating in the 5th level of automation, and the users would be trained through a simulator. The interfaces would reach this goal differently:

- **Ambient:** Different types of environments will be created, based on the real environment outside of the vehicle. Users will feel that they are in control of the vehicle, even if they are not. Augmented Reality was proposed as a good technology for this interaction level, as it could enhance the outside environment (for instance, when it is raining, when it is night, etc.).

- **Graphical:** In this case, the training features would look like a game. The user would be guided through a screen and also by means of audio cues.

- **Tangible:** A removable steering wheel could be included in the car, "that you can just plug in whenever you want to (...) practice with it" (P3). Tangible elements should also be included in the in-vehicle environment, to simulate the sensations that users would feel in case their "practice driving" was really controlling the car. Additionally, users would be able to choose the driving mode that they would like to experience, and their seats should move accordingly; for instance, a "roller coaster mode" could be selected if users feel like "being pushed in your seat and being pushed into the corner" (P3).

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Figure 10. Moodboard illustrating the ideas for the fundamental need 'Competence' [Pexelx, nd]

6) FITNESS:

The scenario that was presented suggested that the car could become a ”personal fitness tracker” (S1), that would be able to track users’ bio-metrics and would provide them with different stimuli to contribute to their health. For instance, the car could sense if the user is feeling tired or hungry, and would suggest improvements accordingly (e.g., stopping in a nearby restaurant). The shape of the stimuli will depend on the user interface that is used:

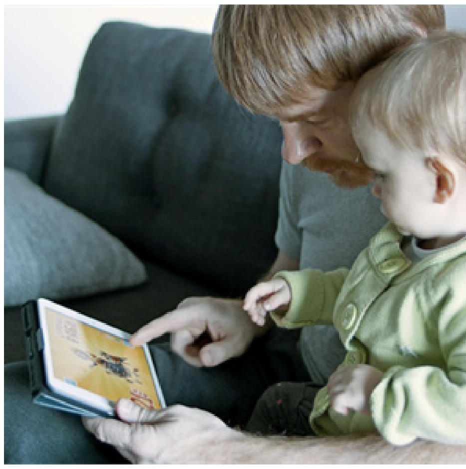
- **Ambient:** The ambient interface should be very fluent, as the participants raised. The car would give stimuli to the users throughout the journey by using the elements of the environment. For instance, users could be suggested to look out of the window in case their eyes are soaring and they need to relax or to stand up and walk around in case they have been seating for a long time.

- **Graphical:** Digital and visual interactive stimuli would be used. As an example, it was pointed out that stressed users could be encouraged to draw on a screen to relax. Another example was that the screens could tell users about healthy groceries that they can buy. Motion sickness could also be reduced by using these interactions.

- **Tangible:** Massage chairs would be used to provide users with physical relaxation.

7) IMPACT:

Participants envisioned that the fundamental need ”impact” could be fulfilled when users contribute to the wellbeing of their families. Therefore, the in-vehicle scenario that they presented was aimed at ”spending quality time with your kid while traveling” (P7), referring to children of young age. As they pointed out, some parents spend a considerable amount of time traveling (e.g., when commuting to work), which makes these moments suitable for contributing to their own family. This contribution will benefit both parents and kids, as they explained. The in-vehicle interactions were defined accordingly:



- **Ambient:** Lighting would change depending on ”how the baby is feeling or what [he/she] is doing” (P7). For instance, if the baby is sleeping, a darker environment would be needed, whereas color lights could be used to stimulate situations where the child is playing. Sound should also be used to favor more calm or creative moments.

- **Graphical:** Parents would be able to be ”in control of the whole environment” (P7) when using screens. They could not only choose what to display (for instance, playing a movie for the kid was raised as an example), but also have some screens that the child can play and interact with, ”screens where the baby can just touch” (P7). Sounds and colors would be part of this kid-vehicle interaction.

- **Tangible:** The car should be a clear space; there should be some tables that users can ”reconfigure as they want or [according to] the necessities” (P7). Storage space could be used for toys (i.e., tangible toys) the child can interact with. Some other necessary functional, tangible elements were also identified: a fridge, a bin, etc.

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Figure 11. Moodboard illustrating the ideas for the fundamental need 'Impact' [Pexelx, nd]

8) MORALITY:

In this case, religion was identified as a very relevant sub-need within morality and people's values, that could have a place in an in-vehicle context too. The scenario that was used to visualize this was a Muslim prayer. The three proposed interfaces would contribute differently to this context. The participants noted that the religious elements that they were giving as examples would change depending on the religion and the event addressed.

- **Ambient:** The lighting will be the base of the ambient experience. By turning the windows lighter or darker, different environments will be created. Prayer sounds could be transmitted through the speakers, and screens could be used to show visuals related to the ceremony.

- **Graphical:** Touch interfaces were mentioned as elements of the graphical user interface. Through touch screens, the interaction with different religious elements could be mimicked (e.g., ”touching the sacred book,” P13). Voice control would also be included here, which users would employ to set their system preferences.

- **Tangible:** A rotating platform could be included in the car, that would always point towards Mecca; the user would be located on top of the platform when praying.

9) PURPOSE:

A therapeutic scenario was proposed that would help users envision their future destination through technology. Participants were inspired by the forward movement of the car, which could be used as a metaphor for users' live direction.

- **Ambient:** Lighting and curtains would be used to create an intimate environment for the user.

- **Graphical:** VR glasses would be provided so that the user can see a virtual environment where their future goals would be shown. A touch screen could also be added to control the environment.

- **Tangible:** In this case, a massage chair will be provided to enhance user's relaxation. Apart from that, it was suggested that by using eye-tracking technology the car could know where the user is looking to move the interfaces accordingly.

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Figure 12. Purpose through VR headsets [Pexelx, nd]

10) RECOGNITION:

The sub-need ”connecting with people that appreciate you” was addressed. Related to that, participants raised that when users travel alone for a long time, interaction with friends, family, and other closely related people might favor users feeling recognized. Following this rationale, a scenario was created around a ”very advanced and modern” (P8) in-vehicle video-calling system, that involved different characteristics depending on the user interface that was addressed:

- **Ambient:** The in-vehicle environment would favor the quality of the video-call settings; for example, the lighting would be adjusted so that the user is properly visible on the webcam (”the car will adapt your lighting so that you are clearly visible”, P8). The sound could be used spatially, to simulate the location of the person that is calling the user.

- **Graphical:** The call would be visualized through a screen. Users should be able to ”control” (P8) the location of the video images; a control panel was mentioned as necessary for it. As such, screens could be located in the driving window, side windows or other seats (beside the user), for instance. Holograms were also pointed out as suitable to position the call where desired inside the car.

- **Tangible:** Users would interact on a more physical level when calling their relatives. For example, the car would ”put a seat beside you” (P8) in case the person on the call is also sitting. Besides, the spaces that are occupied by the holograms could be ”filled with solid” (P8), which would allow physically interacting with the person is in the other side of the call.”

11) RELATEDNESS:

To favor relatedness, participants thought about supporting human relations within community and professional projects by letting users attend meetings virtually when they are not able to attend them in person. Digital twins were mentioned as an enabling technology concept for this scenario. The interfaces were depicted as follows:

- **Ambient:** Virtual reality headsets would provide users with visuals and sounds regarding the virtual environment of the meeting. About the windows, participants suggested that they would "turn into screens when the meeting takes place" (P13) so that in case someone is not wearing the headset, they can also understand what is happening.

- **Graphical:** A tactile screen would be used for the meetings, supported by a voice-based digital assistant.

- **Tangible:** The position of the seats would change depending on the meeting's configuration.

12) <u>SECURITY:</u>

Participants identified that hostile outside environments could be a suitable scenario to support the need for security when in an autonomous vehicle; it was suggested that the vehicle could make users feel ”safe and welcome inside of the vehicle” (from the posters) as well as ”having control of the situation outside” (from the posters). In terms of the user interfaces:

- **Ambient:** It should create a warm atmosphere; diffused lights were suggested as possible in-vehicle elements, as well as regulable and relaxing music and temperature features. Participants suggested that the inside of the vehicle should not be visible from the outside.

- **Graphical:** Displays should be located in the doors and window glasses to show that they are properly locked and safe. Regarding the outside environment, the windows could use augmented reality to track the threats of the environment, so that users can act on them if necessary (e.g., by ”calling the 911,” P5). Another option would be to blur the outside, in case users prefer to be unconscious about what is happening.

