MASTER THESIS

Mediating between Human Driver and Automation through Human-Machine Interface for Highly Automated Vehicles

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MSc. Design for Interaction
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This Master thesis is part of Mediator Project (https://mediatorproject.eu/)

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EXECUTIVE SUMMARY

This master thesis report gathers the research and design activities executed in 100 working days, in order to investigate the future context of autonomous driving. More specifically, the communication between the human driver and automation during the automated driving modes (Long Out of the Loop and Standby modes) has been investigated to answer the knowledge gaps of mode confusion, transparency, and information load. The project was supervised by SWOV, the Dutch Institute for Road Safety Research.
The project approach refers to a double-diamond structure which includes firstly, context research as background knowledge about autonomous driving and HMI. Secondly, an extensive user research involved experts, drivers, and human factors as the core of the study. Thirdly, an Experience Journey Map was developed to set bases for the design definition and Functional requirements, and HMI qualities. The design goal for the project has been based on the research results, aiming ***to unobtrusively inform drivers about automation status, driving mode and their responsibilities during autonomous driving mode through the HMI, while the driver is performing non-driving related activities***.
The HMI concepts have been developed according to iterative conceptualization and evaluation phases to conduct experiments with participants evaluating lo-fi prototypes about singular interactions and design elements, collecting conclusions, and highlighting strengths for each concept. Those helped to put together a final concept that includes the best elements of previous phases.
The final design proposal is a holistic experience that incorporates together different HMI options such as ambient lighting, central display, variable windshield dimming, the windshield visual effects and haptic feedback in order to create a complete experience to test with a sample of participants.
The final user tests have been conducted digitally with participants who evaluated the interface of automated driving modes while participants were asked to focus on secondary tasks. The tests showed that the ***ambient lighting*** (together with adjustable ***windshield dimming***) of the vehicle certainly helps to set the driver's mindset and support secondary tasks. The ***messages on the windshield and 3D glow effects*** obtained good results in terms of transparency. Drivers, indeed, understood more information about road situations and automation behavior. This encouraging results open horizons to new applications about ambience and visual information. Globally, the new information presented to participants was perceived as pleasant, informative and unobtrusive. Participants accepted the new HMI options with confidence and enthusiasm, although, some aspects of the central display were not fully understood in terms of usability.

In conclusion, the design research conducted in the first part of the project brought a fresh view of the user's perspective. The insights from the human-centered design approach are extremely useful to investigate the communication to establish between humans and automation. This master thesis also contributed to bring some initial but promising results in the new direction of HMI design for Mediator project.

ABBREVIATIONS

AV / AD	= Autonomous Vehicle / Autonomous Driving
HAV / HAD	= Highly Automated Vehicle / Highly Automated Driving
PAV / PAD	= Partially Automated Vehicle / Partially Automated Driving
HMI	= Human-Machine Interface
LOotL	= Long Out of the Loop driving mode
SB	= StandBy driving mode
NDRA	= Non-driving Related Activities (same as secondary tasks)
LIP	= Low Information Preference (users group)
HIP	= High Information Preference (users group)
HUD	= Head-up Display
WSD	= WindShield Displays
SAI	= Situational Awareness Information
BAI	= Behaviour Awareness-Related Information
RI	= Responsibility-related Information (User's Tasks)
TOC	= Transfer of Control
TOR	= Takeover request
SA	= Situational awareness
SUS	= System Usability Scale

CHAPTER AT A GLANCE:

- *Background knowledge*
- *Project connections*
- *Assignment*
- *Project Approach*
- *Me as a Designer*

01 INTRODUCTION

This chapter introduces the author's choices, structure and methods, including the link with TU Delft, Mediator Project and SWOV while providing a general overview of the project.

BACKGROUND KNOWLEDGE

Over the years, the development of automated transportation is increasing rapidly. Subsequently, the safety potential has been changing as well. The Society of Automotive Engineers (SAE) defines the responsibilities between the human driver and an automated driving system with six automation levels, ranging from no-automation (Level 0), where the driver has full control of the vehicle, to full automation (Level 5), where the user is not expected to respond to a request to intervene. However, the transition to Level 5 automation brings new risks such as mode confusion, overreliance, reduced situational awareness and misuse. Moreover, the driver's tasks will change to a more supervisory role, where the communication with the (partially) automated system will happen through the Human Machine Interface (HMI) (Christoph, M., et al., 2019).

PROJECT CONNECTIONS

With the aim of developing a mediating system for drivers in semi-automated and highly automated vehicles, a 4-years project called MEDIATOR has been launched and it is currently, in the second year of the project launch. This project is led by SWOV, the national institute for road safety research, and it also connects a strong network of partners and universities, including TU Delft.

This graduation project, in collaboration with SWOV, will focus on the HMI, defined as the set of all interfaces that allow the user of a vehicle to interact with the vehicle and/or devices connected to it. It is a crucial aspect to ensure that the driver and the automated vehicle have a safe and acceptable exchange of roles.

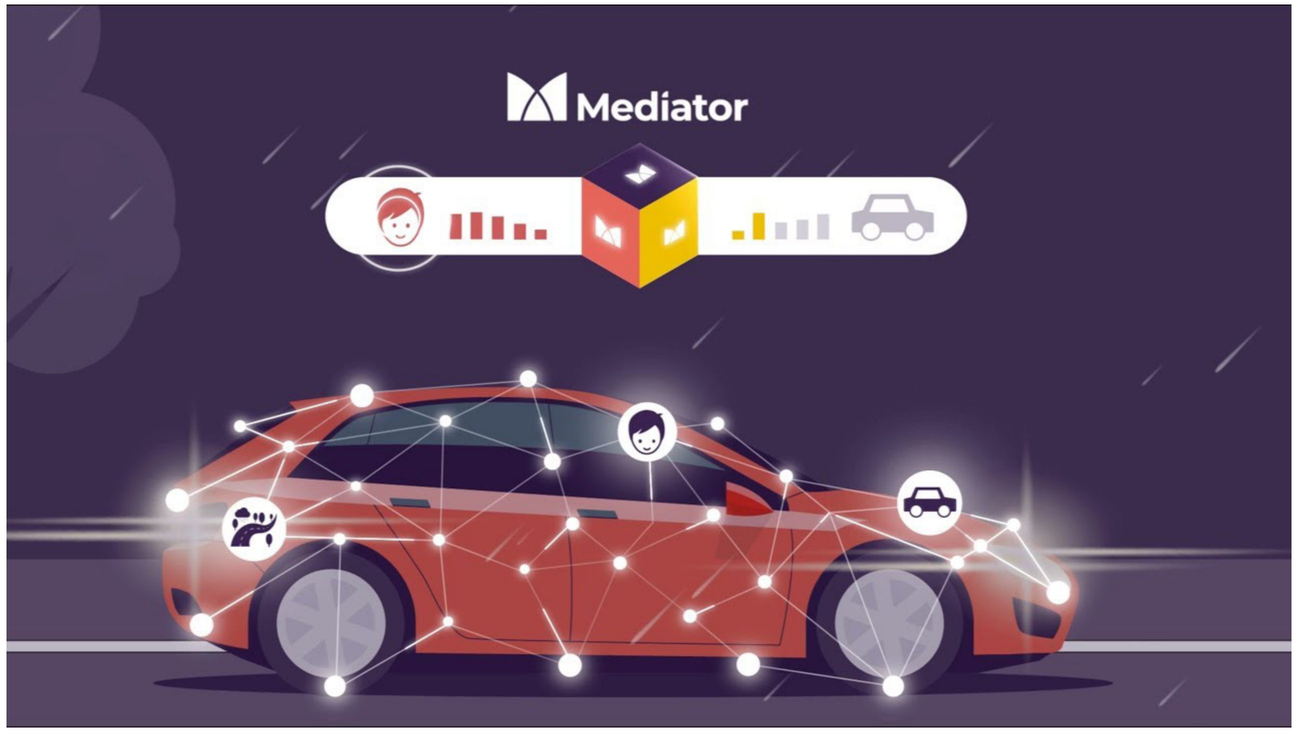


Figure 1 . Mediator Project

ASSIGNMENT

Generally, the HMI should take into consideration several demands that need to be evaluated and balanced: driver needs, available technology, applicable regulations, and the costs. Related challenges include trust, mode awareness, fatigue and distraction, information load, user acceptance, industry acceptance, as well as learning and unlearning.

Amongst all these challenges that Mediator project aims to address, this graduation project mainly focussed on **overreliance** and **mode confusion** within the driving mode, in order to ensure a safe and comfortable driving experience. In this specific scenario, some level of **transparency** is needed for **user acceptance** and **trust** in the system, as well as to develop mental models to anticipate automation functioning and create appropriate reliance. Too much information, however, can cause confusion and **information overload**. How to achieve an optimal **balance** between transparency and information load is where this graduation project contributed to Mediator. The main research questions, therefore, were *"What information should be communicated? When should this information be communicated? And, how should this information be communicated?"*

The assignment consisted of a complete design process, from literature study to user research to draw an analysis of the current state, then the definition of a Design Goal and iterative ideation phases, conceptualization and implementation of promising designs have been tested cyclically, and finally, a final design have been tested and evaluated to assess its effectiveness.

The research and design process of this project was facilitated with experts from Mediator project at SWOV as well as professors from TU Delft.

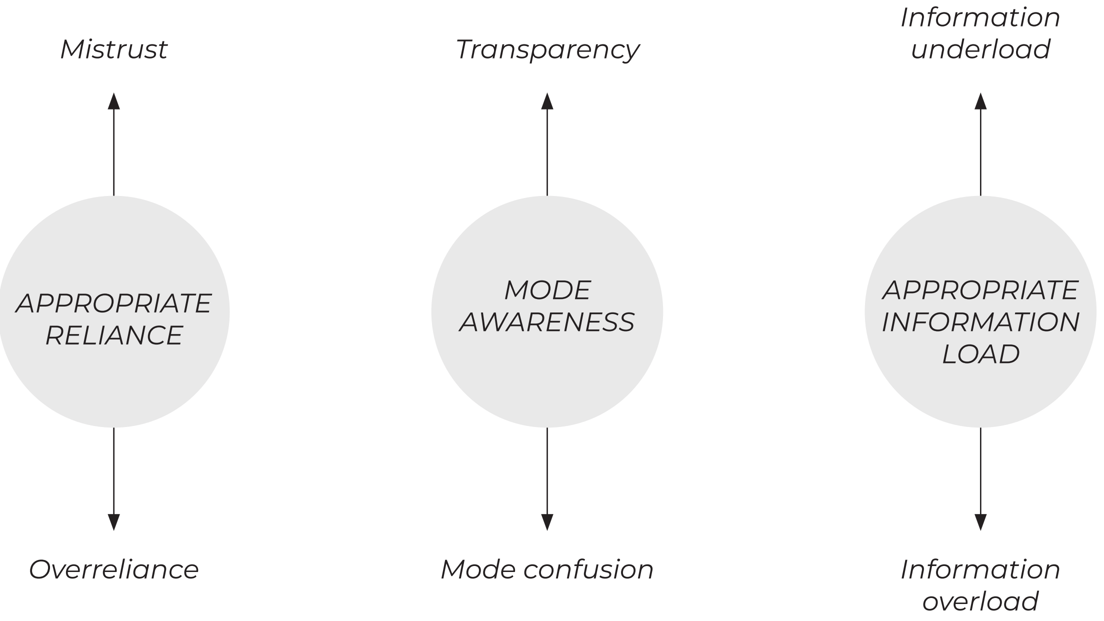


Figure 2 . Assignment's challenges

PROJECT APPROACH

The project approach adopted for this Master Thesis refers to the Double Diamond model developed by the British Council in 2005.
This model represents a way of investigating a problem more widely and deeply by divergent thinking and after that, finding meanings, summarizing, and focusing through convergent thinking. This approach takes action in four phases, as also shown in Figure 3:

• **Discover:** The first phase consists of the Research, to understand the context/problems.
• **Define:** The research outcomes are discussed and interpreted, then the challenge is reframed and design directions are defined.
• **Develop:** The ideation and iteration phase, getting inspired by co-design/creative sessions.
• **Deliver:** The delivery of a final design through evaluating different solutions from iteration.

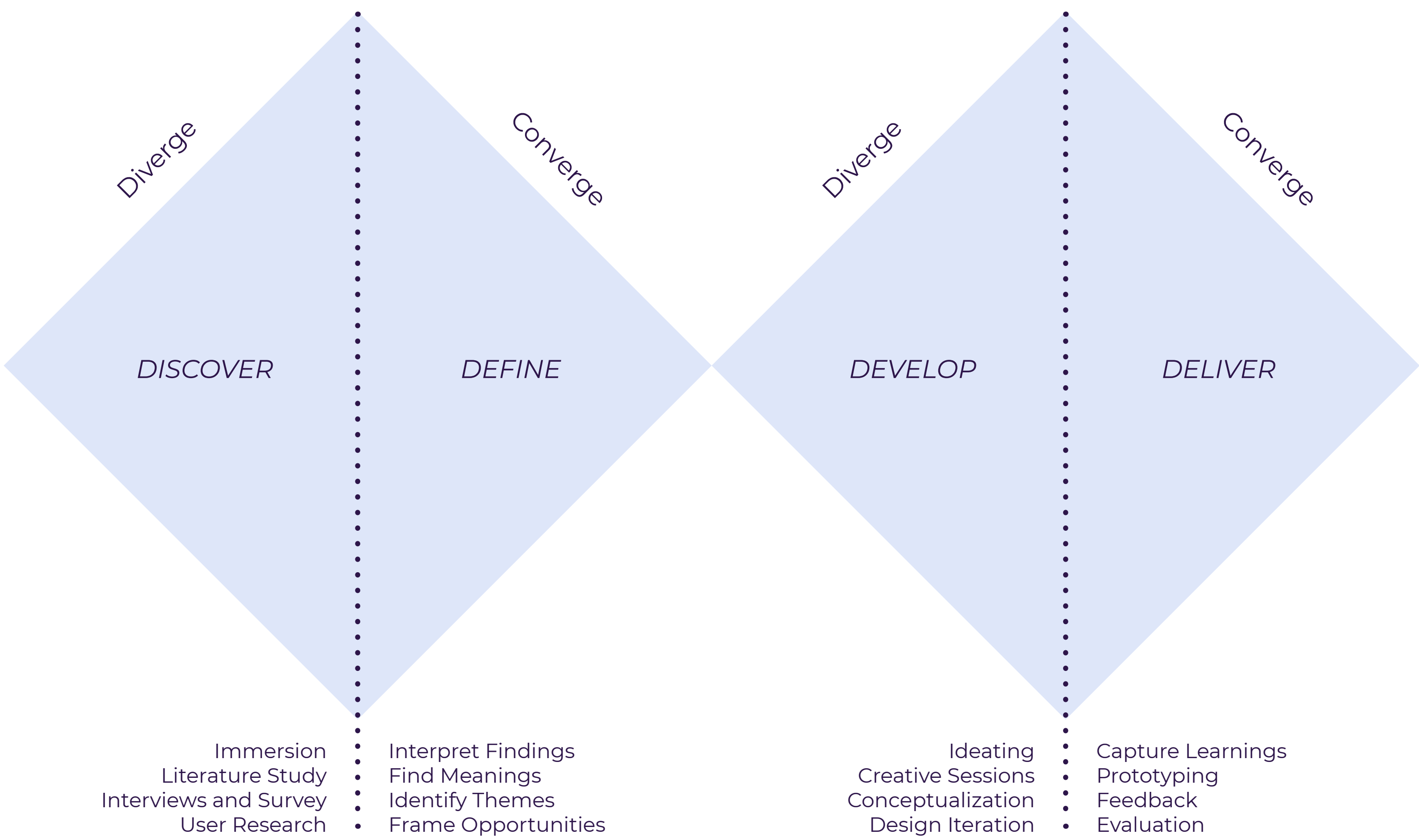
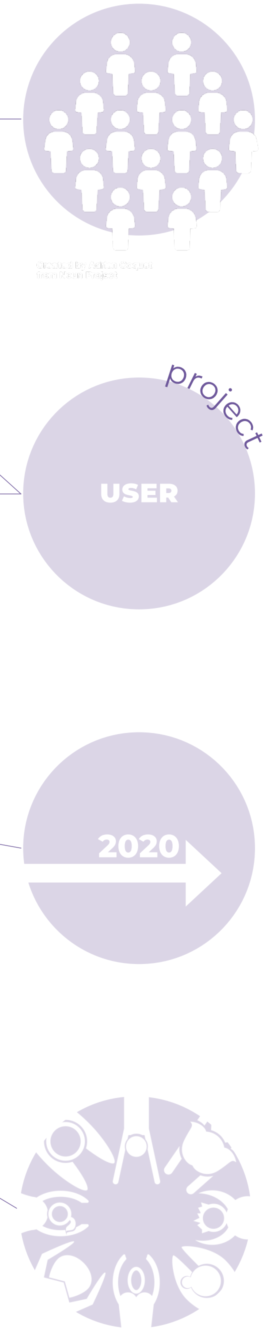


Figure 3 . Double Diamond Project Approach

ME AS A DESIGNER

The design values and principles of the author of this Master Thesis are listed below describing the nature of the designer which subsequently determined the outcomes of the graduation project.