- **Tangible:** Every user should be provided with their own space or individual cabinet, ”divided from the rest of the room” (P5) so that they can feel safe. A button could also be included that the participants can push in case something goes wrong in terms of safety. Lastly, participant 6 even suggested that this button could activate a mechanism where users would be transferred to a safer place (”as if they were ejected from the car,” P6).

13) STIMULATION:

Two scenarios were created to address the fundamental need for stimulation. The first scenario proposed a "party bus" concept, where users could have fun by singing and dancing:

- **Ambient:** The ambiance would be set by different sources and reflections of light (e.g. from a "disco ball", from the "dance floor," P16).
- **Graphical:** A screen would be used to provide users with a karaoke setting where they would be able to see text and images.
- **Tangible:** A microphone would be provided to capture the sound of the singing person. It would be a tangible element users can interact and play with.

The second scenario was linked to stimulating users mentally; a meditation room was suggested accordingly as a potential in-vehicle scenario.

- **Ambient:** Relaxing sounds and music would be used, as well as relaxing smells (e.g., incense). A carpet and trees would be located in the room and were clustered by the participants as part of the environment.
- **Graphical:** No graphical elements were suggested in this case, as the users should be concentrated on connecting with themselves (and not with the vehicle).
- **Tangible:** No interfaces were suggested in this case.

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Figure 13. Moodboard illustrating the ideas for the fundamental need 'Stimulation' [Pexelx, nd]

5.2 PROMISING COMBINATIONS

Below, the collected answers have been visualized in heat maps (see Tables 5 and 6) which serve to represent and communicate the preference densities within the generated solution space. The results for both questions (i.e., most attractive and most innovative scenarios) were also compared and combined, to analyze what the gaps could be concerning desired and technologically attractive scenarios and user interfaces.

Note that the color code shows relative results, meaning that it represents the number of votes that each scenario and use case received in relation to the most voted alternative. Absolute percentages will be added to the explanations.

ATTRACTIVE SCENARIOS AND USER INTERFACES

According to the participants, the scenario that was proposed for fulfilling the fundamental need for 'community' (i.e., "users will cook in the autonomous vehicles, to later share their dishes and ingredients with people in other cars") was the most attractive one (n=5 votes, meaning that the 35.7% of the participants selected it). Following it, we found 'autonomy', 'beauty', and 'recognition', all with 4 votes (28.6%). The remaining scenarios received 3 or 2 votes, being option b in 'stimulation' (i.e., the meditation room) the only one that received 1 vote (7.1%).

Regarding the user interfaces, the ambient user interface was the most selected one (n=18 votes, i.e., 42.9% of the selected combinations) as an attractive interface for the scenarios that were proposed. Second, we found the graphical user interface (n=13 votes, 31.0%), and third, the tangible user interface (n=11 votes, 26.2%).

As far as specific scenario and user interface combinations are concerned, the results are very scattered (e.g., the most voted combinations received a maximum of 3 votes in total) and thus no conclusive patterns could be found in the choices that the participants made, apart from the overall trend towards the ambient user interface as an enabler for scenarios that would be linked to human values or desires (i.e., attractiveness). For instance, regarding the scenarios that were mentioned before (i.e., the most attractive scenarios), different preferences were found depending on the scenario chosen. The 'community' scenario was divided between the ambient (n=3) and the graphical interfaces (n=2). The most attractive interface regarding the need for 'autonomy' was the tangible user interface (which received 3 votes), 'beauty' was equally divided between the ambient and graphical UIs (each of them with 2 votes), while participants selected all interfaces for the 'recognition' scenario (ambient, n=2; graphical and tangible with 1 vote). 'Relatedness' also received 3 votes when combined with the ambient user experience.

INNOVATIVE SCENARIOS AND USER INTERFACES

Regarding innovativeness, the results were more concentrated than in the previous case, meaning that higher contrast can be found between the high- and low-density areas of the heat map.

Accordingly, the scenario that would support the need for 'autonomy' received 6 votes, and it was considered innovative by most participants (having been voted by the 42.9 % of the participants). All participants agreed on the tangible user interface being the most innovative for enabling the scenario (i.e., all 6 votes supported the combination). The second most popular scenario when considering innovativeness was 'fitness' (n=5, 35.7 %). In this case, the ambient user interface (n=3) and the graphical user interface (n=2) were selected as innovative. The scenario linked to the need for 'community' followed, with 4 votes. In this case, the tangible user interface was considered to be the most innovative combination (n=3). The scenario for 'competence' also received 3 votes for the tangible user interface.

The remaining scenario and use case combinations belong to the low-density areas, that received isolated votes from the participants.

Overall, when looking for innovative scenarios and user interface combinations, participants mainly chose the tangible user interface (n=15 votes, i.e., 53.6% of the selected combinations). The ambient user interface followed (n=7 votes, 25%) and the graphical user interface was the least selected one (n=6 votes, 21.4%).

Fundamental need	Scenario	Ambient	Graphical	Tangible
Autonomy	The car will change its shape and configuration, considering where it is or where it is going.	1		3
Beauty	Users will be provided with new and exciting virtual views in situations in which outside landscapes are dull and boring.	2	2	
Comfort	A very easy, hassle-free and simple food delivery service will be created to receive food when traveling in an autonomous car.	1	1	1
Community	Users will cook in the autonomous vehicles, to later share their dishes and ingredients with people in other cars.	3	2	
Competence	The car will train users in their driving skills, through a simulator-like environment.			2
Fitness	The car will be a personal fitness tracker, that will be able to track users' bio-metrics. and will provide them with different stimuli to contribute to their health.	2		1
Impact	The car will be a space where to spend quality time with your kid while traveling.	1	1	1
Morality	The car will be a space where you can pray.		1	2
Purpose	The car will be a therapeutic space that will help users envision their future objectives.		2	
Recognition	A very advanced and modern in-vehicle video-calling system that will allow users to connect with people that appreciate them.	2	1	1
Relatedness	Users will be allowed to attend meetings virtually when they are not able to attend them in person as a way to support human relations.	3		
Security	The vehicle will make users feel safe, welcome and under control inside of the vehicle in situations in which the outside environment is hostile.		2	
Stimulation	a) The car will be a party room, where users can have fun by singing and dancing.	2	1	
	b) The car will be a meditation room, where users will be mentally stimulated.	1		

Table 5. Most attractive scenario and use cases.

Fundamental need	Scenario	Ambient	Graphical	Tangible
Autonomy	The car will change its shape and configuration, considering where it is or where it is going.			6
Beauty	Users will be provided with new and exciting virtual views in situations in which outside landscapes are dull and boring.	1		1
Comfort	A very easy, hassle-free and simple food delivery service will be created to receive food when traveling in an autonomous car.			1
Community	Users will cook in the autonomous vehicles, to later share their dishes and ingredients with people in other cars.	1		3
Competence	The car will train users in their driving skills, through a simulator-like environment.			3
Fitness	The car will be a personal fitness tracker, that will be able to track users' bio-metrics. and will provide them with different stimuli to contribute to their health.	3	2	
Impact	The car will be a space where to spend quality time with your kid while traveling.	1		
Morality	The car will be a space where you can pray.		1	
Purpose	The car will be a therapeutic space that will help users envision their future objectives.		1	1
Recognition	A very advanced and modern in-vehicle video-calling system that will allow users to connect with people that appreciate them.		1	
Relatedness	Users will be allowed to attend meetings virtually when they are not able to attend them in person as a way to support human relations.			
Security	The vehicle will make users feel safe, welcome and under control inside of the vehicle in situations in which the outside environment is hostile.			
Stimulation	a) The car will be a party room, where users can have fun by singing and dancing.	1		
	b) The car will be a meditation room, where users will be mentally stimulated.		1	

Table 6. Most innovative scenario and use cases.

ATTRACTIVE vs. INNOVATIVE SCENARIOS: SUBTRACTION AND SUM OF THE RESULTS

Table 7 reflects what the biggest differences are between the votes that 'attractiveness' and 'innovativeness' received. As such, the numbers in every cell indicate the difference in the vote percentage that both concepts received for every combination, being the color of the cell the one of the 'winning' concept. Therefore, by analyzing the table, it can be seen that ambient user interfaces were considered more attractive than innovative, while the tangible user interfaces show a trend of having been considered innovative rather than attractive. Graphical user interfaces have 'winning' combinations from both sides (i.e., 7 that were considered more attractive, 4 that were considered more innovative, and 3 that did not have any difference regarding both perspectives).

Regarding specific UI and scenario combinations, the tangible user interfaces in the 'Autonomy' and 'Community' scenarios can be highlighted as highly innovative (with superiority of 14.3% and 10.7% respectively to the votes that they received for the 'attractiveness' category). The differences in favor of the 'attractive' combinations are slightly lower, being a percentage of 7.1% the highest one, regarding the ambient UI in the 'relatedness' scenario. Nevertheless, more combinations were considered more attractive than innovative, if the whole table is taken into account (19 scenarios against 12).

Fundamental need	Ambient	Graphical	Tangible
Autonomy	2.4		14.3
Beauty	1.2	4.8	3.6
Comfort	2.4	2.4	1.2
Community	3.6	4.8	10.7
Competence			6.0
Fitness	6.0	7.1	2.4
Impact	1.2	2.4	2.4
Morality		1.2	4.8
Purpose		1.2	3.6
Recognition	4.8	1.2	2.4
Relatedness	7.1		
Security		4.8	
Stimulation a)	1.2	2.4	
b)	2.4	3.6	

Table 7. Contrast between attractive and innovative combinations

On the other hand, Table 8 reflects the vote percentage that a scenario and UI combination received in sum. The cases that the participants would consider both innovative and attractive may outstand in this case. For instance, the tangible UI in the 'Autonomy' scenario received the highest vote percentage (i.e., 28.6% of the votes), followed by the competence-tangible and fitness-ambient combinations (each with 15.5% of the votes) and the community-ambient and community-tangible combinations (with 10.7% for each). This also reflects that the graphical UIs received fewer votes overall for both innovativeness and attractiveness. In contrast, the table also shows some areas with very low vote densities, meaning that the scenarios were not considered innovative or attractive by the participants (e.g., 'security') or that one of the UIs concentrated the majority of votes (e.g., in the case of 'competence').

Apart from that, 'Autonomy', 'Community' and 'Fitness' were the top three fundamental needs (with 31.0%, 26.2%, and 25.0% of the votes each), whereas 'Security' (4.8%) and 'Relatedness' (7.1%) were the least chosen ones.

Fundamental need	Ambient	Graphical	Tangible	Total
Autonomy	2.4		28.6	31.0
Beauty	8.3	4.8	3.6	16.7
Comfort	2.4	2.4	6.0	10.7
Community	10.7	4.8	10.7	26.2
Competence			15.5	15.5
Fitness	15.5	7.1	2.4	25.0
Impact	6.0	2.4	2.4	10.7
Morality		6.0	4.8	10.7
Purpose		8.3	3.6	11.9
Recognition	4.8	6.0	2.4	13.1
Relatedness	7.1			7.1
Security		4.8		4.8
Stimulation a)	8.3	2.4		10.7
b)	2.4	3.6		6.0

Table 8. Sum ofbetween attractive and innovative combinations

5.3 INSIGHTS ABOUT THE UIs

ROLE OF THE USER: CHOICE, INVOLVEMENT AND CONTROL

Elements related to the control perception, choices on the interaction type, and user involvement were highlighted as varying among the different interfaces:

- **Passive user role:** low levels of consciousness and demanded attention from the users were linked to a passive user role. This was described as a state in which users do not need to think about controlling the interface, meaning that they should not give step-by-step instruction, and should only monitor the car environment. Related to this, ambient and graphical user interfaces were pointed out ("The main thing with ambiance and graphic [UIs] is that it needs less user involvement. So you need to, be less like active", P4). Participants emphasized further on the ambient user interface, stating that it can automatically sense and track the users ("it tracks your preferences and provide the environment for you," P6) which serves as input for the interface to decide on the environment to create ("the ambient interface (...) normally is always giving you the experience," P6).

- **Active user role:** the description of the active user role was twofold. On the one hand, users would be active actors when having a choice over the interactions with the car environment. According to the participants, choice was related to the graphical user interface ("the graphical one is like (...) to kind of impose your will on the car", P8); some participants suggested that graphical interfaces would provide the user with different options to choose from (P14). On the other hand, direct participation was also mentioned when talking about an active user role. In this case, tangible user interfaces were pointed out ("the tangible might require some more effort from the people that is inside the car", P7), suggesting that users needed to actively use their body to interact with the interface ("for the tangible one, you actually need to like, touch", "you (...) have to actively act on the input that you have, or the element that you have [at] the interface", P4).

In line with these ideas, insights about user control and vehicle agency were brought to the table. A trade-off between both

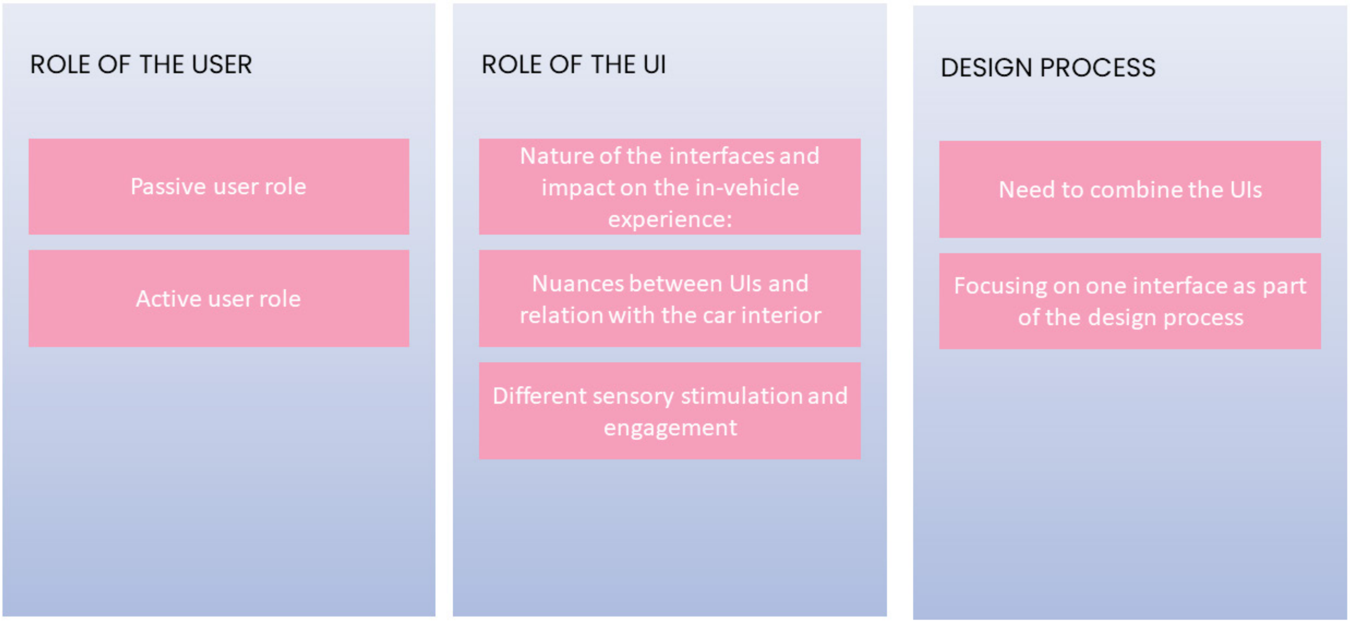

Figure 14. Overview of the themes

concepts was suggested by participant 10, who mentioned that users do not control the ambient and tangible interfaces, which are regulated by the vehicle itself (”I think for the ambient and robotic [tangible] one, it’s much more about the agency of the vehicle. I imagine there will be some kind of AI in there that does those kinds of things.”). P11 also described tangible interfaces as autonomous and not controlled by the users (”let’s say the table pops out automatically (...)”). P6 also talked about user control, suggesting that in the future brain control could be a suitable input for the ambient user interfaces, which would give users control (”the scenario I’m imagining is like maybe in the far far future where you can use your brain to control”). In contrast to these ideas, participants agreed on the fact that users would feel in control when interacting with a graphical user interface (”[about the graphical UI] these classic interfaces like touchscreens (...), where you feel much more in control”, P10).

ROLE OF THE UI: NATURE, IMPACT AND SENSORY STIMULATION WITHIN THE CAR ENVIRONMENT

- **Nature of the interfaces and impact on the in-vehicle experience:** participants had different opinions on the role of the UIs within the in-vehicle environment, mainly concerning the contributions that the interfaces make to the user experience. For instance, P2 argued that the tangible interface is ’basic’ whereas the other two are ’additions’ (”the physical [tangible] interface is the basic one. And the other ones are always going to be kind of adds. So if you want a screen, it’s already an addition that you maybe don’t really need”).

In contrast, on P17’s view, both the graphical and tangible interfaces would be the ’auxiliary’ interfaces, additions that enhance the overall experience (”ambient is more about the environment that the users may not notice, graphical and tangible are auxiliary services that can help users get better experience”). In line with this, some other participants saw the ambient interfaces as having a ’supporting role’ (P11) for an action that can be carried out with one of the other two interfaces, which was also described as 'providing context' (P14) or 'providig an environment' (P6).