*"My design approach revolves around creating **positive social benefits**, starting from the users' point of view, embracing the **human-centered design approach.** I consider my self a good empathizer with people because I love discovering their needs, desires and expectations to realize design projects based on **human necessities.** I believe that design and technology can bring innovation and benefits in many fields, influence social change, and improve the way we live. That's why my designs should be **relevant to current problems** in which people can reflect and relate. In my designs, I always try to adopt an **inclusive mindset**, not only thinking about the easiest and fastest option. I try to find a balance between beautiful design and design that everybody can use, not to discriminate against anyone. I define myself as a confident and creative designer, who loves to work with a diverse team but also self-motivated and always curious to discover and learn more."*



CHAPTER AT A GLANCE:

- *A future driving experience*
- *Human-Machine Interface (HMI)*
- *HMI communication channels and feedback modalities*
- *Mediator Use Cases*

02 CONTEXT RESEARCH

This chapter explores the context of this project: Autonomous Driving and more specifically the Human-Machine Interface of Cars. The benefits of Autonomous Driving are described together with the SAE level of automation and the challenges in terms of interaction. In order to fulfill the research questions, a discussion on the modalities and communication channels were conducted based on Mediator's research (D1.1). In addition, the use cases provided by the mediator are explained and contextualized for this project in this chapter.

DRIVING WILL BECOME AUTONOMOUS: A FUTURE DRIVING EXPERIENCE

The newest technologies are constantly transforming everyone's lifestyles, bringing innovation and revolutions in many different fields, one of those is certainly transportations. For the automotive sector, Autonomous Vehicles (AV) technologies are now being explored with the aim of reducing crashes and fatalities, energy consumption, and congestion while at the same time increasing transport accessibility. Previsions state that AVs are expected to constitute around 50% of vehicle sales, 30% of vehicles, and 40% of all vehicle travel by 2040 (Bagloee, S.A., et al., 2016).

According to NHTSA, the AV revolution will bring many benefits. Safety in primis, most of the car accidents are due to human errors, AVs have the potential to reduce human error and decrease traffic fatality. The time and money spent on the road will be optimized as well, having positive effects on traffic congestions due to the connected function of automated vehicles. This feature will also be able to connect different vehicles on the road and allow much more flexibility and optimization. And finally, from an accessibility perspective, AVs will allow a more inclusive approach to the driving experience, opening doors to more users.

The Society of Automotive Engineers (SAE) defines six levels of driving automation, from level 0: no automation, to level 5: full automation, where the user is not expected to intervene. Figure 4 describes more in detail the responsibilities between the human driver and an automated driving system, and the driving features for each level.
Currently, vehicles on the market reach maximum level 2 of automation, where the driver can activate steering and brake/acceleration support. Before reaching level 5 (expected in around 60 years from now), automation technology still needs to step forward, however, **levels 3 and 4 are now object of investigation and experimentation**. Level 3 and 4 represent already automated driving features, where the vehicle can safely move with little or no human input. Stepping from a level 2 to a level 3 or 4 of automation will change radically the driving experience, and for this reason, it is crucial to study and propose an easy and safe system that communicates tasks and intentions to future drivers.

Challenges

As discussed in this chapter, automation is beneficial in many ways, including road safety, inclusion and environmental issues, but there are ***some Human Factors that have a negative effect on road safety when level 5 is not reached yet.*** This will occur in level 3 and level 4 of automation when the vehicle functions are automated most of the time, but drivers need to assume manual control occasionally. Therefore, in the transition to full-automation level, drivers will have different responsibilities, depending on the driving mode and driving mode available. The changing feature of driving mode (and drivers' responsibilities) on levels 3 and 4 needs to reinvent the communication with users in order to allow a safe and trustworthy journey. In this case, the driver must constantly be aware of his responsibility and role in that specific mode to conduct a safe drive. Consequently, drivers need to know what tasks are allowed, required and absent, but also anticipate actions from the near future.

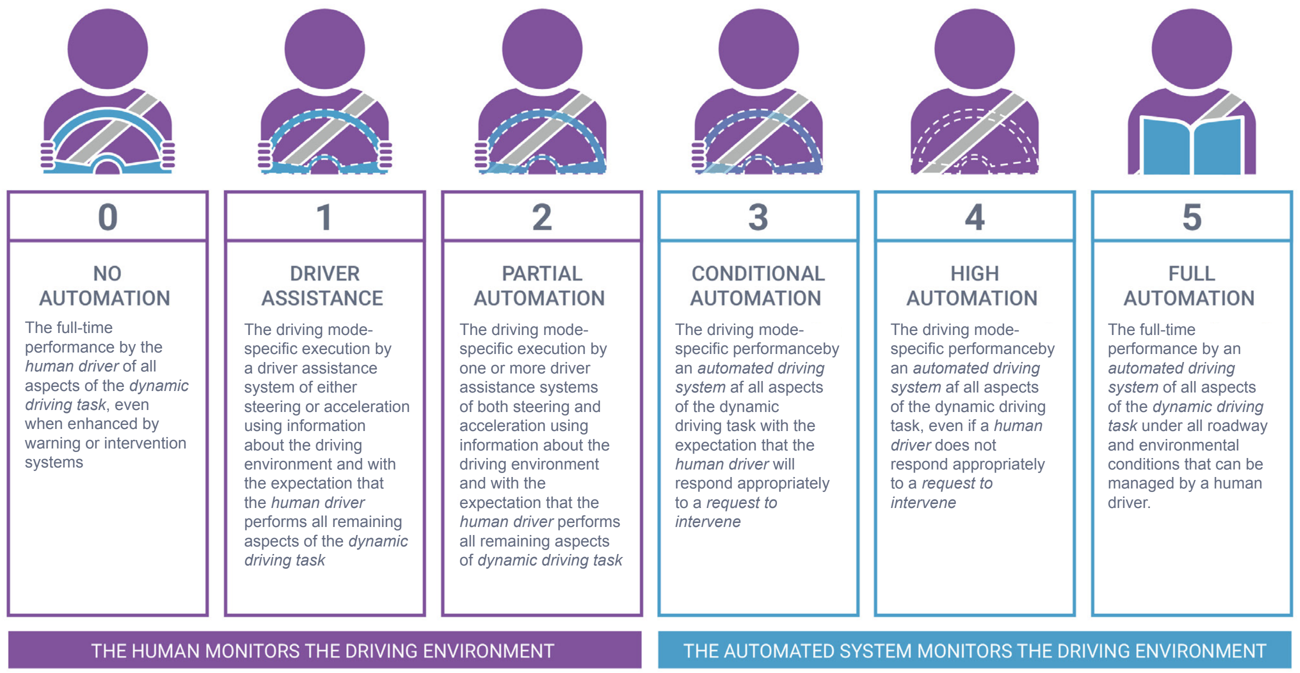


Figure 4 . SAE levels of automation

HUMAN-MACHINE INTERFACE (HMI)

In the context of AD, the HMI will be a crucial aspect to ensure good and safe collaboration between human drivers and vehicles. Carsten & Martens, (2019) define the "HMI" as the set of explicit and implicit communications between the human operator and the vehicle, comprising all vehicle controls that provide channels (input to the vehicle and feedback for the driver) in between.

Features

Currently, HMI's main components are elements the driver interacts with, in order to complete a task related to the driving experience. The components of the HMI are summarized in Figure 5. The HMI is often used to describe the vehicle's visual interfaces, but it actually consists of auditory displays, all the vehicle controls (including the traditional feel transmitted by pedals and steering). Moreover, it includes the vehicle's dynamics within a specific context and additional haptic elements— resistance, pulses, vibrations, physical guidance— used to guide and assist the human.
The elements of the HMI can be divided into three classes primary, secondary, and tertiary, based on the driving task classification (Tönnis et al., 2006). The components of the primary class are those needed to maneuver the car, such as the steering wheel and the pedals, closest to the driver, easily reachable. Secondary components help increasing safety and they are located in an easy-to-reach position. Tertiary components provide driver entertainment and preference information.

The HMI consists of all the parts of Figure 6 and it can be imagined as the bubble that

connects humans and vehicles.
The HMI gives the vehicle insights about human's commands and attention and returns insights about automation to the human driver. The HMI thus has a central and critical role in the operation of the joint system.

In the next section, the modalities and communication channels of the HMI elements are discussed and compared based on their effectiveness and efficiency.

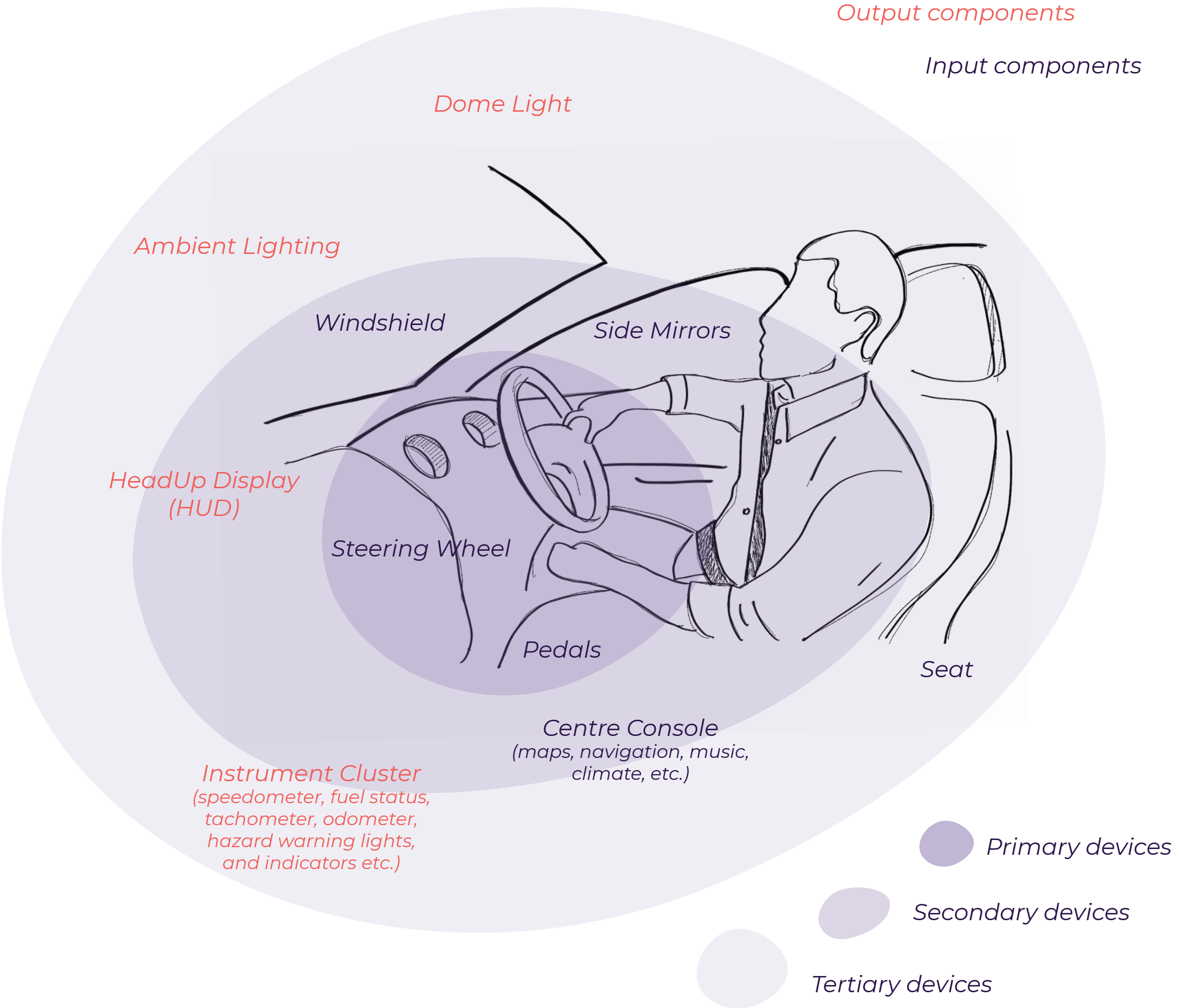


Figure 5 . HMI components

HMI COMMUNICATION CHANNELS AND FEEDBACK MODALITIES

One aspect of the driving experience that will be completely renewed with higher automation levels will be the quality of interaction between the human driver and the intelligent vehicle.

In a Highly Automated Vehicle (HAV), the information exchange consists of input controls, from the human driver to communicate intentions to the vehicle. The output controls where the information from the vehicle is communicated to the human driver. Both input and output controls need to be considered as part of the HMI interaction and, therefore, need to be designed for the AD scenario. It is important now to list all the communication channels and the possible modalities for this information exchange, in order to understand which modalities are the most effective based on the message to convey. As already discussed before, the HMI can be defined as "a set of all interfaces that allow the user of a vehicle to interact with the vehicle and/ or devices connected to it" (Wetzel, 2013). Therefore, the information can be delivered to the user in different sensory modality (vision, audition, touch, olfactory), depending on the circumstances, the type of information and the level of attentive value of the signal. The level of attention needed from the user depends on the urgency of the situation and the time budget for a reaction. Moreover, the variability of information modality can also depend on the user needs and preferences, but this aspect will be discussed later, in Chapter 2. Below, an overview of different communication channels is provided, based on several previous studies.

Visual communication

Usually, the information that is communicated visually to drivers provides safety-related information and information that aims to improve driving performances. Visuals communication is used to inform drivers about the current status of driving and automation system decisions such as collision alerts, lane change decisions, visualizing other road users and obstacles, speed information, and gaze indications. The visual communication mainly occurs via the instrument cluster, HUD, and AR displays. Lindemann, Lee and Rigoll (2018) demonstrated that ***WindShield Displays (WSD) with Augmented Reality elements can increase situation awareness*** in urban environments and may ***prevent loss of trust in the automated system or even increase trust in the vehicle***. However, when the information presented on those displays is supported by ambient lighting, it turns out to have some positive effects on informing and warning users through different colors or patterns (Ayoub et al., 2019). Moreover, according to Yang et al. (2018), it has been demonstrated that *informative ambient lighting improves users' trust and situation awareness on the driving context while performing a secondary non-driving-related activity.*

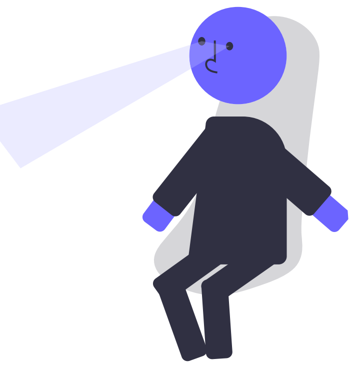


Figure 7 . Visual communication illustration

Auditory communication

Auditory information is used in vehicles as communication and warning tools to manage drivers' attention (Ayoub et al., 2019). Auditory feedback and information, indeed, are more ***immediate*** (Bach et al., 2007) and perceived as ***urgent*** (Bazilinskyy et al., 2018), but at the same time, it results hard for the user to rightly interpret the message that is intended to be communicated with sonorous signals. Auditory information can also be communicated with spoken words (e.g., Kramer, 1994) and this also gives the opportunity to users to interact giving inputs to the vehicle on the same modality. Furthermore, new 3D sound systems have been studied to radiate a sound from a certain position in order to draw attention to that position (e.g., Heydra et al., 2014). However, auditory information can be perceived by users as ***distractive, redundant or intrusive***.