The nature and characteristics of the interfaces were also analyzed from the perspective of intrusiveness and influence on the users and their experiences. In that respect, ambient interfaces were said to be less direct (P16) and intrusive (P11); they would have an influential role in the interaction among users that share an in-vehicle space (" ambiance (...) could change how people in groups are interacting with each other; for example, light and the colors of light can really affect the way people are interacting with each other, but also how an individual is interacting", P18).

As opposed to that, tangible user interfaces were mentioned to be 'highly intrusive and impacting' (P11), with a 'direct influence' (P16) on the passengers. The following quote from P11 illustrates these ideas:

"the robotic interface was kind of highly intrusive, because if it's autonomous, and if it does stuff which is wrong, it has a huge impact on the user. So let's say the table pops out automatically. If it pops out in the wrong position or at the wrong time, it's a very wrong, kind of it will feel very intrusive to the people in the car, whereas if the light is of the wrong color, I mean, probably it's not that much of intrusion to me like, I wouldn't care."

- **Different sensory stimulation and engagement:** it was observed in the workshops that every interface engages different senses (P1). Accordingly, participants suggested that different user interfaces would be selected depending on the kind of stimuli that is wanted (P2).

  Additional insights were revealed in this topic; for instance, it was raised that interfaces contribute differently when users need to connect with themselves or with others, due to the stimuli they bring in.

  Apart from that, sensory accessibility was raised as an issue to take into account. P1 pointed out that users with reduced sensory capabilities (e.g., blind person) should not be disregarded and should be supported by combining different user interfaces ("What if I cannot see, what do I do with a graphical interface? Maybe the other interfaces could help me and actually experiencing that").

- **Nuances between UIs and relation with the car interior:** participants reflected on how the different user interfaces would be included in the car environment. For instance, P1 mentioned that every interface could be connected to a different part of the car; it was suggested that the graphical UI could be related to the car interior, the ambient to the interactions with the outside while the tangible would be related to the seats or steering wheel. Nevertheless, P2 highlighted that the car interior is a physical setup, meaning that the graphical and ambient interfaces need to be embedded in that environment, which usually makes them adopt physical characteristics. Besides, P2 added that there are already many essential elements in a car, which are already physical options, that could be used for interactions with the users.

  Confronting opinions were raised in this matter; while some participants thought that the elements of the tangible interface are already part of the physical environment, others raised that the tangible UI does not feel like part of the car ("From my point of view, the tangible one is hard to add on a car. It makes you feel that's not part of the car", P9).

  Apart from that, the comments of the participants reflected that the boundaries and nuances between the three UIs proposed are not completely fixed. As such, it was mentioned that the graphical can be part of the ambient interface (P5), in case users want to personalize the environment and input their choices.

  The tangible interface was also said to be evolving. P4 said that there has been an evolution from the tangible to the graphical UIs in the automotive sector, as many physical elements have been replaced by screens ("before, (...) to lock the doors, you had to push a button. But now the button is on a screen. So it's just, instead of a tangible, now it's graphical, (...) So the tangible is being kind of substituted by the graphic at the moment, I think", P4). Additionally, it was mentioned that the tangible UIs could also become ambient as their nuances are not that clearly fixed ("if you have feedback from the car, that is temperature or whatever, then it turns into ambient instead of tangible, (...), even though there's kind of nuance there, an ambiguity between what's tangible and what's ambiance", P4).

DESIGN PROCESS: DIVIDE TO COMBINE

- **Need to combine the UIs:** many participants came to the conclusion that all three interfaces are important ("So, all three of them are important, but in a different way, and they connect to each other", P16), as they overlap in reality (P17) and thus choosing only one of them would be harder, as P2 stated.

  Related to that, it was raised that a complete solution would be created by combining the three interfaces, as the advantages and constraints of all three could work together ("in the end, if you combine all of them is the more complete", P2; "I wouldn't say that one interface will be best, but it needs to be taken into consideration, what the constraint, the advantages that one interface has (...) and maybe how those different ones can work together", P1). Moreover, P3 stated that a "smart" combination of senses would always be needed, for which combining user interfaces seemed to be interesting.

- **Focusing on one interface as part of the design process:** when commenting on the exercises they carried out, participants claimed that separating the user interfaces was also beneficial, as it forced them to think about specific aspects of each user interface (P5), which help them collect many ideas ("I think (...) it was quite nice, like this exercise, because we really tried to force ourselves to think how we can do this one thing or how we can do all of these functions that we have, with only one type of interface. It makes it collect a lot of ideas", P10). As P10 suggested, designers could first think about the interfaces separately, and "later [they] would combine the interfaces".

Chapter 6 -

DISCUSSION

The following chapter discusses the results that were obtained through this study, by connecting the insights from the literature to the results and to the feedback that the experts proposed. Fundamental needs in the context of autonomous vehicles and the most promising scenarios are discussed first, to later specify the limitations, contributions, and future research lines that this project might entail.

6.1 FUNDAMENTAL NEEDS IN AVs

Meaningful scenarios were created and ranked by the participants, which revealed that some fundamental needs were considered more relevant or prominent for the in-vehicle, autonomous contexts that were depicted in the study. In this section, we will refer back to the literature, the validation sessions, and to the latest practices in the mobility sector to see if our fundamental need hierarchy could be generalized to further AV contexts.

In line with the concept of sub-needs by [Desmet and Fokkinga, 2020a], E4 stated that domain-specific hierarchies can be found among the fundamental needs (i.e., "I wouldn't say [there is a] hierarchy in the level of [fundamental need] fulfillment in a general, (...) domain-free sense, but in actual activity, I would say people may prefer to fulfill certain needs in certain scenarios or activities"). This is something that we also found in the outcomes of our research; when asked about the most promising scenarios (i.e., most attractive and most innovative), participants gave the most votes to the fundamental needs 'autonomy', 'community', and 'fitness', followed by 'beauty' and 'competence'.

Comparing this resulting needs hierarchy to prior academic work, two different ways of approaching user needs in autonomous vehicles have been found. Some authors try to find categories among the needs and activities mentioned by participants, while others apply a top-down approach to analyze the needs of a specific framework (our approach would belong to this second category). From the first group, we have summarized the contributions in Section 2.2.4 (see Table 3), by relating the future activities and needs envisioned by users with the 'Typology of 13 fundamental needs'. As we can see in the table, the fundamental needs for 'stimulation' and 'fitness' were the most addressed ones, followed by 'relatedness', 'comfort', and 'security'. In the second group, [Distler et al., 2018] would give an example in which they analyzed six human needs in the context of AVs (i.e., autonomy, competence, relatedness, popularity, stimulation, and security), which were framed by [Hassenzahl et al., 2013] as relevant for providing users with positive experiences. The results of the study showed that 'security', 'autonomy', and 'competence' were perceived by participants as the most important needs.

According to E4, need hierarchies mainly depend on the demographic information of every user (i.e., they are shaped ”according to their own personality, life experience, and social status” and ”all kinds of demographic information,” E4), and thus, the results of the current research should be attributed to the specific characteristics of the participants we recruited for the workshops, who were mainly young master students in science and engineering-related fields (related to that, E4 commented: ”I also feel curious to know why they didn’t choose the one [of] stimulation because I would say ’the car can be a party room’ will be something really appreciated by students here, at their age”). In that respect, more nuanced descriptions of the users might be needed when talking about a fundamental need hierarchy in the context of autonomous vehicles, as will be mentioned in the implications for practice (Section 6.4).

As far as the automotive and mobility sectors are concerned, E6 and E3 discussed the fundamental needs that manufacturers mostly address. According to E6, the industry has mainly taken care of the needs for ’autonomy’, ’beauty’, comfort’, ’recognition’, and ’security’. For instance, autonomy would be a core need in mobility, as shown by the latest developments in batteries and new transportation modes such as VTOLs (i.e., Vertical Take-Off and Landing vehicles). Nuance was also added to how autonomy is addressed, as it is usually provided from a vehicle perspective rather than from the perspective of users. In this regard, E3 mentioned that ’a ton of research’ can be found in autonomous in-vehicle configurations, that would be aimed at adapting the vehicle interiors to the different user profiles and activities that AV users would like to carry out. Beauty would also be a historically relevant feature in the automotive sector (E6), where vehicle styling was highlighted. E6 also mentioned that the needs for community and fitness are not that addressed in the sector (”I don’t think really there’s a lot of stuff happening (...) in the community aspect in mobility,” E6). In contrast to this, E3 said that ’community’ is something they have been looking to enhance in the context of single personal mobility modes (i.e., bicycles), where spontaneous social interactions could be favored and created.