Haptic communication

Haptic information and tactile feedback are used mainly to provide the user with warning signals (especially on approaching threats) and driving assistance. It has been demonstrated that tactile stimuli increases the awareness of drivers to prevent accidents by providing vibration in the steering wheel or in the driver seat (Ayoub et al., 2019). Wan and Wu (2017) investigated the effects of vibration patterns on a vehicle take-over request to the driver engaged in a secondary task. They demonstrated that ***faster response times*** were observed ***in specific vibration patterns***. Moreover, the haptic signal depending on the situation can vary in amplitude, rhythm, frequency and spatial location (Huimin, Kuber, & Sears, 2017). Haptics and gestures are considered as effective control tools and inputs that allow drivers to interact with the vehicle using tactile sensation and body movements (Ayoub et al., 2019). Touch screens, buttons and other control tactile interactions such as knobs are overall considered to be easy to understand and to learn even for non-experienced users but on the other hand, those also require visual attention while driving (Large at al., 2015).

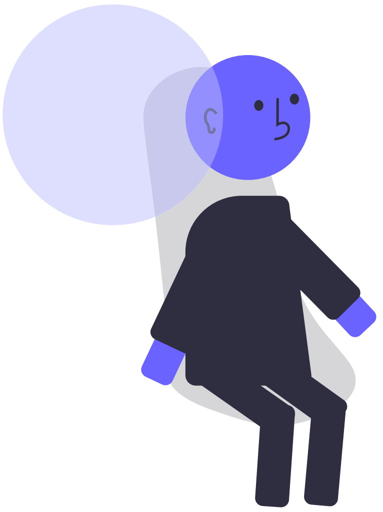


Figure 8 . Auditory communication illustration

Figure 9 . Haptic communication illustration

Multimodal communication

Information can be communicated also in a multimodal way, using different sensory stimuli together to deliver a message to users. According to Bazilinskyy et al., (2018), ***multimodal signals result to be more effective for high-urgency situations***, whilst auditory cues are preferable in low-urgency situations. Drivers, especially when they are engaged in a visually distracting non-driving task, may overlook visual warnings or may not consider a visual signal as urgent (Petermeijer et al., 2017). However, drivers' attention is particularly attracted using vibrotactile take-over requests on the seat, which can be perceived even when drivers are engaged in visual or auditory non-driving tasks (Petermeijer et al., 2016). Combining auditory and vibrotactile take-over requests can result in slight reductions in take-over time compared to unimodal auditory and vibrotactile take-over requests (Petermeijer et al., 2017).

Figure 10 . Multimodal communication illustration

Different communication channels comparison

The main conclusion is that auditory and vibrotactile output controls are the most powerful and imminent modalities to deliver urgent information to the user, but it is also perceived as urgent information that requires a fast response from the driver. Those modalities are especially recommended as warnings during a takeover request, but they do not effectively communicate a specific message to users (Petermeijer et al., 2017). In other words, auditory and haptics help waking up the user from the out of the loop situation, however, they are not effective in creating situation awareness by informing the driver about the road context. ***Appropriately designed visual messages, on the other hand, can effectively support drivers in making the right manoeuvre*** (braking or changing lane) after resuming manual control, informing the driver on the road context and assisting the users moves (Eriksson et al., 2019). Furthermore, *visual outputs are powerful to prove the driver information on the automation behaviour and consequently, to generate transparency, trust and situational awareness*.

Modalities' Features Overview

The table below, summarizes the different modalities' features, positive and negative aspects. It is difficult to provide a reliable reaction time because this mostly depends on the design and how is it communicated with a certain modality.

However, the modalities can be classified from slowest to fastest in terms of reaction time based on many research and tests done on the topic, considering that none of those modalities exceed 10 seconds of reaction time.

MODALITY	REACTION TIME	TYPES	PRO & CONS
Visual	- Slowest (still more effective and faster than no signal)	Visual messages	+ convey complex info - requires visual attention
		HUD/AR	+ better automation understanding - increase visual complexity
		Ambient lighting	+ unobtrusive + less cognitive workload - limited content
Auditory	+	Spoken words	+ voice command - limited dialogues - it can be distracting
		Sonorous signals	+ less cognitive workload + less annoying - limited content
		3D Sound systems	- more situation awareness - it can be distracting
Haptic	++	Vibration feedback	+ fast reaction time + effiecient for urgent messages - limited content of information
Multimodal/ multisensory	+++ Fastest	Multiple modalities together	++ fast reaction time ++ effiecient for urgent messages - intrusive and/or annoying

Table 1 . Modalities' Features Overview: comparing Visual, Auditory, Haptic and Multimodal feedback system communication

MEDIATOR USE CASES

Within the Mediator Project, it has already been investigated the Use Cases for the transition to full automation systems (Figure 11). The use cases are presented along with a storyline of a hypothetical full trip experience of a highly automated vehicle, analyzing all the critical situations and pointing out interactions that need to be designed in the HMI in terms of human-automation communication. The scenario shows how the automation system will interchange between four driving modes: "Human Driving" (no automation), "Continuous Mediation" (driving assistance and partial automation), "Driver Standby, Short-Term Out of the Loop Mediation" and "Driver Long Out of the Loop Mediation" (both for full automation).

Among the driving modes this research will *focus on the interactions during high automated driving modes, which are the Driver Standby (SB) and the Driver Long Out of the Loop (LOotL) and the "switch down" transition between them*, described more in detail in the next paragraphs.

The storyline in the bottom of figure 11 makes a prediction of all the possible automation phases, dividing the whole experience in use cases, which consist of: *"switch up"*, *"switch down"* transitions, where a change of driving mode is decided to occur (from the system or intentionally from the driver) and ***"during" phases, where the HMI needs to either prevent dangerous behaviors ("preventive" actions) or correct wrong users behaviors ("corrective" actions).***

- ***Corrective actions*** are actions to attempt to correct degrading human performance. These can be warnings with different intensity levels, attempts to get attention back to the human driving or supervision task, and attempts to get the human sufficiently alert for worst-case, fast take-over from full automation.

- ***Preventive actions*** correspond to ongoing activities or information/interaction that aim to prevent human fitness from degrading to a degraded state in which correction becomes necessary.

The HMI challenge for highly automated vehicles consists of designing an efficient communication system that is usable throughout the various use cases and addressing associated issues of trust, transparency, and user's personal preferences (see Chapter 3). Because all these use cases will be addressed within the Mediator project, this graduation project will focus mainly on the "during" sub-scenarios of the full automation driving modes and the transition from LOotL and SB. The "preventive" and "corrective" information and actions of the HMI during the "Driver Standby" and "Long Out of the Loop" will be a core part of this project.

An overview of the HMI challenges related to the driving modes (SB and LOotL) considered for this graduation project's assignment are summarised in the next paragraphs and are being investigated more in-depth in Chapter 3, about user research.

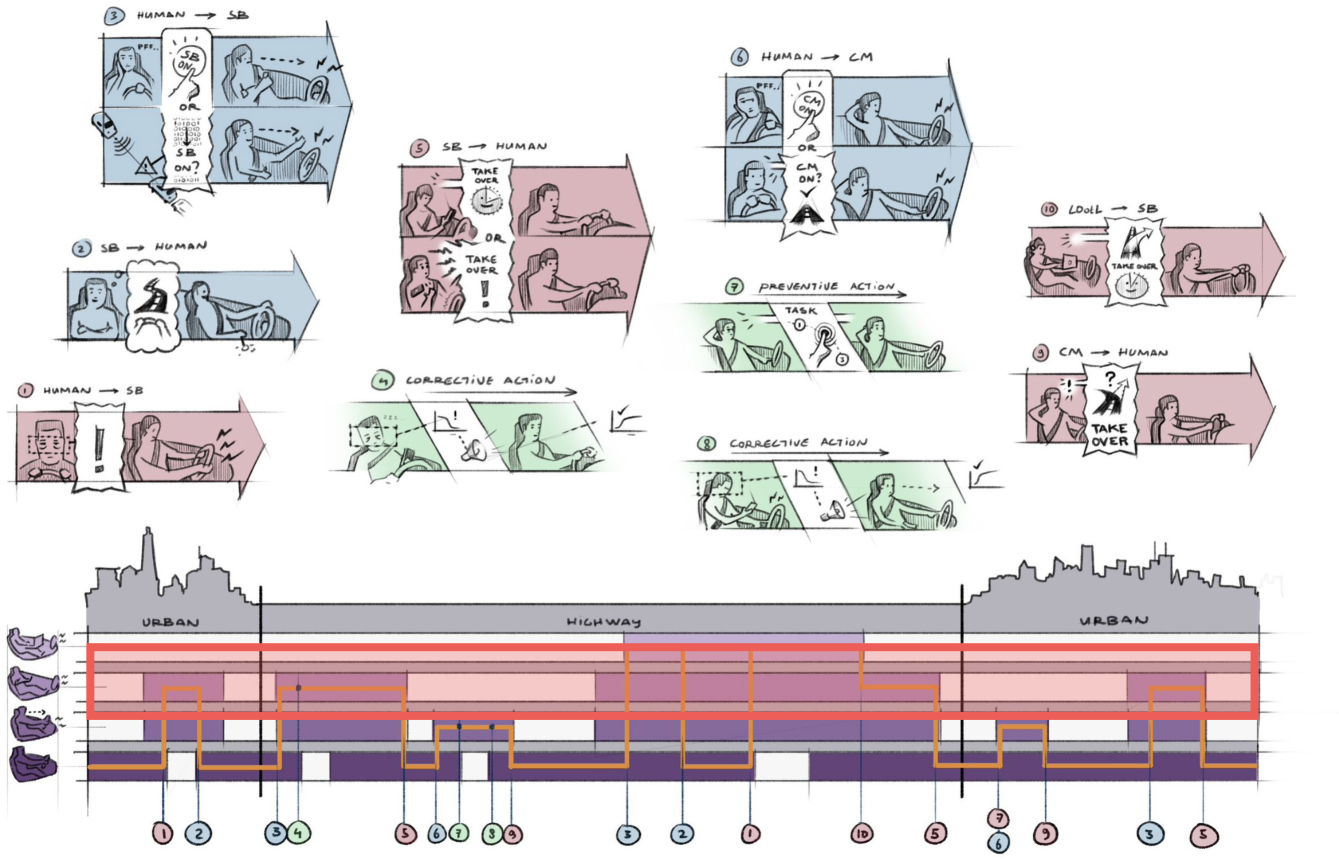


Figure 11 . MEDIATOR use cases

Time Budget

Both in SB and LOotL, the "time budget" is an important variable that needs to be simultaneously and coherently addressed by the human factors/driver state, automation state, central decision logic, and HMI tasks. This relates to the automation's prediction of guaranteed time in which automation ON can be guaranteed, in order to make drivers aware there will be a transfer of control, and to make them understand the automation can not handle every situation. The time budget also consists of the resumed time before the automation releases the control to the driver and, therefore, the estimation of time needed to "wake the driver up" from the NDRA. However, this variable is to be investigated further in relation to different automated modes SB and LOotL during the Experts Interviews and User Research.

In terms of human factors and HMI, the "time budget" requires making this variable (explicitly or implicitly) transparent to the human driver in an understandable way, through the HMI. The system should offer automated options only when it is feasible and comfortable, by considering timely TOC procedures, and by keeping the human driver aware of available time during the driving modes; all taking the time budget into account.
The continuous, transparent communication of the time budget to the human via the HMI is seen as a key "preventive" activity of the HMI.
(Mediator Use Cases, 2020)

Driving mode: Driver Standby (SB)

In Driver Standby mode, the automation level is full, so it is the first mode opportunity where the driver is not required to monitor the road context and the system anymore (this occurs in Continuous Mediation instead). Here, the user can go shortly (order of minutes) out of the loop and perform activities not related to driving, as long as it is possible for the user to take back control of the car in few seconds, around 10 seconds, as shown in figure 12.

Therefore, the consequent issues arising from the SB, and to be investigated further are:

- Human too far out of the loop - high degradation; highly distracted, drowsy, sleepy; possibly due to overreliance
- Mode confusion and unclarity about worst-case fallback
- Lack of trust and transparency
- User's Personal differences (e.g. due age, experience, information preference, ...)

Driving mode: Long Out of the Loop (LOotL)

In Driver Long Out of the Loop mode, the automation level is full as well, with the main difference that the user can stay out of the loop for longer (order of hours) and a Transfer of Control (TOC) needs to be communicated to the driver minutes ahead. Here, the user can plan and perform NDRAs that take a longer time, as shown in figure 13, however, the driver needs to know that there is the possibility of TOC.

Consequently, the problems derived from LOotL mode are:

- User immersed in work for a long time
- Bring back to the road situation
- Time budget depending on the activity
- Driver's Personal differences (e.g. due age, experience, information preference, ...)

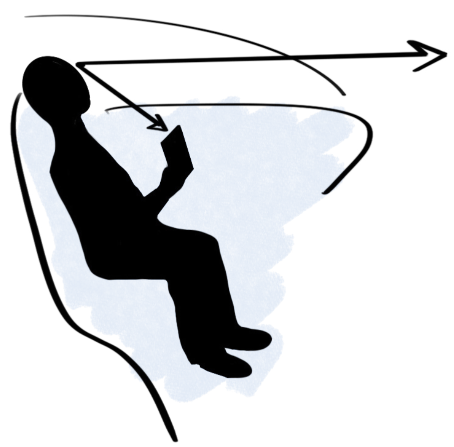


Figure 12 . Driver Standby illustration

Figure 13 . Driver Long Out of the Loop illustration

CHAPTER AT A GLANCE:

- *Literature study on User Perception*
- *Experts Interviews*
- *Users Questionnaire*
- *Generative Research*
- *Experience Journey Map*

03 USER RESEARCH

This chapter represents the major part of the Design Research conducted for this graduation project. Starting from the literature study on Human Factors, the Interviews with experts of the field of Autonomous Driving to Mediator researchers and 3Me Professors. Then an Online survey was created to investigate users' opinions on Partially Automated Driving systems and their expectations for High Automated systems. Next, three Generative Research sessions investigated contexts which can be considered analogous to Autonomous Driving in terms of interactions, and some interesting similarities to everyday life situations were found. This chapter concludes with all the insights overview in an Experience Journey Map.

Introduction

The User Research approach adopted for this project explored different research methods to investigate the context around users of autonomous vehicles and the cognitive mechanisms that play in this research context. First, a literature study investigated the Human Factors. This was followed by expert interviews and a survey to investigate information importance and preference, along with users' activities, and expectations. Next, generative research was conducted to investigate on analogous contexts to analyze the Human Factors deeper, in everyday life experiences. Table 2 summarizes the research methods and the link between goals, the impact, and the description of each method.

	Goal (WHAT)	Impact (WHY)	Description (HOW)
Literature Study	Investigate **Trust** and **Over-reliance**, **Information Load** and **Mode Confusion/Mode awareness**	To investigate the project's background and the knowledge gaps context, to review the state-of-art of Human Factors on the topic	Starting from Mediator D1.1, some additional research has been conducted about context and Human Factors that have relevance in this project
Experts Interviews	Investigate **Information Importance/ Information Load preferences** and **modalities** from expert's perspective (more accurate predictions)	Understand more technical aspects, validate findings of the Literature Study, Investigate on some Human Factor's from experts' view	5 experts have been interviewed and asked opinion on the information that HMI should communicate to users in different driving modes
User Survey	Investigate different **Driving Modes** from users' point of view in terms of desirable **activities/ communication** with automation	Experienced drivers of PAD systems can be considered the more experienced also in the field of the research and project themselves in the future scenario	A qualitative online survey was shared on forums and social platforms, with open-ended questions to collect experiences and opinions
Generative Research sessions	Investigate Analogous Context to autonomous Driving to analyze in-depth the **interactions** around the use cases	Understand how Human Factors of this project lies in people's everyday lives and how these articulate in those contexts, and which cognitive mechanisms are activated	Three Contextmapping sessions were conducted. People chose contexts where Trust, Information Load, Attention, Mode Confusion play an active role. Reflect on those situations and build-up on each others' experiences

Table 2 . Goal, Impact, Description of User Research Methods used for this Master thesis project

LITERATURE STUDY ON USER PERCEPTION

TRUST & OVER-RELIANCE

One of the main Human Factors (HF) that affects the efficiency of automation is human trust in the system, because if drivers do not trust the automation, they will not make use of available automated opportunities, and in the end, it will become harder to obtain a trustworthy relation with it. Hence, the challenge here is to improve elicit trust by addressing factors that impact trust while driving. However, at the same time, if users trust the automation excessively, they might create wrong expectations on the operational domain of the system, over-relying on automation. Similarly to the study on level 2 automation by Victor et al. (2018), which showed how some drivers expected the level 2 automated vehicle to be able to handle critical situations even when the HMI communicates to the driver to take control, this risk can be even more in level 3 and 4.

How to generate appropriate trust?