To conclude, there are no well-defined need hierarchies that we could generalize for the context of AVs, at first sight. Nevertheless, two conclusions could be done here, which manufacturers might want to take into account when proposing new experience-concepts (See Section 6.5). First, some fundamental needs are often more prominent (for instance, 'Autonomy'), both in academia and real-life applications, which suggests that they are probably relevant to the context of autonomous vehicles. Second, by comparing the results from the literature with the traditional needs that are addressed in the mobility sector, we can see that manufacturers could take inspiration from academic work to open their scope of action to some relevant but still unattended needs. For example, the need for 'fitness' and 'community' can be pointed out.

6.2 PROMISING COMBINATIONS

Promising scenario and UI combinations were identified from two different angles; namely, participants were asked to vote for the most attractive and most innovative combinations according to their own preferences. Some gaps were found between both result categories, being the main difference that attractive combinations were mostly related to ambient UIs, whereas innovativeness was linked to the tangible UIs.

The experts discussed the potential reasons behind this contrast. Regarding **attractive** scenario and UI combinations, it was raised that the ambient user interfaces might be preferred by the participants as they offer interactions that feel ”more elemental, natural and human”, similar to the ”ambient nudges” that we experience in real life (E1). As E1 explained, ”for the ambient user interface, I would say that the closest analog is personal interaction, either social or environmental, which is to say it is the closest thing that we have to replicate our actual natural, non-technological, non-material engagements with the world”. Similarly, E3 and E4 referred to ambient UIs as more appealing and relaxed than the other two interfaces. Users might experience them as ”immersive” (E1), ”less invasive”, ”more subtle” and located in the background (E3), and thus, as less attention-demanding. Finally, convenience was also mentioned as a reason behind the results obtained for the attractiveness category. E5 pointed out that in this category participants chose the scenarios that could be useful in their everyday lives and thus they were also being pragmatic in a way when choosing ambient UIs (”people are just being pragmatic; although it’s not as impressive or futuristic as some of the other things that pop up [in] the tangible user interface part, still, it’s more convenient," E5).

In contrast, the concept of **innovativeness** was overall perceived to be better represented by tangible user interfaces. First, experts claimed that both technology (E4) and ”futuristic” elements (E1, E5) (e.g., space transformations), which are usually linked to innovation, were among the proposed tangible UIs (”innovativeness, people usually associate it with technology. [And] when we [are] speaking of technology, we usually imagine something really tangible”, E4). Second, participants may see tangible elements, such as ”mechanical advancements” (E3) or hardware (E5) as more difficult to innovate on, and therefore, they voted the tangible UIs as more innovative. Related to that, E1 raised that people are ”biased towards tangible things;" examples are needed ”based on which to form opinions and rank” and those are harder to find with the other two user interfaces (for instance, ”people haven’t seen 1000 variations of a hologram” (E1), while they are more used to having examples of tangible variations). Besides, the experts added nuance to the word used in the questionnaire. As E4 and E3 pointed out, ’innovative’ is different from ’novel’; while novelty might be linked to unprecedented ideas or combinations, innovation is usually seen as pushed by technology. Finally, according to E4, when being asked about innovations participants voted for alternatives they would like to see happening but don’t envision in a near future.

Concerning **graphical user interfaces,** E3 raised that we have ”gotten used” to them due to the vast presence they currently have in our lives, which could be the cause of the fewer votes they received for both categories.

These discussions could also be related to different **innovation frameworks.** According to [Dell’Era et al., 2018], innovation can be based on new technologies, meanings, or both. Incremental (i.e., ’incremental technology improvements’ and ’meaning adaptations to the evolution of sociocultural models’) or radical innovations (i.e., ’radical technology improvements’ and ’generation of new meanings’) could take place for these categories; by combining those two axes, the authors propose a bi-dimensional framework. Concerning our research, we could link the meaning axis to the scenarios (as scenarios would give meaning to the future in-vehicle experiences) while the technology axis would be represented by the three different UIs.

In this regard, we could say that, when voting for the most innovative scenarios, participants chose the scenarios that generated new meanings in the in-vehicle environments. For instance, seeing a car as a personal fitness tracker (see ’fitness’ scenario) or as a simulator where to train one’s driving skills (see ’competence’ scenario) is something that current cars do not offer; in contrast, we would have scenarios that do not introduce any new meanings to the current cars (e.g., the car as space were to spend quality time or cars used for delivery-services).

Once the scenarios were chosen, we hypothesize that, when voting for the most innovative UI adaptations, participants chose the technology that they perceived as the most radical improvement. The results show that these were mainly tangible UIs, with an exception in the fundamental need for 'fitness', where the ambient UI was chosen. Looking closer at this case, the vehicle agency might have been seen by participants as more breakthrough than a massage chair which would still fit our hypothesis.

On the other hand, the category of most attractive scenarios would represent what participants would like to have in an in-vehicle environment. The concept of user-centered innovation that [Dell'Era et al., 2018] discuss may be related to the results of this category. As they claim, " user-centered innovation often concerns better ideas to solve established problems; (...) a new how, a new way to address the challenges considered relevant" (p. 2). As such, the prominent scenarios, in this case, include in-vehicle video calling systems (see 'recognition') or party rooms (see 'stimulation'). Both examples are adaptations of currently available solutions in the mobility sector (for instance, a limousine would be a vehicle that could be used for partying). Our hypothesis here is that in this case, participants voted for the values that they would like to support in future AVs, being the means for experiencing those innovations things they can imagine, representing mainly incremental innovations.

[König and Neumayr, 2017] state that "people regularly react with caution and wariness to new things and change" (p. 43), which may be the reason why the results for innovation and attraction are not coincident in our study. Related to that, [Rogers, 1983] classifies five different innovation adopter categories, claiming that individuals in a social system adopt an innovation in a time sequence, rather than at the same time. Adoption of innovation usually follows a normal, bell-shaped curve when plotting time and frequency.

6.3 LIMITATIONS

This study is mainly limited by its exploratory nature. The project was conceived as an initial exploration into the fields of robotics and user experience design of autonomous vehicle environments, and, as such, we are still not able to specify concrete design concepts. The results serve rather to set a solid ground to understand the context, to give recommendations, and to clarify the design directions that could possibly be taken in later concept development stages, that would need further scoping, research, and detailing activities.

This said, the constraints and decisions that were taken in every stage of the project entailed certain additional limitations that should be taken into account, both to understand the value of the results that are offered and as a consideration when planning future research. First, regarding the initial scope of the research, a simplification of the levels of automation was done (by neglecting the constrains of SAE level 3) in order to simplify the preliminary approach that the research was taking. Further work might also consider the third level of automation, as it brings in relevant constraints to the driver's user experience.

Second, regarding the workshops, the fact that participants were quite homogeneous is a limitation to consider. More varied demographics and expertise levels into the field of AVs would have been included in case time and resource constraints didn't exist. Besides, both in the questionnaires and the number of workshops that were carried reaching saturation would have been beneficial. Future work might consider this by, for example, scaling the questionnaire to statistically sound numbers of respondent. Concerning the data analysis stage, researcher bias might have been introduced as only one researcher transcribed, analyzed and coded the data. Researcher triangulation techniques shall be included in future work.

Finally, regarding the final results, it is important to mention that the results that fundamental need hierarchies and most promising combinations got might be affected by the specific scenarios that the participants designed, as well as by the personal biases of the 18 participants that took part in the research. Future work might consider repeating the same tests with different scenarios to see if the results are consistent.

6.4 CONTRIBUTIONS

The results of this study may contribute both academic knowledge and industrial practice to frame the topic of in-vehicle experience design in the autonomous vehicle context.

The ultimate goal of this research is to give recommendations on how to provide meaningful autonomous experiences for future drivers and passengers, and to explore how could this be done by implementing technologies from the fields of robotics and artificial intelligence. As such, the 'typology of 13 fundamental needs' has been taken as a framework to see how those needs could be addressed with different UIs. Participants were asked about the most promising scenario and UI combinations; accordingly, we offer results about what participants would like to have in the future and also about what scenarios they considered most innovative. Finally, insights about how the different UIs affect the in-vehicle experiences have been gathered and clustered.

IMPLICATIONS FOR PRACTICE

Practitioners might use these results in two ways. First, possible design directions are given, by pointing out relevant fundamental needs, that differ to some extent to the fundamental needs that industrial practice has covered until now. For instance, manufacturers could consider how to include 'fitness' elements within the experiences they provide. User perceptions on different UIs can also be used as guidelines.

Second, this project could also be seen as an example of how we can design for meaningfulness within autonomous vehicles or technology-driven settings. The sequence it suggests, that goes from fundamental needs to specifying scenarios, to later defining UIs and, finally considering technology, is an approach that industrial practice could also adopt.

IMPLICATIONS FOR THEORY

Regarding theory, this research explores the concept of fundamental needs in autonomous vehicle contexts, which might contribute to further advance in understanding how meaningful user experiences can be provided for future passengers. Apart from that, analyzing the concept of interface and comparing ambient, graphical and tangible UIs might help further define the implications of each interface in the interactions with the users.

FUTURE RESEARCH

Future research might consider some of the additional research paths that were revealed through the study.

Regarding meaningful autonomous vehicle experiences, it would be interesting to analyze context dependent fundamental need hierarchies across different demographics. This would be relevant to know, so that manufacturers can direct their designs to certain customer segments. Based on that, AI technologies could be used to personalize user experiences further.

Further work could also be done in the classification of the UIs. Mapping out the interactions that each UI enables, the boundaries and combinations of different interface types as well as the engaged senses might be interesting.

Finally, this study also revealed that the strategic component should not be underestimated when providing users with new AV experiences, as users might have different perceptions into what a promising scenario is (as an innovative scenario might not be attractive, as the results revealed).

Chapter 7

PROJECT CONCLUSION

The following chapter serves as a wrap up of the project.

7.1 PROJECT CONCLUSION

This study has explored the concept of meaningfulness within future autonomous vehicle environments, with the aim to analyze how robotics technology could enhance future non-driving-related activities.

An extensive literature review on the topics of driving automation, user needs within AVs, robotics, AI, and user interfaces was done, which revealed that ample capabilities can be derived from robotics and AI, requiring additional boundaries for the design of meaningful user experiences. Therefore, focus was set on studying scenarios (that would be designed to address fundamental needs) and user interfaces (that would be the means by which technology and users interact).

Co-creative workshops were carried out with a total of 18 participants, to study what in-vehicle scenarios could be designed to support fundamental needs in non-driving-related activities, as well as to rank the most promising scenario and UI combinations. Insights on how different types of user interfaces affect the in-vehicle user experience were also gathered. Those results were validated with six experts from related academic fields, which brought in nuance on the preliminary analysis that was carried.

The results of the study show that 'autonomy', 'community', and 'fitness' are the fundamental needs that stood out. We also learned that participants find ambient interfaces more attractive while they link tangible interfaces more to the concept of innovativeness.

This initial exploration into the field hopes to set a theoretical base to upcoming design and development projects. Practitioners could take the results as guidelines and use the process for their own designs. Finally, regarding theory, this work hopes to help clarify the factors that influence user experience in autonomous vehicles.

REFERENCES

[Alpers et al., 2020] Alpers, B. S., Cornn, K., Feitzinger, L. E., Khaliq, U., Park, S. Y., Beigi, B., Hills-Bunnell, D. J., Hyman, T., Deshpande, K., Yajima, R., Leifer, L., and Shluzas, L. A. (2020). Capturing passenger experience in a ride-sharing autonomous vehicle: The role of digital assistants in user interface design. pages 83–93. Association for Computing Machinery, Inc.

[Azevedo-Sa et al., 2021] Azevedo-Sa, H., Jayaraman, S. K., Esterwood, C. T., Yang, X. J., Robert, L. P., and Tilbury, D. M. (2021). Real-time estimation of drivers' trust in automated driving systems. *International Journal of Social Robotics,* 13:1911–1927.

[Beardow et al., 2020] Beardow, C., Lomas, D., and Maden, W. V. D. (2020). Designing smart systems: Reframing artificial intelligence for human-centered designers.

[Beer et al., 2014] Beer, J. M., Fisk, A. D., and Rogers, W. A. (2014). Toward a framework for levels of robot autonomy in human-robot interaction. *Journal of Human-Robot Interaction,* 3:74

[Bekey, 1998] Bekey, G. A. (1998). On autonomous robots.

[Bennett and Lemoine, 2014] Bennett, N. and Lemoine, G. J. (2014). What vuca really means for you. *Harvard Business Review.*

[Blessing, 2003] Blessing, L. (2003). What is this thing called design research?

[Cash, 2018] Cash, P. J. (2018). Developing theory-driven design research. *Design Studies,* 56:84–119.

[Coeckelbergh, 2019] Coeckelbergh, M. (2019). Ethics of artificial intelligence: Some ethical issues and regulatory challenges. pages 31–34.

[Coppola and Silvestri, 2019] Coppola, P. and Silvestri, F. (2019). Autonomous vehicles and future mobility solutions.

[Dell'Era et al., 2018] Dell'Era, C., Altuna, N., and Verganti, R. (2018). Designing radical innovations of meanings for society: Envisioning new scenarios for smart mobility. *Creativity and Innovation Management,* 27:387–400.

[Desmet, 2020] Desmet, P. (2020). *Need profiles of 16 alarm clock designs.* Delft University of Technology, Netherlands. Internal Report.

[Desmet and Fokkinga, 2020a] Desmet, P. and Fokkinga, S. (2020a). Beyond maslow's pyramid: Introducing a typology of thirteen fundamental needs for human-centered design. *Multimodal Technologies and Interaction,* 4:1–22.

[Desmet and Fokkinga, 2020b] Desmet, P. M. A. and Fokkinga, S. F. (2020b). Thirteen fundamental psychological needs.

[Distler et al., 2018] Distler, V., Lallemand, C., and Bellet, T. (2018). Acceptability and acceptance of autonomous mobility on demand: The impact of an immersive experience. volume 2018-April. Association for Computing Machinery.

[Filev et al., 2013] Filev, D., Lu, J., and Hrovat, D. (2013). Focus on dynamic systems control.

[Floridi, 2019] Floridi, L. (2019). Autonomous vehicles: from whetherand when to where and how. *Philosophy and Technology,* 32:569–573.

[Garcia et al., 2007] Garcia, E., Jimenez, M. A., de Santos, P. G., and Armada, M. (2007). The evolution of robotics research: From industrial robotics to field and service robotics. *IEEE Robotics Automation Magazine.*

[Garcia and Calantone, 2002] Garcia, R. and Calantone, R. (2002). A critical look at technological innovation typology and innovativeness terminology: a literature review.

[Geiser and Kim, 2021] Geiser, F. and Kim, E. (2021). Exploring meaningful user experience in the domain of mobility.

[Giacomin, 2014] Giacomin, J. (2014). *What is human centred design?* Design Journal, 17:606–623.

[Giraldi, 2020] Giraldi, L. (2020). The future of user experience designin the interior of autonomous car driven by ai. In Ahram, T., Karwowski, W., Vergnano, A., Leali, F., and Taiar, R., editors, *Intelligent Human Systems Integration,* volume 1131, pages 46–51. Springer.

[Gross, 2003] Gross, T. (2003). Ambient interfaces in a web-based theatre of work. pages 55–62. Institute of Electrical and Electronics Engineers (IEEE).

[Gruver, 1994] Gruver, W. A. (1994). Intelligent robotics in manufacturing, service, and rehabilitation: An overview. *IEEE Transactions on industrial electronics,* 41.

[Gujónsdóttir and Lindquist, 2008]Gujónsdóttir, R. and Lindquist, S. (2008). Personas and scenarios: Design tool or a communication device? pages 165–176. ACM Press.

[Hassenzahl et al., 2013] Hassenzahl, M., Eckoldt, K., Diefenbach, S., Laschke, M., Lenz, E., and Kim, J. (2013). Designing moments of meaning and pleasure. experience design and happiness. *International Journal of Design,* 7:21–31.

[Helldin et al., 2013] Helldin, T., Falkman, G., Riveiro, M., and Davidsson, S. (2013). Presenting system uncertainty in automotive uis for supporting trust calibration in autonomous driving. pages 210–217.

[Hookway, 2014] Hookway, B. (2014). *INTERFACE.*

[Human and Watkins, 2022] Human, S. and Watkins, R. (2022). Needs and artificial intelligence.

[IBM, 2019] IBM (2019). Characteristics of ai. [Online consultation date: 2022-04-30].

[Iizuka et al., 2014] Iizuka, S., Iio, J., and Matsubara, H. (2014). Reviewing the role of the science fiction special interest group via user interfaces: The case of science fiction movies. *Industrial Applications of Affective Engineering,* pages 233–240.

[Jazdi et al., 2020] Jazdi, N., Talkhestani, B. A., Maschler, B., and Weyrich, M. (2020). Realization of ai-enhanced industrial automation systems using intelligent digital twins. volume 97, pages 396–400. Elsevier B.V.