The appropriate balance of trust between the human driver and the automation means avoiding the wrong or dangerous use of the automation system (Wicks, Berman, & Jones, 1999). To trigger this mechanism, ***the user must be aware of the capabilities and limitations of the automation system*** (Lee & Moray, 1994; Muir, 1987). It is, therefore, necessary that the ***information about automation is accessible to the user at appropriate depth levels to the situation.*** However, the way this information is communicated through the HMI also affects the balance of trust. The way this information is communicated has to be ***understandable for the user and correspond to the user's cognitive mechanisms*** to encourage the generation of trust (Lee & See, 2004). For this reason, it is important to investigate deeper with potential users what kind of information they expect from the HMI to communicate and in which modality, in order to get the right access to the information they need at any time they expect to find and to obtain trust in the automated system.

USER PREFERENCES, EXPECTATIONS AND INFORMATION NEED

Many studies investigated the user expectations and need for information during levels of automation. The most interesting conclusions are from Beggiato et al. (2015) that contributed to starting this research project on the users' perception of the future scenario about Highly Automated Vehicles. This study focused on an automated system and human factors that have an influence on trust between humans and automation. It was found that information about ***current system status, time left before a change in the level of automation, system reliability, navigation data, current and planned maneuvers, current speed, speed limits and upcoming critical scenarios*** are the most demanded in automated vehicles regardless of the driving mode users are in. The results indicated that users expected information from the HMI to support transparency. The HMI should include information about automation logic and behavior to enable users to understand the automation at any time before strat trusting the system. Therefore, it emerged that a big amount of this kind of information promotes user acceptance and decreasing demand for information once the user gets trust and confidence in the system. In a few words, ***the more trust, the less information is demanded.*** The study also discussed and concluded that for these reasons, adaptive displays and personalized information can be considered a solution for this change of information need overtime. However, it has not been investigated within the study of Beggiato et al. the expectations and needs of these trust factors when users are engaged in non-driving related activities, so it becomes crucial to research on how to include those in the HMI design (Diels & Thomson, 2018).

Another crucial result obtained from Feierle et al. (2020) is that NDRA have an impact on users' visual attention on the windshield display and watching at the road context, while no influence was found in visual attention on instrument cluster. Moreover, ***no difference in information need was found, so the same information should still stay accessible to passengers, regardless of the experience or engagement in NDRA***. So the main problem will become ***how to convey crucial information*** during driver's NDRA to avoid unsafe situations.
Relevant information for the user during High Automation levels (SB, LOotL) can be divided in 3 groups, to be evaluated based on user preferences while they are performing some secondary tasks:

- ***Responsibility-related Information*** (about User's Tasks)
- ***Situational Awareness-related Information*** (what the vehicle sees)
- ***Behaviour Awareness-Related Information*** (what the vehicle is going to do)

In addition, according to Ulahannan et al. (2020), there are some differences in information needs during Highly Automated Driving, due to personal preference of individuals. After the experiment conducted within this research, two groupings of drivers were identified: ***High Information Preference users (HIP)***, "I want to be able to understand what the car decides to do", and ***Low Information Preference users (LIP)*** "the vehicle should only tell me if I need to take control". This needs also to be verified for higher levels of automation and in situations where drivers are performing other NDRA.

MODE CONFUSION AND SITUATION AWARENESS

Many studies confirm that during automated driving modes, human drivers tend to rely too much on the automation and they start NDRA even when situation awareness is needed and the role of drivers is to keep eyes on the road (Vlakveld, 2015). In this scenario, mode confusion is to be avoided and simultaneously, drivers' responsibilities need to be clearly communicated.
Some theories also predict ***it is likely that the drivers will deactivate important information about road context and automation in order to fully immerse in their secondary activity.*** Hence, it becomes crucial to make the communication smooth and non-intrusive, while preventing this behavior of blocking important notification from the HMI.

Key Findings & Takeaways

- Relevant information to communicate during SB and LOotL are:
  - SAI = **Situational Awareness Information** (what the vehicle sees)
  - BAI = **Behaviour Awareness-Related Information** (what the the vehicle is going to do)
  - RI = **Responsibility-related Information** (User's Tasks)

- There are **two categories of users**:
  1. HIP: **High Information Preference**, *"I want to be able to understand what the car decides to do"*
  2. LIP: **Low Information Preference** *"the vehicle should only tell me if I need to take control"*

- **Information should be always accessible to the user but in a non-intrusive way**, to avoid Information Overload

- **Visual outputs are the less invasive way to generate transparency, trust and situational awareness**, informative ambient lighting especially during non-driving-related activity

EXPERTS INTERVIEWS

Some experts in the field of automation and HMI were interviewed with the goal of getting knowledge about technical aspects of automation in terms of available technologies and opportunities, getting a more specific overview of the user in the future scenario of vehicles' high level of automation. For this reason and in order to validate and compare with the literature study, professors and researchers from the Faculty of 3Me (TU Delft), a colleague from SWOV, and an HMI Researcher from Mediator were recruited and interrogated.

Interviewees

Riender Happee
professor 3Me

So-Yeon Kim
PhD candidate IDE

Silvia Varotto
SWOV researcher

Pavlo Bazilinskyy
PostDoc 3Me

Arun Muthumani
Human Factors and HMI Designer at Autoliv

Goals

- Discuss future scenario of user experience and HMI requirements in high-level automation
- Investigate the user context from different expertise perspectives
- Validate and improve insights and conclusions from the literature study
- Investigate the importance of information during sub-scenarios
- Investigating user preferences
- Collect insights to draw a conclusive experience journey map (page 49) on high-level automation user experience

Method

In total 5 semi-structured experts' interviews were conducted online. One of the participant's results were not considered valid for the aim of the research because one of the interviews was done with two participants, where one of them relied too much on the other's choices. The procedure of the interviews is shown in detail in Figure 14. The interviews took around one hour each, starting from some open question and then filling a table where participants could express subjective preferences of HMI information (see Appendix 3). The interviews were recorded and transcribed and analyzed according to context mapping methodology (Stappers, 2012). From the quotes and interpretations, some patterns were found and clustered in categories.

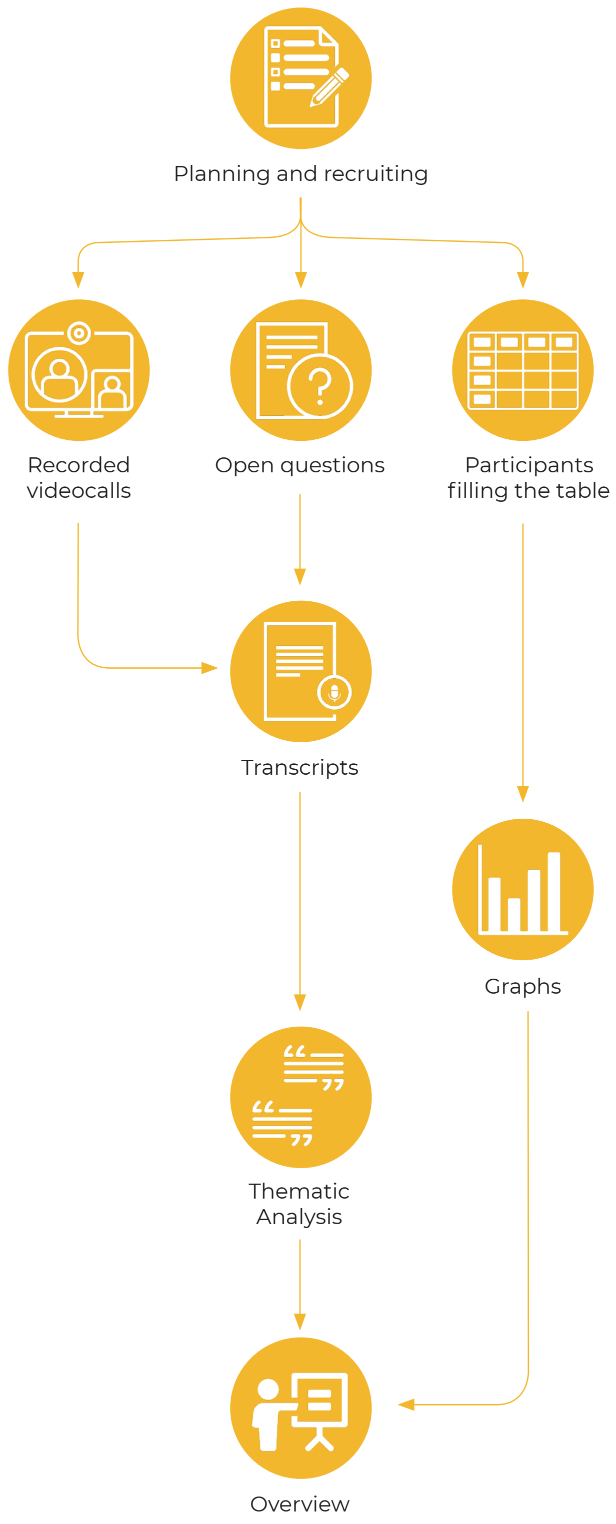


Figure 14 . Interviews procedure illustration

Results

The interviews confirmed most of the knowledge acquired from the literature study, but also provided important data that confirms especially the subjectivity of users' information preferences during the three automation phases investigated.

During the interviews, the participants were asked to give a prediction on their own possible driving behavior with highly automated vehicles. Based on their answers, two of the participants reflected more HIP group, while the other two participants declared to be more cautious, representing more LIP group, as shown below.

HIP (High Information Preference)

More information on route decisions in HAD

A bit more information and notifications about automation behaviour during HAD

Showing driver's responsibility important in every level of automation

Know more details about the next driving mode available

"For me, it will take time to get into the new system. I am cautious. I want to see how the automation behaves before trusting"

LIP (Low Information Preference)

Less information on route decisions in HAD

Less information and less intrusive notifications about automation behaviour during HAD

Showing driver's responsibility is slightly less important in higher automation levels because users have fewer responsibilities

Know fewer details about the next driving mode available

"I also to be a user that prefer less information and notifications"

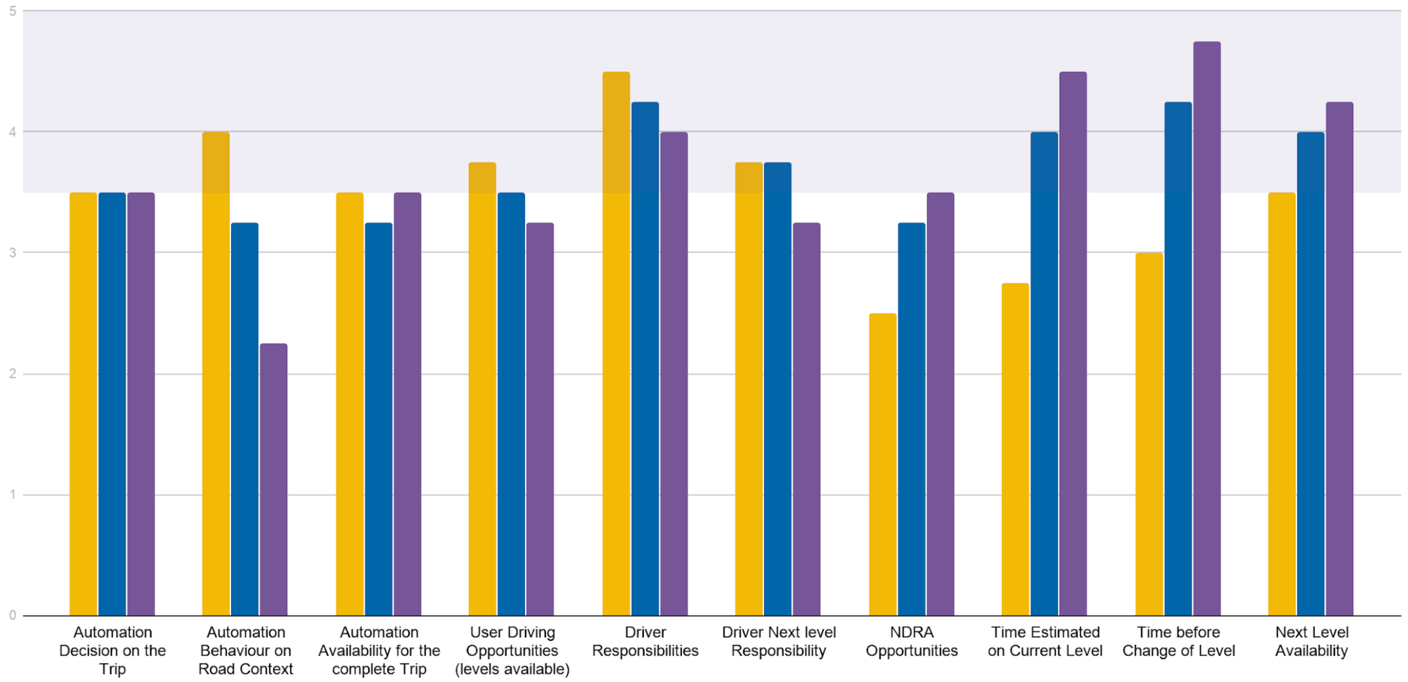


Figure 15 . Graph Average Results, Information Importance: comparing Continuous Mediation, Standby and Long Out of the Loop driving modes.

The interviews showed that all the participants, regardless of the information preference group, chose the same information as the most important to be communicated *during automation mode and performing NDRA*. That information is: **Driver's responsibilities** and **Time before change of level**.

A table was completed by the participants filling it with numbers (1 to 5), based on the importance of the type of information during the three levels of automation from the sub-scenarios: Continuous Mediation, Standby and Long Out of the Loop. The results from the table have been translated into column charts, compared between them and drew an average graph, Figure 15. In the graph, we can see that there are consistent differences between CM and SB/LOotL, while participants did not differenciated so much between SB and LOotL. Nevertheless, information about Driver Responsibilities was considered crucial for all the three modes. Information about Time Estimated on Current Level and Time before Change of Level were considered the most important related to SB and LOotL. Lastly, also information about Next Mode Available was rated high by participants.

The results from this study are not only related to this graph, most of the insights came from the previous discussion and exchange while filling the table. The interviews recordings were transcribed (with otter.ai) and then elaborated following thematic analysis approach (Braun et al., 2006). The outcomes are summarized in Table 3 and in the Takeaways section afterwards.

Theme	Interpretation	Quotes
Trust	· Automated driving style should be similar to driver's style · Trust in the system depend on communication on HMI (transparency)	"User acceptance will start only when the system will simulate the driver's driving style. There you start trusting the system." "To build the trust, you need to communicate perfectly what is the vehicle going to do"
User Preferences	· Information and notifications should be adjusted based on the user profile	"I will take time to get into the new system, I am cautious. Personalization is key
Responsibility	· By assigning more responsibility to users even when automation can manage the situation, there are more chances to have a right amount of responsibility's perception from the user. · While users are immersed in NDRA they are more likely to forget about their responsibility · In SB, the driver still has the responsibility to respond to a quick TOR, in few seconds, it is important that the user is aware of this to plan his secondary tasks consequently · In LOotL, the responsibility of the user goes down, user need to be aware of this as well, feel more relaxed and freer to perform longer secondary tasks.	"We keep forgetting about what are the responsibilities because we engage so much in the secondary task, especially. If you're out of the loop for a longer time, then you get really confused like what exactly is the responsibility" "User responsibility it's quite high in level 3, the car do not promise that you can stay for long out of the loop and the user need to be ready to take control. It looks like user is mainly responsible"
Mode Confusion	· The distinction between levels needs to be relevant in order to avoid mode confusion. · A first training and reminders during the journey explaining driving modes and secondary tasks allowed · Constant communication of current mode and user's responsibility	"A mandatory training when the driver receives the car, where it is explained how to use the system, limitations of the system, types of NDRA" "If you communicate the current level constantly and responding responsibilities then mode confusion is prevented. for example, with some visual cues"
Information	· Time left before change of mode because user can lose 'here and now' (in LOotL), and because of imminent quick TOR (in SB)	"Expressing the time before change to new automation level is really important. User need to know how much time they have before stopping doing NDRA"
Information Modality	· The information shouldn't be intrusive and annoying for the user, there is the risk of disactivating of important messages · Lighting and color coding are the most promising modalities for LOotL and secondary task scenarios · Notification on device when the user is performing a NDRA with a device · Haptic feedback is a good way to deliver messages.	"I made an experimentation with a cabin soundscape solution (that give the user the idea of the driving) can express the status of automation and vehicle behaviour. The drivers didn't like it too much, the sound was perceived as bothering and alert." "Lighting is more commonly suggested to give users feedback. Light bars may be the least intrusive and can communicate the status of automation."

Table 3 . Interviews insights by theme

Limitations

This set of interviews with experts in the field of autonomous vehicles was really helpful to confirm insights gained from the literature study and to collect subjective opinions about information importance and user's preferences, although it is important to mention the study's limitations.
Questions about information importance and user's preference are influenced by experts' extensive knowledge about the topic. Their answers, indeed, can be biased by their research on the topic and the results may not be directly from their own point of view.
For this reason, only the results of this session of interviews are not considered enough to build reliable user research.
The study needs to be triangulated with users' questionnaires and generative sessions to investigate further on the topic.

Key Findings & Takeaways

• **In SB, the driver still has the responsibility to respond to a quick TOR, in few seconds,** user needs to be aware of this to plan secondary tasks consequently

• **In LOotL, the responsibility of the user goes down,** user need to be aware of this as well, feel more relaxed and freer to perform longer secondary tasks

• Communication of **current mode and user's responsibility should be constant**

• **Time left before change of mode** because user can lose 'here and now' (in LOotL), and because of imminent quick TOR (in SB)

• **Information Preference is subjective,** smart personalization could be key

• **Trust on the automation depends on HMI transparency** of automation behavior

USERS QUESTIONNAIRE

An online questionnaire was created with Google Forms to collect drivers' experiences with cars on the market that have advanced partially automated options, such as Tesla Autopilot, Jaguar I-Pace Autosteer, and others. The survey was published (15-21 June) on online forums such as Reddit.com and Facebook groups where owners of cars with those features exchange experience, news, and opinions. An overview of the questionnaire's procedure is illustrated in Figure 16.

Goals

• Identify eventual issues with partially automated systems with experienced users
• Investigating users' driving attitude and habits
• Investigating users' opinion and emotions about automation
• Investigate users' preferences on information load and modality of current and future automated systems
• Investigate the importance of information during the two sub-scenarios (SB and LOotL)
• Draw a conclusive experience journey map (page 49) on high-level automation user experience

Method

The questionnaire consisted of three parts. In the first one, the questions were introductory about personal details to investigate the composition of participants with questions about age, driving experience, driving time, etc. In the second part, participants need to describe their experience with partially automated driving such as Autopilot / Pilot Assist system / Traffic Jam Assistant. In the

Figure 16 . Interviews procedure illustration

third part, people were asked to imagine a future scenario of High Automated Driving, where they could perform non-driving related activities, describing what the activities and interactions in those cars will be useful for them. Some questions of the second part asked the participants to answer about illegal activities (NDRAs while driving with partially automated mode). For this reason, at the beginning of the questionnaire participants were informed about it and that this study has no link with authorities. Moreover, they were asked the consent of data elaboration based on their answers in an anonymous way.

There were 54 participants in total (M=80%, F=20%, 38.9% between 36-50 y/o, 29.6% between 51-65 y/o, 24.1% between 26-35 y/o and 7.4% between 18-25 y/o) and 83.3% of them have been driving cars for more than 10 years. Most of the respondents (74%) were Tesla owners and had experience with Autopilot function, the rest of participants own other cars, such as Jaguar I-Pace, Golf7, Volvo XC40, etc.

Analysis

The online questionnaire can be considered qualitative because less structured compared to a quantitative survey. The questionnaire contained many open-ended questions in order to get richer information about their experience, understanding their motivations and their opinion on the future. Since the questionnaire had a qualitative nature, the analysis refers again to the thematic analysis approach (Braun et al., 2006). In this situation with 54 respondents, the analysis of the open-ended questions has been run through Excel, interpreting the answers of participants and finding topics and themes by the researcher. The frequency on the same topic was calculated and similar topics were clustered together. In this way patterns and preferences have been identified and will be discussed in the next section. Then, the analysis on the same open-ended was run again with a Word Cloud generator. This tool analyses the text and automatically creates a visualization of the words that have been used the most in the given text. The bigger a word appears, the more frequent it was mentioned in the text. In the next section, the results are being discussed and finally, the two analysis approaches will be compared.

Results

A full in-detailed description of the answer and analysis-per-question can be found in Appendix 5. Below, the main outcomes of the questionnaire are summarized and the analysis methods are then compared.

Partially Automated Driving Experience

The 48.1% of the participants in this study are people who use PAD systems every time the option is possible (other 37% declare to use it often), especially on highways and freeways, but also during traffic situations. Most of the people feel relaxed and positive emotion during PAD (86%) and that is the reason they use it so often. Contrarily, more than half the sample felt negative such as anxious on their first experiences with PAD. Moreover, more than 50% of the participants affirmed they perform secondary tasks during PAD, especially checking the phone.

'Bad' PAD Experiences

The main problem participants had with PAD was *phantom braking*, mentioned by almost half the sample. Many people mentioned that they could not understand the reason for the sudden braking which confirms a l*ack of communication* from the system between driver and automation.

Another common issue mentioned by 13% of the sample is *unexpected decision* or *driving style*, for example, someone stated *"The vehicle may switch lanes at a time that is not polite to a passing driver"*. This means that if the car does not simulate the driving style or the driver cannot predict automation decisions, the driver feels suspicious or can get scared.

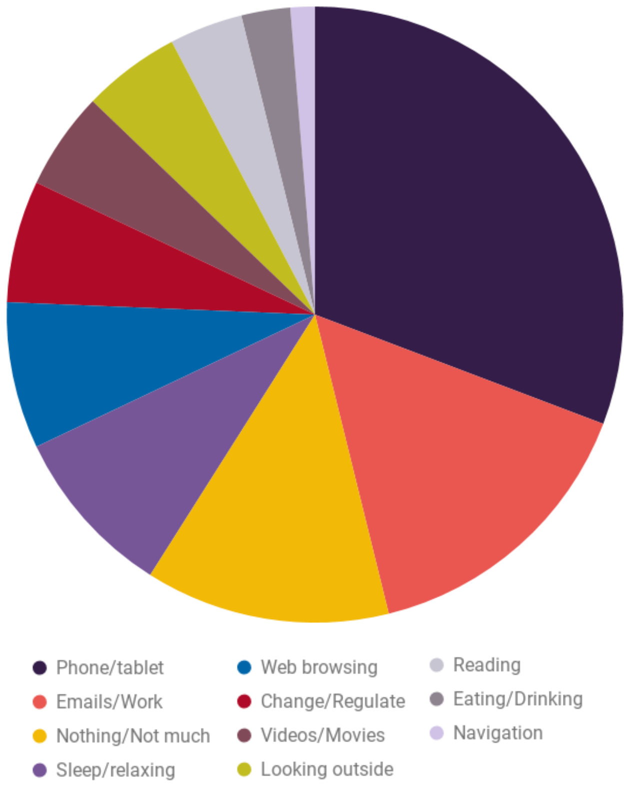


Figure 17 . Non-driving related activities for 1-5 minutes out of the loop (SB)

Non-Driving Related Activities change depending on time out of the loop available

Some participants mentioned that they usually perform some secondary tasks during Partially automated Driving and the most popular activity is checking the phone. It is interesting to understand from this survey how people will plan their time based on the available time to stay out of the driving loop. It can be noticed a difference in tasks between 1-5 minutes out of the loop and 30+ minutes of time. In 1-5 minutes time, almost half of the sample would stay at the phone or tablet working, replying to emails, starting a call, etc. (see Figure 17), and 13% (10 people) said they would not do anything, still monitoring similarly to PAD. When will be possible to have 30+ minutes of time, people would perform longer activities, as shown in Figure 18, and only 4% (3 people) stated they would not perform any secondary activities.

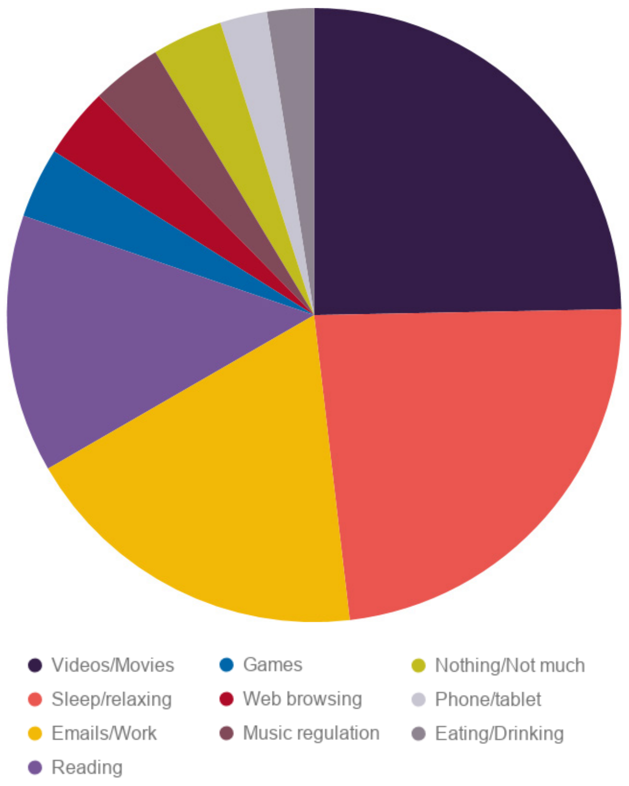


Figure 18 . Non-driving related activities for 30+ minutes out of the loop (LOotL)

What information to communicate during HAD?

The participants showed similar opinions in terms of information to receive from the HMI in both scenarios. First of all, they want to know if their attention/intervention is needed (23%); the 18% of participants also want to be informed about road context information such as traffic conditions and warnings; the 13% wants information about *Time Before Change of mode* or *Expected Time in the same mode*. The difference between SB and LOotL is that *Automation Status* seems to be more important in the SB mode (10%), while in LOotL it is more relevant to communicate the *Progress on the Route (12%)*: *"The car has assumed responsibility. I no longer care what it's doing unless it has decided it cannot take me to my destination"* so that the human understands if everything is good with the automation. Some people also mentioned they want to know about *Automation Decisions* about road context such as speed, next moves, etc. (only 6%), and those people who will probably reflect the HIP category, more careful about the driving context.

How to communicate information during HAD?

Auditory and *Visual modalities* were the most popular among participants for both SB and LOotL. Figures 19 and 20 show the outcomes from the WordCloud Analysis on this topic. Some more results emerge from the thematic analysis. First, more people mentioned the Haptic Modality in LOotL, and then 3 people, especially for LOotL scenario, mentioned *"Telepathy, information direct to the brain"*. However, generally, people imagined a familiar future scenario, similar to the current vehicles. This topic is indeed the most difficult to investigate through an online survey, and it will be elaborated later especially during the design iterations.

The complete analysis of the questionnaire can be found in Appendix 6, in addition, reflections and takeaways can be found at page 42, in order to summarize the insights from this study.

Figure 19 . WordCloud about information modality in SB mode

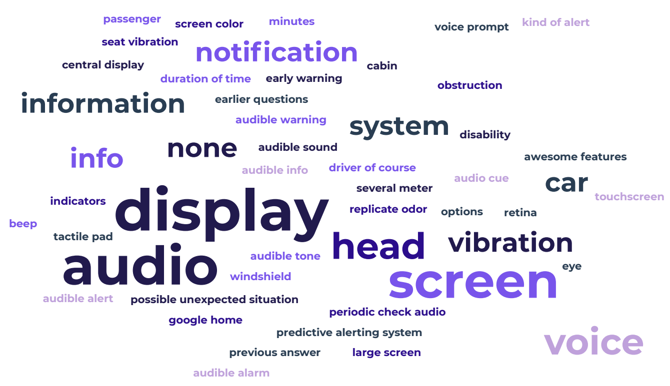


Figure 20 . WordCloud about information modality in LOotL mode

Method Reflection: Thematic Analysis vs. Word Cloud Analysis

This online questionnaire also compared the effectiveness of two analysis methods, Thematic Analysis and WordCloud. The first one is way more time-consuming and has some limitations due to the subjectiveness of the interpretation of participants' answers. However, it is a method that brings to light more interesting results.

WordCloud is a faster method to analyze answers without the researcher's interpretation issue. For this reason, it is less biased, but at the same time, the results that you can get from the visualization are not as rich as with Thematic Analysis.

Example 1 shows when WordCloud is more effective: short answers (adjectives, listing objects, qualities, etc.).

Example 2 shows when Thematic Analysis is more effective: long descriptions and the questions are similar to an interview.

Example 1

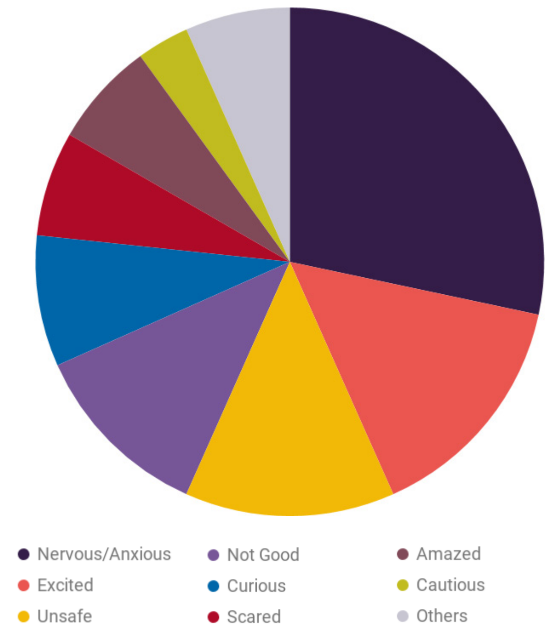


Figure 21 . Thematic Analysis result on question about first experience with PAD

Example 2

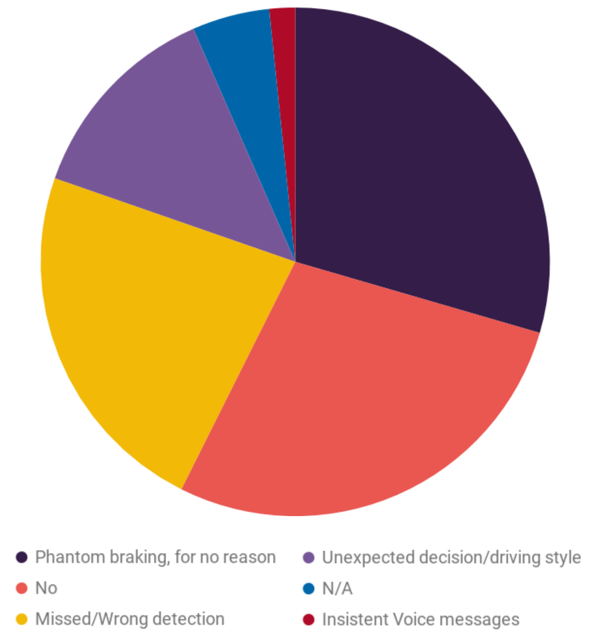


Figure 23 . Thematic Analysis result on question about bad experience with PAD

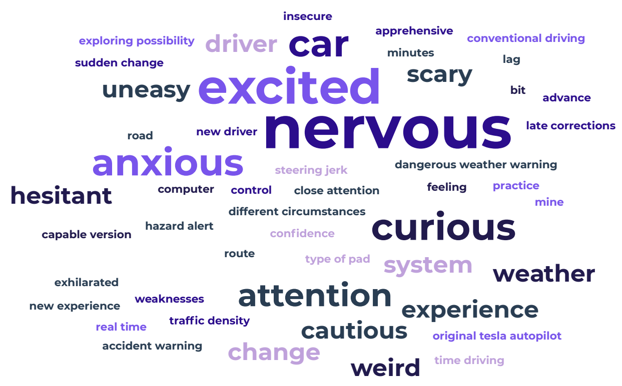


Figure 22 . WordCloud: first experience with PAD

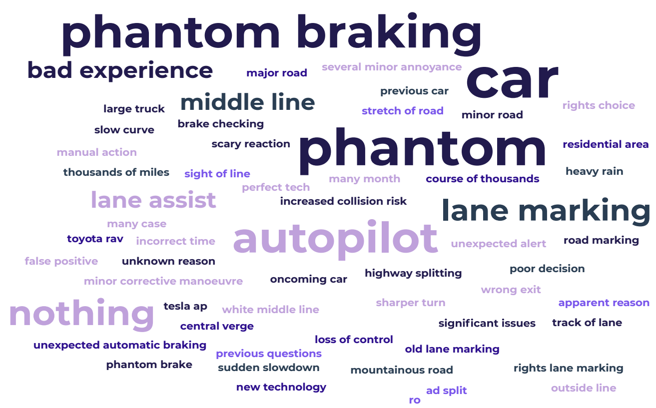


Figure 24 . WordCloud: a bad experience with PAD

Limitations

Even though this user research has brought many interesting results for the project, some study limitations are to be mentioned.
First, the sample of participants is not representative enough of the complete range of people that will potentially use autonomous driving. The new generation of people that will be more familiar with PAD systems or people who have not experienced with PAD systems at all, were not considered for this questionnaire. Another important limitation was that only a limited circle of people active on Facebook groups and forums were recruited for this questionnaire. People who are part of these groups are particularly optimistic and open towards technology and innovation. This may have influenced the completeness of the results by not taking into consideration who might be more reluctant to the project or distrustful of the system. In conclusion, the results concerning information importance and preferences only fit the limited group of people analyzed in this test. Further research could investigate a similar topic on a larger scale and sample.