[Kaplan and Haenlein, 2019] Kaplan, A. and Haenlein, M. (2019). Siri, siri, in my hand: Who's the fairest in the land? on the interpretations, illustrations, and implications of artificial intelligence.

[Khayyam et al., 2020] Khayyam, H., Javadi, B., Jalili, M., and Jazar, R. N. (2020). Artificial intelligence and internet of things for autonomous vehicles. pages 39–68. Springer International Publishing, Cham.

[Kim et al., 2018] Kim, E., Beckman, S. L., and Agogino, A. (2018). Design roadmapping in an uncertain world: Implementing a customer experience-focused strategy. *California Management Review,* 61:43–70.

[Kim et al., 2015] Kim, H. S., Yoon, S. H., Kim, M. J., and Ji, Y. G. (2015). Deriving future user experiences in autonomous vehicle. pages 112–117. Association for Computing Machinery, Inc.

[Kim et al., 2020] Kim, S., Chang, J. J. E., Park, H. H., Song, S. U., Cha, C. B., Kim, J. W., and Kang, N. (2020). Autonomous taxi service design and user experience. *International Journal of Human-Computer Interaction,* 36:429–448

[Krome et al., 2015] Krome, S., Goddard, W., Greuter, S., Walz, S. P., and Gerlicher, A. (2015). A contextbased design process for future use cases of autonomous driving. pages 265–272. Association for Computing Machinery (ACM).

[König and Neumayr, 2017] König, M. and Neumayr, L. (2017). Users' resistance towards radical innovations: The case of the self-driving car. *Transportation Research Part F: Traffic Psychology and Behaviour,* 44:42–52.

[Large et al., 2019] Large, D. R., Burnett, G., Salanitri, D., Lawson, A.,and Box, E. (2019). A longitudinal simulator study to explore drivers' behaviour in level 3 automated vehicles. pages 222–232. Association for Computing Machinery, Inc.

[Lee et al., 2022] Lee, S. C., Nadri, C., Sanghavi, H., and Jeon, M. (2022). Eliciting user needs and design requirements for user experience infully automated vehicles. *International Journal of Human Computer Interaction,* 38:227–239.

[Maslow, 1943] Maslow, A. H. (1943). *A Theory of Human Motivation.* Psychological Review.

[Meschtscherjakov et al., 2015] Meschtscherjakov, A., Tscheligi, M., Szostak, D., Ratan, R., McCall, R., Politis, I., and Krome, S. (2015). Experiencing autonomous vehicles: Crossing the boundaries between a drive and a ride. volume 18, pages 2413–2416. Association for Computing Machinery.

[NHTSA, nd] NHTSA (n.d.). Preliminary statement of policy concerning automated vehicles. Nationa Highway Traffic Safety Administration Preliminary Statement of Policy Concerning Automated Vehicles.

[Ong et al., 2019] Ong, A., Troncoso, J., Yeung, A., Kim, E., and Agogino, A. M. (2019). Towards flexible ridesharing experiences: human-centered design of segmented shared spaces. In Stephanidis, C., editor, *HCI International 2019 - Posters - 21st International Conference, HCII 2019, Proceedings,* volume 1034 of *Communications in Computer and Information Science,* pages 373–380. HCI International, Springer.

[Oulasvirta et al., 2020] Oulasvirta, A., Dayama, N. R., Shiripour, M.,John, M., and Karrenbauer, A. (2020). Combinatorial optimization of graphical user interface designs. *Proceedings of the IEEE,* 108:434–464.

[Patton, 2015] Patton, M. Q. (2015). Qualitative research and evaluation methods. Integrating design and practice. SAGE Publications, 4thedition.

[Pfleging et al., 2016] Pfleging, B., Rang, M., and Broy, N. (2016). Investigating user needs for non-driving-related activities during automated driving. pages 91–99. Association for Computing Machinery.

[Pfleging and Schmidt, 2015] Pfleging, B. and Schmidt, A. (2015). (non-) driving-related activities in the car: Defining driver activities for manual and automated driving.

[Ravitch and Carl, 2015] Ravitch, S. M. and Carl, N. M. (2015). Validity: Processes, strategies and considerations. In *Qualitative research: bridging the conceptual, theoretical and methodological,* chapter 6, pages 186–211. SAGE publications, London.

[Razavian et al., 2020] Razavian, N., Knoll, F., and Geras, K. J. (2020). Artificial intelligence explained for nonexperts. *Seminars in Musculoskeletal Radiology,* 24:3–11.

[Riek, 2012] Riek, L. (2012). Wizard of oz studies in hri: A systematic review and new reporting guidelines. *Journal of Human-Robot Interaction,* pages 119–136.

[Riener et al., 2022] Riener, A., Jeon, M., and Alvarez, I., editors (2022). *User Experience Design in the Era of Automated Driving,* volume 980. Springer International Publishing.

[Rogers, 1983] Rogers, E. M. (1983). *Diffusion of innovations.* Free Press.

[Royakkers and van Est, 2015] Royakkers, L. and van Est, R. (2015). A literature review on new robotics: Automation from love to war. *International Journal of Social Robotics*, 7:549–570.

[Russell and Norvig, 2022] Russell, S. and Norvig, P. (2022). *Artificial Intelligence. A modern approach.* Pearson, 4th edition.

[Rödel et al., 2014] Rödel, C., Stadler, S., Meschtscherjakov, A., andTscheligi, M. (2014). Towards autonomous cars: The effect of autonomy levels on acceptance and user experience. Association for Computing Machinery.

[SAE, 2021] SAE (2021). *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles.* SAE International.

[Sanders and Stappers, 2020] Sanders, E. and Stappers, P. J. (2020). *Convivial Toolbox. Generative research for the front end of design.* BIS, 5th edition.

[Sivak and Schoettle, 2016] Sivak, M. and Schoettle, B. (2016). Would selfdriving vehicles increase occupant productivity? sustainable worldwide transportation.

[Tang et al., 2020] Tang, P., Sun, X., and Cao, S. (2020). Investigating user activities and the corresponding requirements for information and functions in autonomous vehicles of the future. *International Journal of Industrial Ergonomics,* 80.

[Trubia et al., 2020] Trubia, S., Severino, A., Curto, S., Arena, F., and Pau, G. (2020). Smart roads: An overview of what future mobility will look like. *Infrastructures,* 5:1–12.

[van der Meer and Heijne, 2019] van der Meer, H. and Heijne, K. (2019). *Road Map for Creative Problem Solving Techniques.* Boom.

[Wright et al., 2017] Wright, T. J., Agrawal, R., Samuel, S., Wang, Y., Zilberstein, S., and Fisher, D. L. (2017). Effects of alert cue specificity on situation awareness in transfer of control in level 3 automation. *Transportation Research Record,* 2663:27–33.

[Xu, 2005] Xu, D. (2005). Tangible user interface for children an overview.

[Yang et al., 2020] Yang, L., Semiromi, M. B., Auger, D., Dmitruk, A., Brighton, J., and Zhao, Y. (2020). The implication of non-driving activities on situation awareness and take-over performance in level 3 automation. volume 2020-October, pages 5075–5080. IEEE Computer Society.

APPENDIX

A. Graduation brief

Framing opportunities of AI-systems in the autonomous vehicle exper 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 - 2022 22 - 07 - 2022 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, ...).

FRAMING THE OPPORTUNITIES OF AI-SYSTEMS IN THE AUTONOMOUS VEHICLE EXPERIENCE

The spread of autonomous vehicles (AVs), whose technology is becoming more accessible and ordinary (Trubia et al., 2020), opens new paradigms and opportunities to the mobility industry. Khayyam et al. (2020) mention the “releasing of driver time and business opportunities” and “new potential market opportunities” among the benefits that AVs bring. Related to that, it is envisioned that the user behaviour will completely change when travelling in autonomous vehicles, due to the change in their roles and tasks; for instance, when the relevance of driving decreases, new spatial meanings will be created (Kim et al., 2015). Therefore, many authors claim the need for understanding the factors that influence user experience in autonomous vehicles (Alpers et al., 2020), seek to elicit user needs and design requirements (Lee et al., 2022) and highlight that automobile manufacturers could offer “new technologies for functions that go beyond traditional needs” (Lu et al., 2013). This is even more important in higher levels of automation (namely, level NHSTA-4), in which “the vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip” (Rödel et al., 2014).