Key Findings & Takeaways

- **Driving with autonomous features is considered as a positive experience for users,** that is why they use it so often

- **When users don't understand the reason for unexpected movements/decisions, they consider them as 'bad experiences'**

- **Drivers plan different activities based on time out of the loop available**

- Knowing **IF their attention/ intervention is needed and WHEN**

- For SB, knowing **Automation Status**

- For LOotL, knowing **Route Progress**

GENERATIVE RESEARCH

"People can express an infinite number of ideas through a limited set of stimulus items"
- Convivial Toolbox, 2012

PARTICIPATORY MINDSET – GENERATIVE DESIGN RESEARCH – GENERATIVE TOOLS – ENACTMENTS

Generative Design Research is a design-led approach and adopts a participatory mindset using generative tools to let users express their experiences in a playful way and at the same time, become more aware of their experience. In Generative Research sessions, participants express their goals, motivations, meanings, latent needs, and practical matters and then, are asked to generate alternatives to the current analyzed situation.

Goals

- Understand in-depth users' perspectives
- Translate user experiences into desirable and familiar design solutions to avoid user rejection
- Understand human-centered HMI requirements based on contexts' analogies

Analogous contextmapping will investigate participants' experiences and interactions of familiar situations in which the user automatically experienced "situation/ responsibility awareness" and "divided attention" *similarly to how they would do in the autonomous car context.* In this way, exploring emotions, current interactions and needs in analogous contexts, the users will reveal latent insights that will be translated and interpreted into desirable interactions for the autonomous driving context.

How do participants currently feel (especially about their responsibility) in analogous contexts and how would they like to feel?

Which similar interactions are interesting findings for HMI of AV?

INVESTIGATION SCOPE:
Trust, Divided attention and Situation Awareness, Mode Confusion, Transparency, Responsibility

This method will help to define a design goal that is more desirable for users and start thinking about original ideas and concepts based on human behavior.

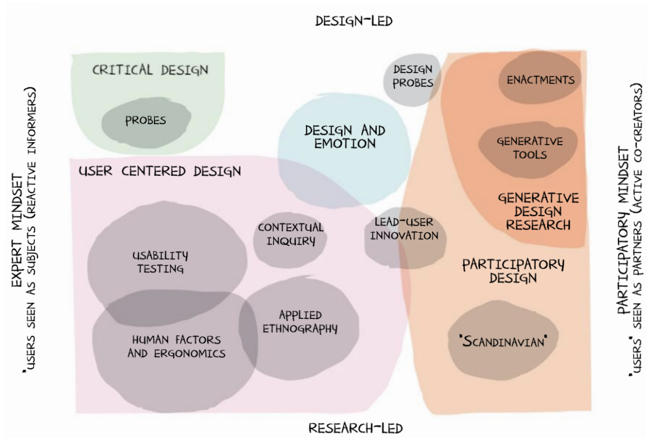


Figure 25 . Design research map: Generative Design Reseach on top right, from: Convivial Toolbox, 2012

Method

For this qualitative study, 9 people were recruited to conduct 3 sessions of 2 hours with 3 people each. The three groups were organized in such a way that participants did not know each other and have different experiences, enriching the conversation. The context of the Contextmapping sessions will be an Analogous Contexts (different from the driving context, different from highly automated vehicle, but a context where people need to have situation awareness of the context while performing another activity). Every participant, some days before the session, was given a booklet to fill for three days, where they choose a context between the examples or a similar one of their choice. After the session, the insights from analogous contexts will be analyzed and translated in possible directions in terms of interactions drivers-HMI.

The sessions took place online via video call, so it was easily possible to record the session, after asking to sign a consent form to each participant. In order to create a similar environment to an ordinary contexmapping session, the participants were asked to use Miro (www.miro.com) as a whiteboard where to collaborate and co-work together at the same time.

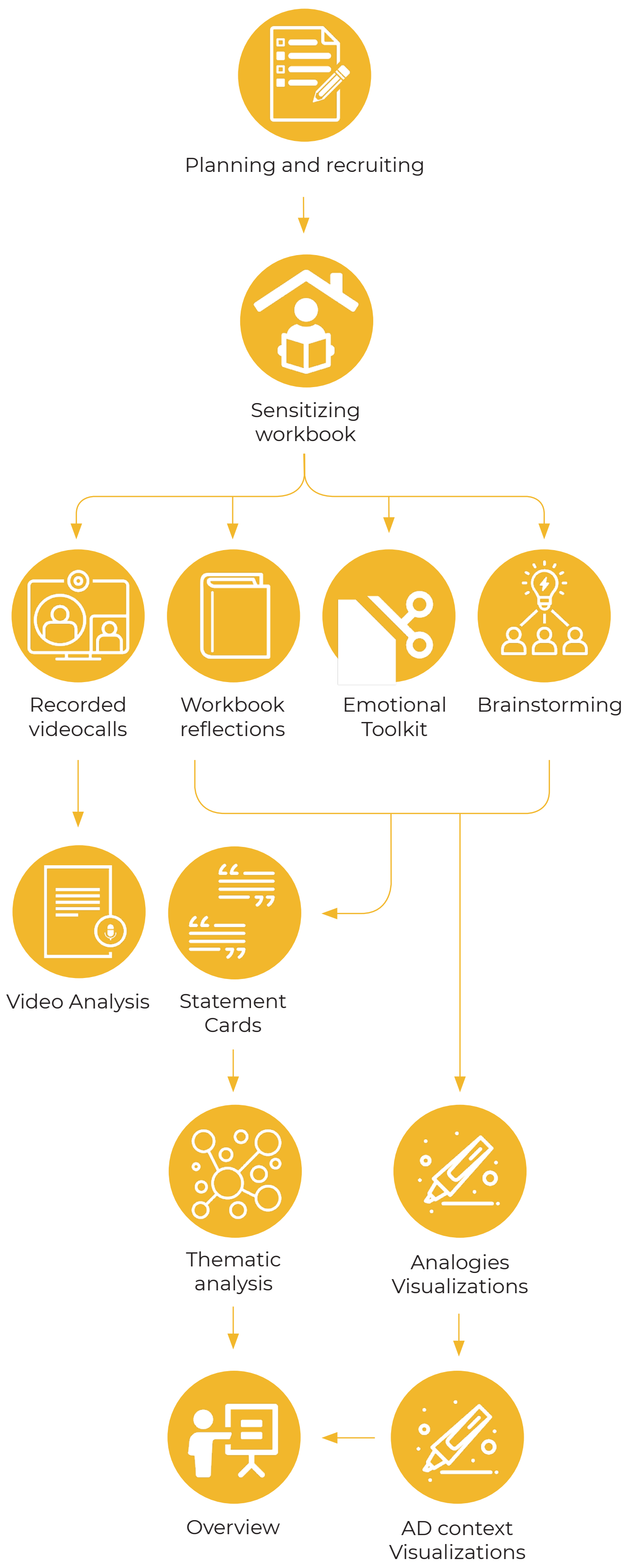
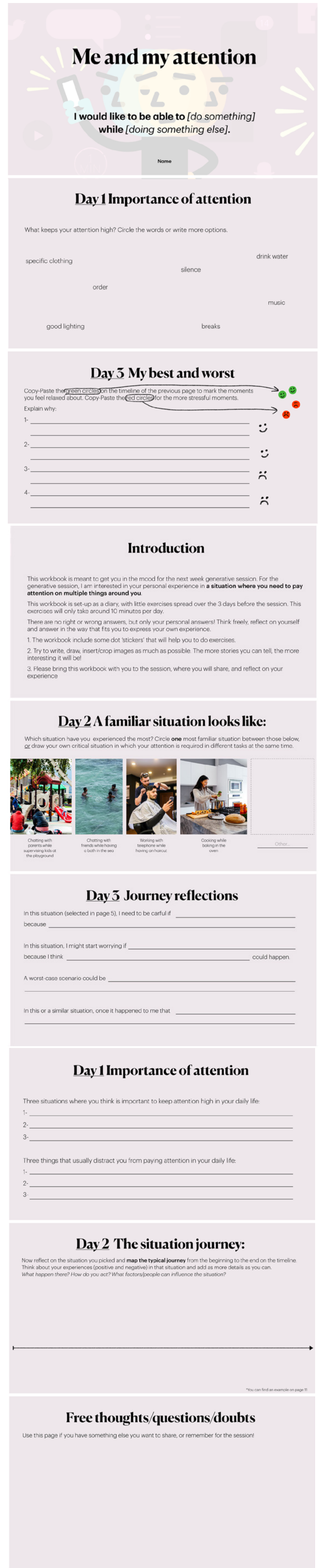


Figure 26 . Interviews procedure illustration

Figure 27 . Visual Mindmap 1: mother at the playground analogous context. Similar interactions that could happen in a playground, while a mother need to supervise the kid and at the same time talking with other parents

Figure 28 . Visual Mindmap 2: kitchen analogous context. Similar interactions that could happen in the kitchen while cooking something while baking something else

Figure 29 . To the right: Sensitizing Workbook



Method Steps

- Define topic and plan activities.
- Capture perceptions in mind maps, see Figures 27 and 28.
- Conduct preliminary research.
- Provide participants with homework activities, see Figure 29.
- Do several exercises, which can be individual, in couples, collages, presentations, build upon other's experiences, see Figure 30.
- Ask frequently "how do you feel about it?" and "What does it mean for you?"
- Write down impressions, immediately after the session.
- Analyse outcomes and find directions.
- Create a rich visual environment of interpretations and categories, see Figure 29.

Sessions

The sessions online went smoothly, in terms of results that can be considered as good as an ordinary contextmapping session. The time spent on explaining Miro platform has been compensated with a faster way of composing the collage with Emotional Toolkit. Moreover, people were free to import other pictures from the browser and that was easy and fast.

Analysis

For the analysis of the Contexmapping sessions Analysis on the wall method (Convivial Toolbox, 2012) was chosen to gain deeper insights. All the video footage from the three sessions were reviewed carefully while completing statement cards.
Statement cards will bring to light any reflections and interpretation from the session by the researcher, allowing further elaboration about the Autonomous Driving context, with the limitation that for this project there is only one researcher, while generally the analysis is conducted by a team of researchers.

Once the statement cards are completed, those were divided into thematic clusters and reviewed again. After the analysis on the wall, a first visualization (Figure 28) of the interactions that emerged during the sessions was created to investigate similarities with Autonomous Driving. All more relevant insights from the comparison were then translated into a second visualization (Figure 29) where those interactions were interpreted as significant reflections.

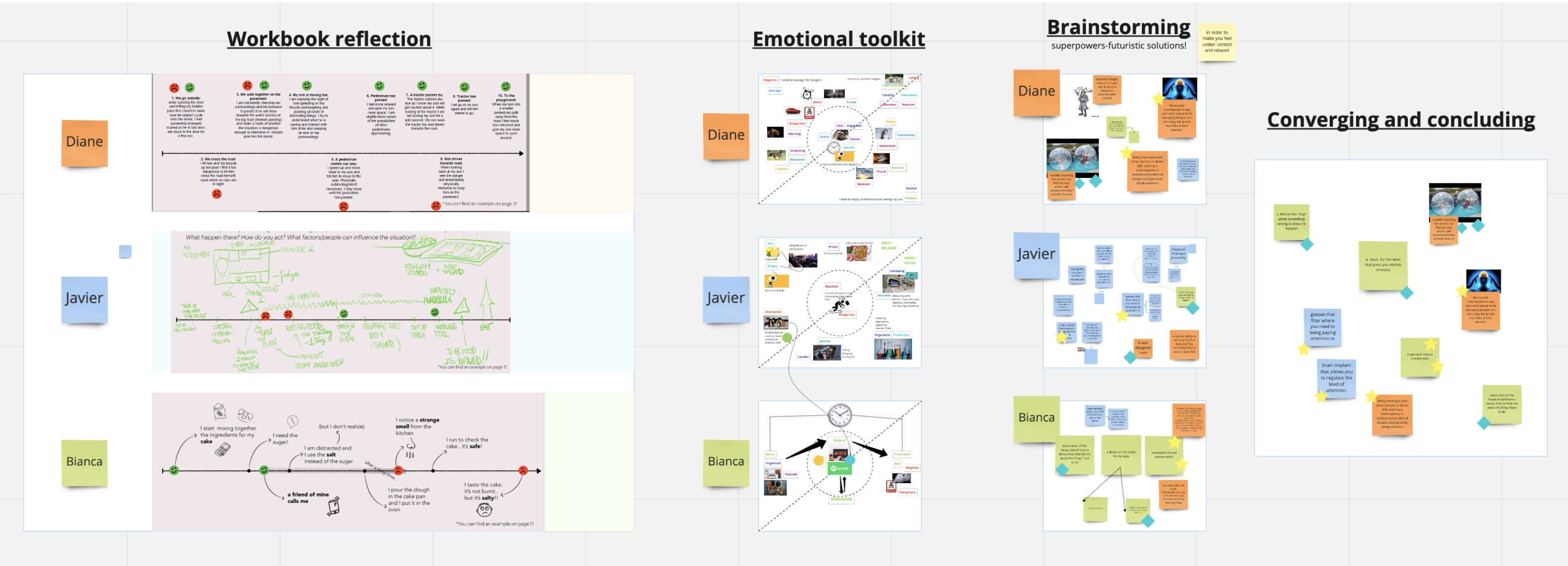


Figure 30 . Miro boards from session 2

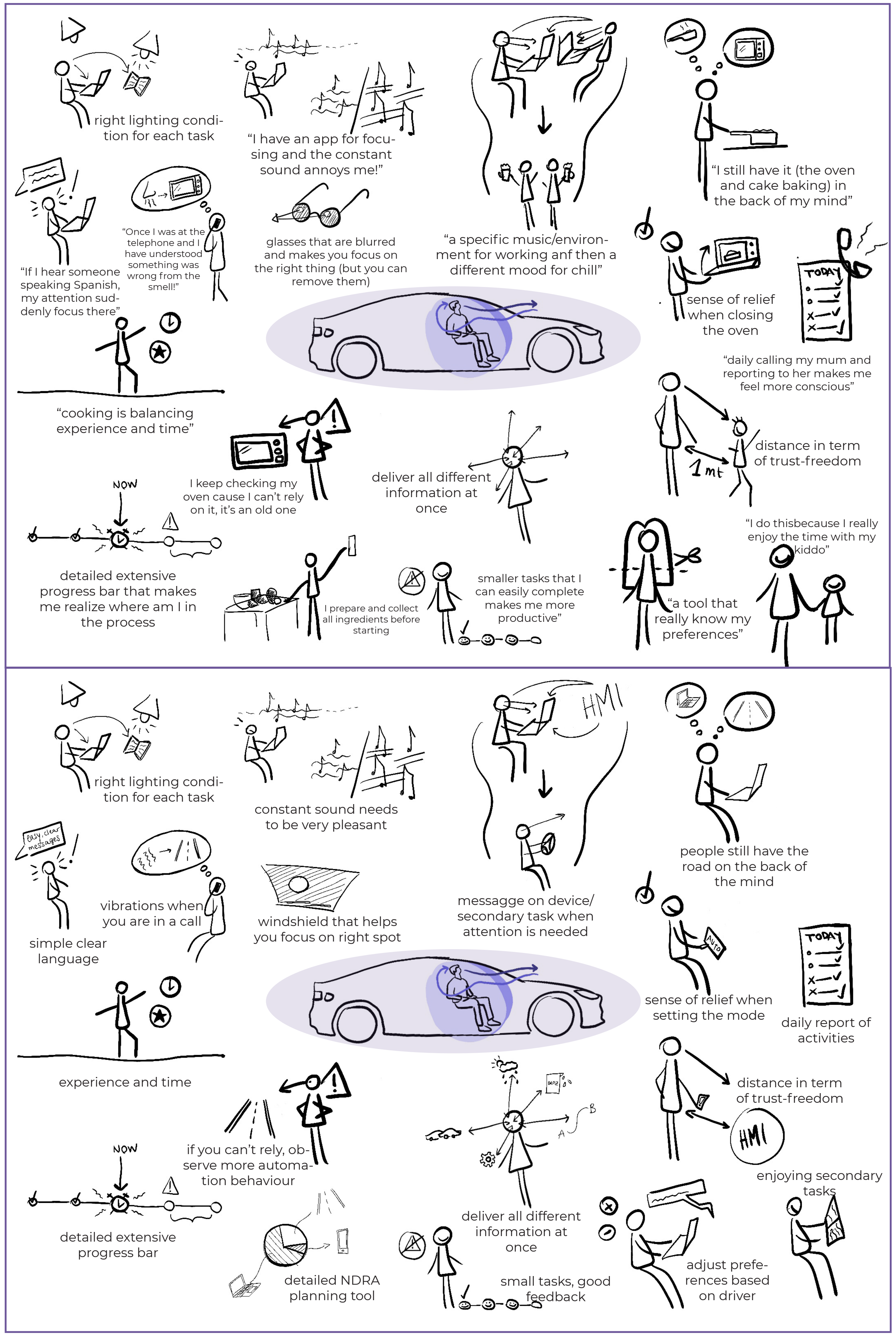


Figure 28 & 29 . Visualization of outcomes (on top) and interpretation (bottom picture)

Results

The takeaways and reflections from the Generative Design Research have been summarized in the table below. An overview of Research and Analysis methods is provided in table 4, before introducing the Experience Journey Map.

Key Findings & Takeaways

• The **Human Factors** analyzed for this project lies in **people's everyday life situations** and, most of the times, those articulate in the same way even in different contexts. **The underlying cognitive mechanisms are the same.**

• **Experience (with the system) and Time management** are secret ingredients to balance the Human Factors

• **Emotional attachment makes feel more attentive**

• Information communicated in a **familiar language** is better understood

• **Planning** part of the process is a crucial aspect for the success

• The **benefits / positive emotions** are the reason why people are motivated to use the system

• People want to **unconsciously be aware of the situation** without being interrupted or without intrusive signals

Literature Study	Human Factors			Experience Journey Map
Experts Interviews	Information Importance Graph	Interpretation Cards	Thematic Analysis	
User Survey	Graphs Interpretation	Excel Thematic Analysis	WordCloud	
Generative Research sessions	Interpretation Cards	Analysis on the Wall	Analogies Visualization	

Table 4 . Research methods overview

EXPERIENCE JOURNEY MAP

To summarize all the results and insights collected from the user research and the literature study, an Experience Journey Map was created. The stages were based on the Mediator Use Cases and then elaborated with the insights gained from the User research.

The top part of the Journey Map, consisting of *Automation*, *Driver's Activity* and *HMI touchpoints,* gives an overview of the interactions between automation and driver through the HMI.

The bottom part, including *Human Factors*, *Opportunities*, *Emotions*, *Quotes*, are those values and interpretations emerged from the User Research's converging activities. These values bring to light reflections on future interaction and helped to outline design opportunities and directions.

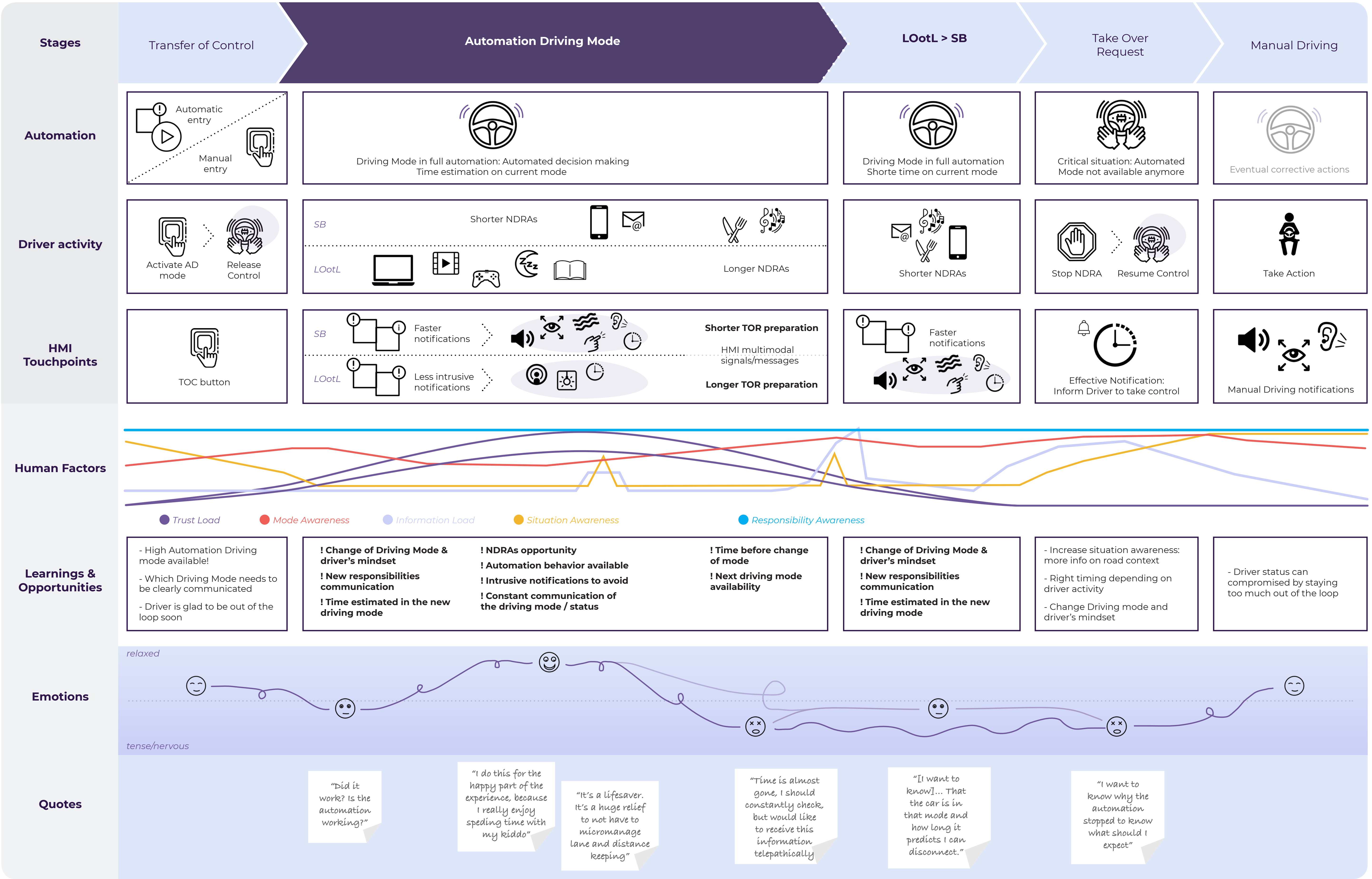


Figure 30 . Experience Journey Map

04 FROM RESEARCH TO DESIGN

From the conclusions of the Context research about Autonomous Driving and the results gained from the extensive User Research, this chapter will elaborate on project requirements, the Design Goal, Users' groups and design directions.

CHAPTER AT A GLANCE:

- *Storyboard*
- *Functional Requirements*
- *Users' Groups*
- *Design Goal*

FUNCTIONAL REQUIREMENTES

The Experience Journey Map helped in formulating requirements for this project. In order to further elaborate the content of the Experience Journey Map, first, a storyboard that illustrates and explains the interaction from a user perspective, see Appendix 8.
The frames of the experience described with the Experience Journey map, are now listed below in order to indicate separated moments where differents requirements are needed.

Frames

1. **Overall requirements**
2. When switching to SB automated driving
3. When switching to LOotL automated driving
4. **When switching from LOotL to SB**
5. **During SB automated driving**
6. **During LOotL automated driving**
7. When switching from SB to manual driving

1. Overall requirements

• All the information should be communicated in an understandable way and not cause ambiguity/doubtfulness to drivers

• Limitations and capabilities of the system should be clear to the driver

• Information should be easily accessible to the user but in different levels of intrusiveness based on the importance of information, in order to avoid Information Overload

• The HMI should include personalization opportunities in the information load and the appearance of the interface

WHY? REFERENCE TO THE RESEARCH:

1.1 Information should be understandable by users, as someone from the **Experts Interviews** said there should be *"A mandatory training when the driver receives the car, where it is explained how to use the system, limitations of the system, types of NDRA, new indicators and icons, ..."*
In the **Generative Session,** some people mentioned the importance of experience with the system, secret ingredients to balance the Human Factors and achieve the trust and confidence with automation

1.2 According to the **Literature study**, different emergency level situations should lead to different intrusiveness of system feedback output to drivers. Visual outputs are the less invasive and annoying way to generate transparency, trust and situational awareness, informative ambient lighting, especially during non-driving-related activity.

1.3 From the **Literature review** and the **Generative Session** it emerged that Information Preference is subjective, smart personalization depending on the user, the mood or situation could be key

Figure 30 . Interactions Storyboard

4. When switching from LOotL to SB

• The HMI must give a clear message to the driver that invites the user to reschedule/ plan secondary tasks appropriate to SB driving mode.

• The ambience of the vehicle should communicate the change of mode.

4.1 Planning activities and secondary tasks are crucial moments as already discussed in **Time Budget paragraph and Generative Research chapter**. To be able to plan this, users need to be warned and in advance and they need to notice the change.

4.2 The change of mode should be communicated in a way that is not perceived as annoying or intrusive. From the **literature**, the most promising way is visual feedback, especially ambience lighting showed quite promising results in other studies.
On the other hand, the change of driving mode should be communicated in a noticeable way when the driver is performing any secondary activity. The visual ambience should be able to convey this info in every situations and make use of other feedback modalities if necessary.

5. During SB automated driving

• The HMI should *constantly and unobtrusively* communicate the driving mode is on and its status clearly

• The HMI should communicate the role of the driver and responsibilities in that mode

• The HMI should suggest secondary tasks allowed and remark the difference with LOotL

• The HMI should clearly provide and remind the estimated time before the change of driving mode

• The HMI should unobtrusively anticipate automation moves/decisions to drivers

• Automation actions and decisions should always be available

5.1 An insight from the **Experts Interviews** was that the current driving mode and drivers' responsibilities should be communicated constantly in order to prevent mode confusion, as someone stated *"If you communicate the current level constantly and responding responsibilities then mode confusion is prevented. For example, with some visual cues"*
However, both the from **Generative sessions** and User Questionnaires, people expressed a need for unobtrusive modalities.

5.2 From the **Experts Interviews**, it is clear that in SB, the driver has the responsibility to respond to a quick TOR in few seconds, so to make this clear for users (**Generative sessions**), the HMI should suggest adequate secondary tasks to this driving mode and the user should understand the difference with LOotL.

5.3 From the **Experts Interview**, we understood the importance of providing and reminding drivers about the time left before changing the driving mode. When performing other "immersive" tasks, the driver can lose 'here and now' (especially in LOotL), and in SB, because of imminent quick TOR possibility. Moreover, the **Users Questionnaire** demonstrated how users plan different activities based on the time available with full automation, so this feature is also crucial for planning the secondary tasks.

5.4 From **Experts Interviews**, it emerged that to enhance trust on the automation, the HMI should provide transparency of information about automation behavior, as someone said: *"To build the trust, you need to communicate perfectly what is the vehicle going to do".*
This statement has been strengthened by the **Users Questionnaire** since many participants mentioned that they had 'bad experiences' when they cannot understand the reason for automation unexpected movements/decisions. However, understanding the problem and the automation logic could help them trust the system until some system limitations are crossed.

6. During LOotL automated driving

- The HMI should *constantly and unobtrusively* communicate the driving mode is on and its status clearly
- The HMI should communicate the role of the driver and responsibilities in that mode
- The HMI should clearly provide and remind the estimated time before the change of driving mode
- The HMI should occasionally call the driver's attention to prevent the driver's unfitness
- The HMI should unobtrusively anticipate automation moves/decisions to drivers
- Automation actions and decisions should be always available
- The HMI should show the route progress in an understandable and clear way

6.1 Same reference as 5.1

6.2 Same reference as 5.3

6.3 From the Literature, Experts Interviews and the Generative session it emerged that when people are fully immersed in secondary tasks, they want to unconsciously be aware of the background situation without being interrupted or without intrusive signals, but somehow being supervisors

6.4 Same reference as 5.4

6.5 The User Questionnaire showed that the main difference between SB and LOotL was that in SB drivers are more interested in automation behavior, while in LOotL people only want to have necessary information including the route progress to have an overview of the trip. *"The car has assumed responsibility. I no longer care what it's doing, unless it has decided it cannot take me to my destination. I would like to know something about the route and time to get to destination, delays, traffic information, ..."*

USERS GROUPS

Since for this project focusing only on a specific target group would cut out many different types of potential users, the use of personas is less relevant for the scope of this master thesis. However, from the Literature study about User perception, it emerged that the future drivers of HAV can be divided into two Users Groups as introduced before, the Low Information Preference group (LIP) and the High Information Preference group (HIP). According to Ulahannan et al. (2020), the differences in information preference between the two groups are summarized in tables 6 and 7. The HIP group wants to have more detailed information about automation and their tasks, while LIP wants less information. This can cause risks for level 2 automation especially in the monitoring task. Although it is important to consider that Ulahannan's study has been done on Partially Automated vehicles (level 2 automation), yet during the User Research -including Experts Interviews, Users Questionnaires, and Generative sessions- the two groups were identified as well, and similar patterns have been found also with HAV.

Events	1 Handover	2 Traffic	3 Junction	4 Steady State	5 Handover
HIP	Primary (f = 179)	Secondary (f = 190)	Secondary (f = 196)	Secondary (f = 152)	Primary (f = 146)
LIP		Tertiary/ Primary (f = 40)	Tertiary/ Primary (f = 48)	Tertiary/ Primary (f = 46)	

Table 6 . Differences between HIP and LIP groups (Ulahannan et al., 2020)

High Information Preferences	Low Information Preferences
• Wanted detailed information on the vehicle's situational awareness etc. • More accepting of the limitations of L2 driving automation and wanted to work with the system. • More concerned with secondary information	• Wanted less information on the status of self driving and not concerned with assisting the system • Wanted the vehicle to offer assistive features • More concerned with either tertiary or primary information

Table 7 . Information preferences of HIP and LIP users groups (Ulahannan et al., 2020)

For these reasons, it has been decided to consider LIP and HIP as a good example of Users Groups for this project. It has been found that HIP drivers are the most suitable users for partially autonomous systems (level 2), "with their acceptance of technological limitations and willingness to work with the secondary information provided by the system" (figure 31). Within this project instead, the two different driving modes, SB and LOotL, require different engagement and awareness with HMI information. In SB driving mode, the LIP group should be more similar to HIP in order to ensure a safer trip, while in LOOtL there can be more differences between the groups for the experience to be safe anyway. The picture below illustrates these relations according to the driving modes. The design development of this project should give drivers the right preference of freedom according to this model.

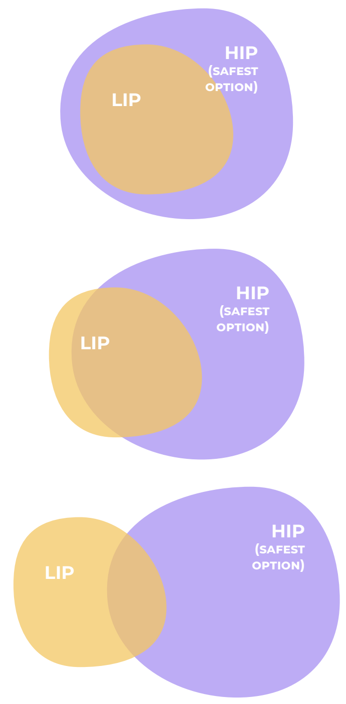


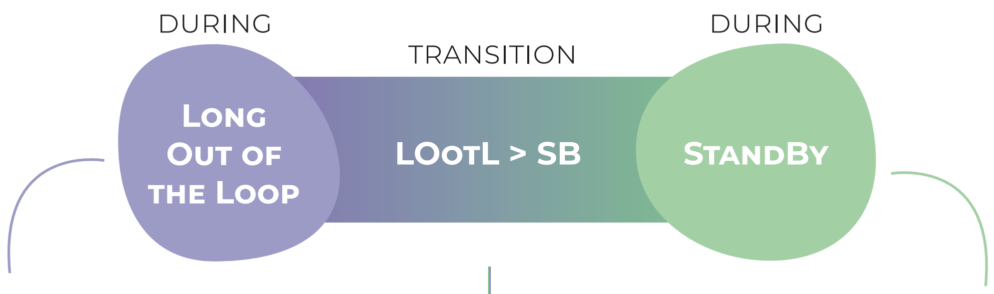
Figure 31 . Relation between the Users Groups in different automation levels (top = L2, middle = L3, bottom = L4)

DESIGN GOAL

The design goal of this master thesis is:

“To unobtrusively inform drivers about automation status, driving mode and their responsibilities during autonomous driving mode through the HMI, while the driver is performing non-driving related activities.”