To date, research around the user experience in Autonomous Vehicles has mainly focused on improving the driving task performance and reducing safety concerns (Meschtscherjakov et al., 2015), such as the system take-over in the third automation level (Kim et al., 2015). Driver trust and information support systems (Riener et al., 2022) have also been widely analysed. Nevertheless, there is an emerging trend on studies that analyse the new role of autonomous vehicles and focus on the non-driving-related activities that passengers and drivers will carry (Kim et al., 2015; Pfleging & Schmidt, 2015). For instance, Geiser and Kim (2021) proposed an approach to understand what a meaningful user experience is in the mobility domain by looking at how fundamental needs and sub-needs can be fulfilled. They analysed how inborn, universal needs (Desmet & Fokkinga, 2020) are operationalized in specific goals and desires within the mobility context. Exploring what a meaningful autonomous experience is for future drivers and passengers is a knowledge area to still discover.

Besides, in-vehicle single-sided interventions are usually proposed for AV systems (e.g., an improved UI design). Alpers et al. (2020) suggest that interventions could also work in response to a passenger’s monitored physiological and emotional state, through the design of control feedback loops. Continuous measures, contextual factors and personalization are revealed by Reiner et al. (2022) as new directions that will enable emotional regulation processes, and thus lead to improved in-vehicle experiences.

In this regard, AI-sub-systems might open a new opportunity area that should be explored further. Using the concept of sub-systems, the focus is pull away from the main driving AI-system and secondary non-driving-related future activities are addressed.

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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.

With this in mind, two main challenges are identified. First, a methodological challenge is found when addressing the design of AI-related experiences. Things "now hold both perception and possible agency (e.g., AI), and thus "participate" in design and use in ways that previous industrially produced objects could not" (Giaccardi, 2022). Accordingly, the 'things-centred design' (Giaccardi & Redström, 2020) design approach presents a valuable addition for designing with the Internet of Things. Second, the challenge of how to design experiences that fit all contexts and users arises. Assessments that are sensitive to the needs of a specific and changing context (van der Maden, 2022) could be used to measure the impact of context-dependent factors on the users and their experience. Actions to improve and optimize those factors could later be taken by using feedback loops.

The ultimate goal of this research is to give recommendations on how to "provide meaningful autonomous experiences for future drivers and passengers". Therefore, the research will aim at answering the following research question and sub-questions:

- RQ: What are the most relevant fundamental needs and sub-needs for the future user experience in autonomous vehicles?
-SQ1: What opportunities do AI-sub-systems present for fulfilling those needs?
-SQ2: Based on that, what new functionalities can be implemented in autonomous vehicles to enhance the future user experience?

ASSIGNMENT **

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

Research on the user needs within the future autonomous vehicle experience and the opportunities of AI-sub-systems in their fulfilment. Based on that, recommendations and strategic opportunity spaces will be delivered as an outcome, to inform automotive manufacturers for a later design and conceptualization stage.

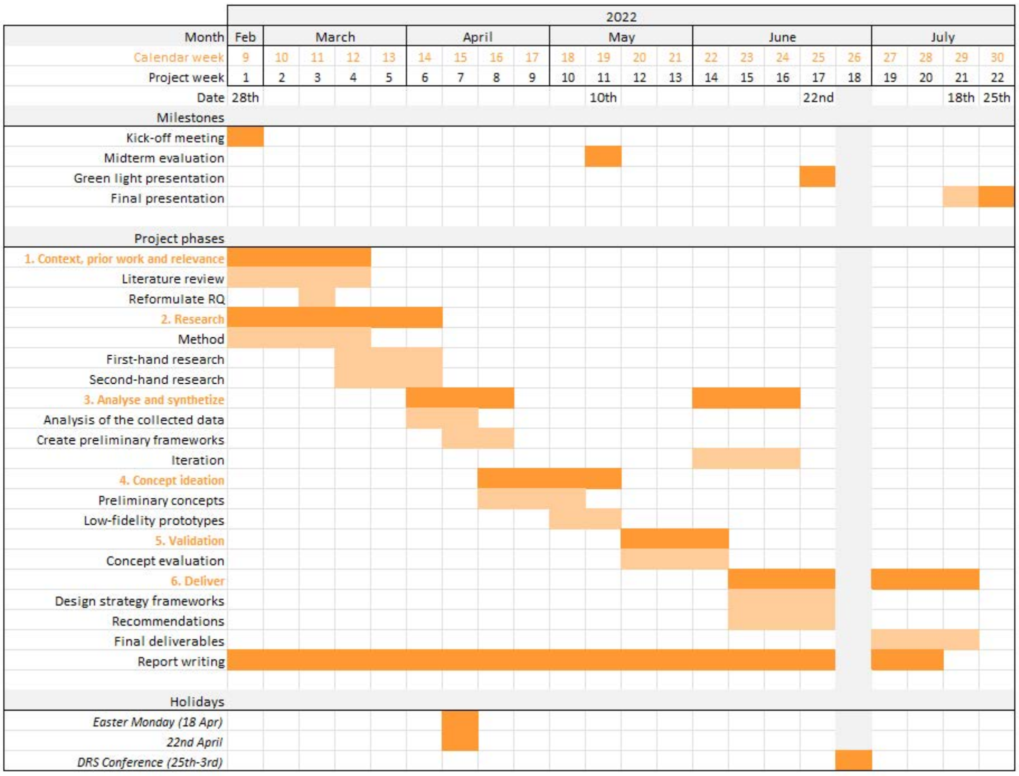
This research project is part of a larger research and development initiative that TU Delft is working on together with an automotive manufacturer in the concept of in-vehicle sub-robots (that are addressed here as AI-systems or AI-sub-systems). It aims to set a common ground for later concept development stages. First, in the research stage, information will be collected, relevant to the user experience in autonomous vehicles and the autonomous mobility contexts. A combination of desk research (e.g., literature review), preliminary qualitative first-hand research (e.g., observations and interviews) and second-hand research (e.g., introspection research) will be conducted. Second, the collected data will be analyzed and synthetized. It will be a process of making sense of information, framing and understanding user needs, which will become inputs for creating imperatives in reframed mobility opportunities.Third, preliminary concepts will be created by following the guidelines of the formulated frameworks; the aim here will be to explore what new (AI-driven) functionalities could be implemented in autonomous vehicles to enhance the user experience. Low-fidelity prototypes of the concepts will be created.
Lastly, in the validation stage, an evaluation will be conducted in those prototypes, and an iteration will consequently be done in the frameworks. Based on the new frameworks, recommendations will be given to inform automotive manufacturers for a later design and conceptualization stage.

The expected outcome is the delivery of design strategy frameworks, preliminary recommendations and/or opportunity spaces for the development of an (in-vehicle) sub-robot concept that will improve the user

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 - 2022 | 22 - 7 - 2022 end date



PHASES:
1. Context, prior work and relevance
2. Research
3. Analyse and synthetize
4.Concept ideation
5. Validation
6. Deliver

MILESTONES:
Midterm evaluation: (week 19) 10th of May
Green-light presentation: (week 25) 22nd June
Final presentation: anytime from 18th July to 31st July or end of August (29th, 30th, 31st)

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.

The compulsory and elective semesters of the Strategic Product Design Master program gave me some valuable competences for this Graduation project. On the one hand, in the SPD Research course, I learned the mindset required for approaching research, as well as the tools and methods that can be used. In Design Strategy Project, I trained conceptualization and problem-solving skills in abstract and complex contexts. I understood what opportunity identification means, and how it is linked to value creation. In the Design Roadmapping course, I learned to create visions for future scenarios and to develop roadmaps towards them. Finally, thanks to the Joint Interdisciplinary Project that I participated on during my elective semester, I learned to manage projects in multidisciplinary environments. I hope to be able to prove all these competences with my Master Thesis.

Apart from those, there are certain competences that I should still acquire, and the Graduation Project will be a good opportunity for that. I listed them below:
-Mapping and designing user experiences.
-Implementing design methodologies that go beyond Human-centred approaches (e.g. things centred design or impact-centred design).
-Designing for AI systems.
-Measuring the impact of context-dependent factors (I already worked on this during the Health and Psychology elective, but I think that I can still dive deeper on the topic).
-Project management of an individual research project.
-Aligning research outcomes and industry needs.

Besides, there are also two personal learning ambitions behind this project. First, I would like to get more in-depth knowledge in the mobility subject. After doing a 10-week project for NS in the subject of remote driving and conducting a research on the resilience of public transport, I would like to combine both autonomous processes and the mobility field. Second, I want to learn how user experience can be designed as well as optimized, as it is something I find very interesting but could not experience yet. All in all, I am eager to face a future-oriented technological problem that sets users in the center.

FINAL COMMENTS

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