However, the Design Goal has been explored for each driving mode as below to be more specific for each frame of the journey.



“To inform drivers during LOotL about the time available to perform longenger secondary tasks, and at the same time giving access to important contextual information about automation and road situation in an unobtrusive way”

“The HMI should quickly inform drivers about the new driving mode, new responsibilities and secondary tasks available while the driver is performing non-driving related activities.”

“To inform drivers during SB about secondary tasks recommended, the time before switching mode and fast takeover time, but at the same time giving access to important contextual information about automation and road situation in an unobtrusive way”

HMI Qualities

After the definition of the Functional Requirements and the Design Goal, it has been elaborated on the qualities the HMI should have in the future concepts. The product qualities are not the design of the product itself, but it is a tool for designers that support them taking direction for the ideation process.

INFORMATIVE
The HMI should first of all inform the driver about important information that ensures a safe journey.

UNOBTRUSIVE
In SB and LOotL, since the driver can perform some secondary tasks the HMI should not be intrusive or disturbing the users.

SUPPORTING & RELAXING
The HMI should be perceived as supporting the user in both the driving tasks (for automation and driver’s awareness) and the secondary tasks and relaxing at the same time, not to feel under pressure.

DIRECTIVE
The HMI should direct the drivers to choose the right tasks for every driving mode.

EXPLANATORY
The HMI should have a more transparent sublevel that allows the user to go deeper in automation logic and reasoning, only if the driver wants to dig in.

CLEAR & UNDERSTANDABLE
The HMI should give clear indications and be understandable by every user. Confusion and ambiguity are to be avoided.

INTUITIVE
The HMI should lead the driver to easily find the information needed without effort.

SHAPABLE/ADJUSTABLE
The HMI should feel like it is customized for every user or every mood, as it understands every user, but also personalized for different situations.

CHAPTER AT A GLANCE:

- *Creative Session*
- *Conceptual Designing and Evaluation*
- *Converging Strategy*

05 IDEAS & CONCEPTS

This chapter consists of all the creative process, starting from a creative session with design students. Then 3 iterative conceptualization phases, each consisting of 3 concepts were evaluated with participants to collect opinions about singular interactions. The chapter concludes with the strategy to converge into one final and holistic design to test further.

CREATIVE SESSION

"Creativity is the process that leads to novel and useful solutions to given open problems"

- Heijne et al., 2019

CREATIVE FACILITATION – IDEATION – CO-DESIGN – INTEGRATED CREATIVE PROBLEM SOLVING (ICPS)

Creative Facilitation is the practice and skills of managing a research group through a creative process experimenting with methods and techniques in order to solve a given problem or to create new ideas and visions. The challenge of a facilitator is to keep the research group motivated and into the given problem in a relaxed yet productive and collaborative environment.

Goals

At the beginning of the ideating phase, a creative session was organized with 6 master students (3 students from the master Integrated Product Design and 3 students from Design for Interaction) in order to generate many ideas that fit the design goal of this project. The goal of the creative session is to explore design directions out of the box, to be further investigated later, in the conceptualization and iteration phases.

The session was facilitated by the author of this project and the method used for the session plan refers to "Road Map for Creative Problem Solving Techniques, Organizing and facilitating group sessions" (Heijne et al., 2019).

The participants were given a short introduction to the method first and then a briefing and explanation of the design challenge, the problem-as-given. After explaining the topic of the session, the Research Group was guided into the Problem Finding phase, about getting from problem-as-given to problem-as-perceived. By involving the Research Group to reformulate the problem statement, the RG better understood the urgency of finding ideas for the problem statement they created. The Problem Finding is then followed by Idea Finding phase, where participants generate many out of the box ideas based on the problem-as-perceived (Heijne, et al, 2019).

Challenge (problem-as-given):
"How to make users of autonomous cars (level 3/4) feel aware of the current mode and their responsibilities during full automation mode while performing secondary tasks?"

Session Plan

The session was organized based on the desired outcomes of having many different ideas (Fluency) and a variety of abstraction levels (Flexibility). Since the purpose of the session was not coming up with solutions but ideas, the completeness and quality of results were not required.

The entire session plan and more details about the session can be found in Appendix 9. Table 8 includes a summary of the session's clusters and insights.

Theme
Idea
Reflection

Direct clear feedback
- Direct communication that implies interface language, such as hand gestures, chatbox, talking, ...
- Communicating information in a way that the driver needs to reply/undestand and confirm that the message was received
- By pressing a button, anytime the car gives you a summary of automation status
- Always use 2 channels to convey a notification, to ensure the message arrives
- Direct communication is easy and clear but to be verified when driver performs NDRAs

Personified HMI
- An inanimate wearable object (glasses or device) that also talk to users
- Adding personality to vehicle, make it intimate like J.A.R.V.I.S. in "Iron man", an assistant that you can trust and create meaningful relation
- Feeling cared for, such as mom experience, you rely on something that can protect you and will advise when needed to take action
- Assign human features to automation to make driver have a more familiar experience with the interface

Animated HMI components
- Change the design/texture/ position of steering wheel to convey driver's responsibility
- Change the texture/position/ cushion/massage to define different driving modes
- Closest HMI components to users can convey clear messages during NDRA

Big Brother
- Non-see through windows to convey the message that the car will manage the situation and the driver does not need to supervise anymore
- The system tracks the driver's eyes and the ceiling wakes the driver up when sleeping
- The vehicle tracks the driver's behaviour and acts consequently to decrease the risks, increase awareness of driving mode

Personalized Preferences
- The car adapt to the user. The driver can personalize his journey as he wants, based on the vehicle's autonomy available
- Each user has a profile were s/he can personalize some notification and communication preferences
- Combining senses based on user preferences
- The driver should learn the automation limitations and capabilities but is the vehicle that should adapt to the user's preferences and behave accordingly to those

Layering Communication
- More urgency and more channels depending on the gravity of the situation
- Gradually increasing trigger intensity
- Giving the opportunity to get confidency gradually
- Reproducing the feeling of being somewhere else, depending on the driving mode and the expected activity

Ambient/ Atmosphere
- Create a chill/relaxed atmosphere during LOotL, while when switching to SB, the colors and light are getting brighter and the driver switch into a mood of awareness
- The atmosphere can change through colors, smell, light, sounds and textures to evoke driver's different moods
- It smells good when approaching to destination
- Create a soothing environment through warm lights, chill music/sounds, asmr, warm temperature, lavander smell, ...
- Every detail of the environment can make the experience being perceived in a different way. Exploring with different stimuli for a complete experience that do not disturb, seems to be the most popular option

Feeling Safe
- Feeling like being in an airplane watching in-flight tv and updates on flight/phone
- Feeling like being pampered by your mom
- Feeling safe is like feeling you can sleep in a boat, or caravan
- Reproducing the feeling of being somewhere else, depending on the driving mode and the expected activity

Gamification
- An experience that makes you feel in control by using a playful/friendly language
- Make the communication like a game with challenges
- Gamification helps keeping driver's motivation high using a easy familiar language

Table 8 . Insights of creative session

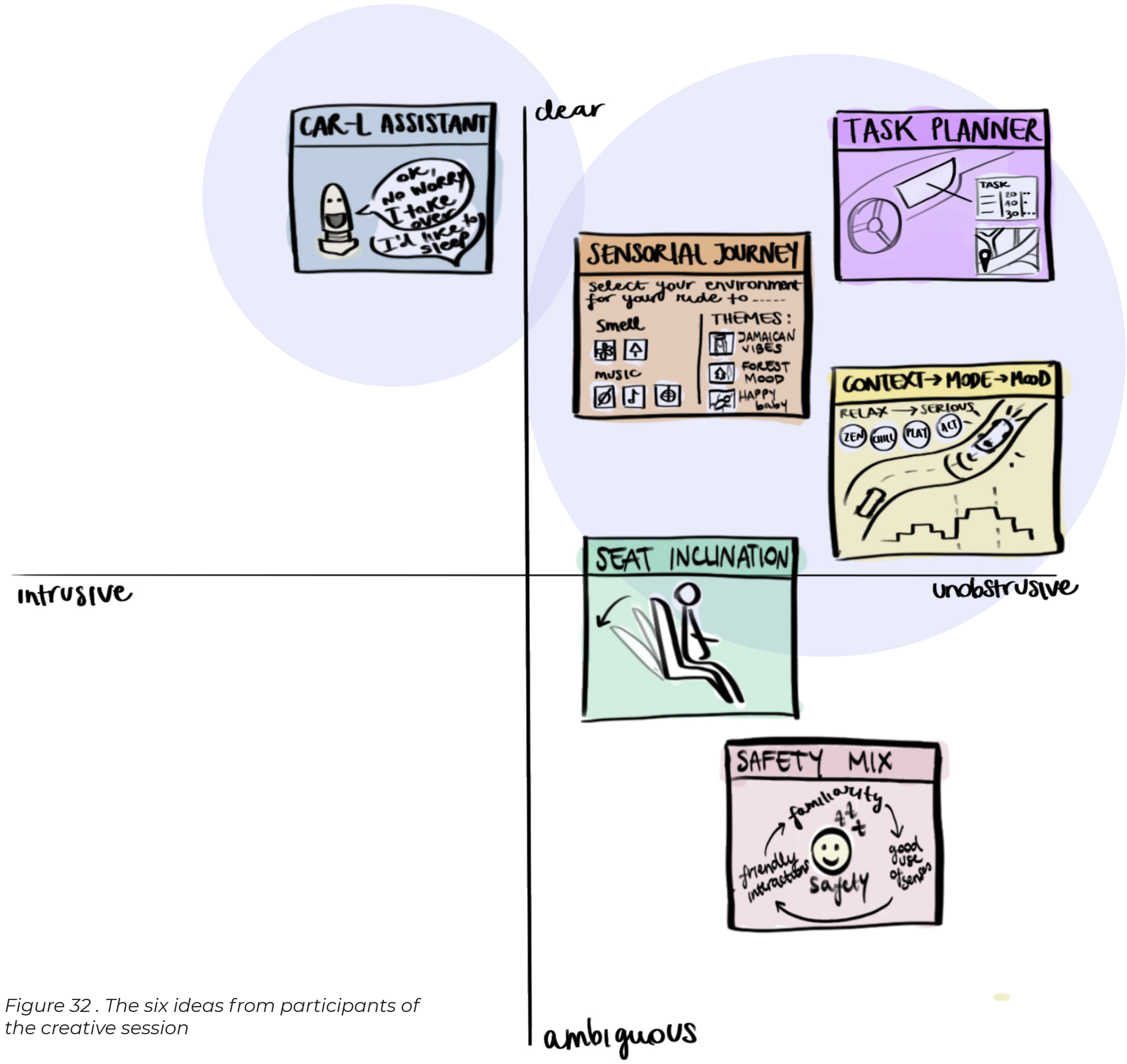


Figure 32 . The six ideas from participants of the creative session

Outcomes

All the ideas generated during the session were summarized on page 63, and clustered into 9 themes. Many of the ideas were repeated and popular among the participants of the session. The session terminated with each participant pitching an idea between all of the generated ones, developed in only 5/10 minutes individually. The six posters generated helped to present the 30 seconds pitch. These ideas are briefly explained and classified in Figure 32 and then were used to generate the three concepts described in the next chapter.

Reflections

The creative session, despite the restrictions due to COVID safety rules, contributed to starting with ideation project with different ideas, questioning the point of view of the author of this project, varying and verifying the directions of the project, together with other designers and colleagues of IDE Faculty.

CONCEPTUAL DESIGNING AND EVALUATION

The ideas generated from the creative session were mapped according to a vertical axis, the ambiguous-clear potential of communication, and a horizontal axis, intrusive-unobtrusive potential quality of interaction with the vehicle (see Figure 32). In order to match the design goal of this project, the ideas that considered potentially clear and unobtrusive were used as a base for the generation of the first three concepts, part of Conceptualization Phase 1. For this project three Conceptualization & Evaluation Phases were generated to explore different possibilities for the final holistic design and test singular interactions in specific parts of the vehicle. The method used in these conceptualization phases is inspired to Interaction Prototyping & Evaluation (Delft Design Guide, 2017), where low-fidelity prototyping concepts are quickly tried out to check if the assumptions of designers are feasible. In this way, concepts were developed and iterated at a fast pace based on real users' opinions.

The three phases illustrated in figure 33, correspond to different areas of design, in order to cover different levels of the same experience. The first one on the Experience level is inspired by the outcomes of the creative session. The second one, to investigate how different kinds of information can be conveyed by the ambience and atmosphere of the autonomous vehicle. The third one, to investigate which information is necessary to display on the central screen of the vehicle to ensure the completeness of information, clear communication, safe and comfortable experience. The next chapters will describe in detail the 3 concept phases.

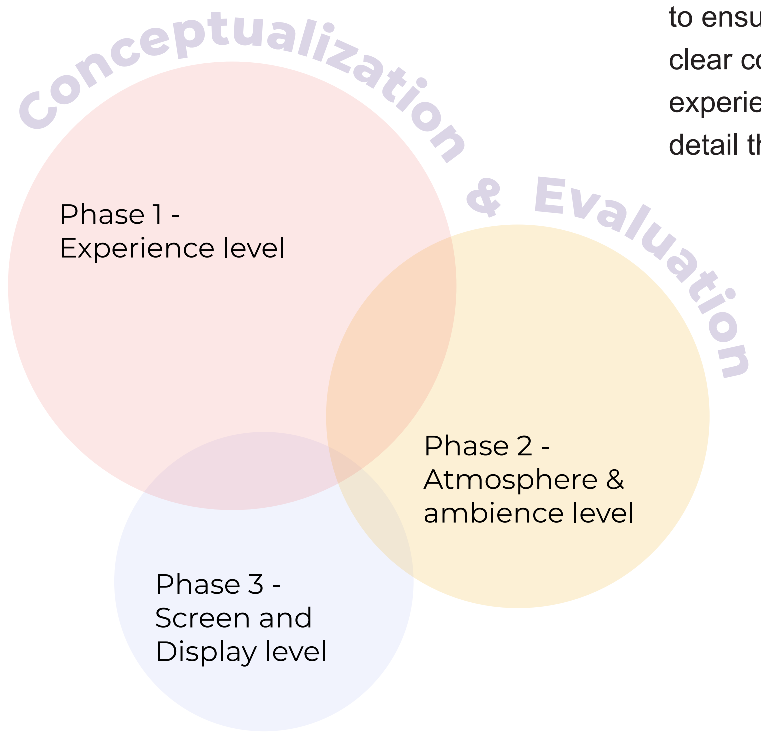


Figure 33 . Conceptualization & Evaluation phases

CONCEPTUALIZATION 1 - EXPERIENCE LEVEL

The first Conceptualization phase consisted of the generation and evaluation of three concepts: Copilot, Subliminal Awareness and Tailored Journey.

A - Copilot concept (figure 34) is based on the idea of having personal assistants guiding the user during full automation driving modes. The driver can talk to the assistants or have additional information only in a visual modality. Moreover, the dynamic lighting enhances the experience through movements and colors.

B - Subliminal awareness concept (figure 35) is based on the idea of having an environment that suggests you silently the right thing to do. Similarly to the Philips responsive smart lighting, the lighting sets the atmosphere and conveys information.

C - Tailored journey concept (figure 36) is based on the idea of having a totally personalized driving experience where users choose how to manage the time during the journey and how to set the mode and get notified.

The goal of this phase was to test different concepts on the Experience level.
The test questions were:
- Which kind of experience do people expect for level 3/4 of automation?
- Which modality works better to understand the automation?
- And which elements/technologies can enhance the experience of the "during" LOotL and SB when users are performing secondary tasks?

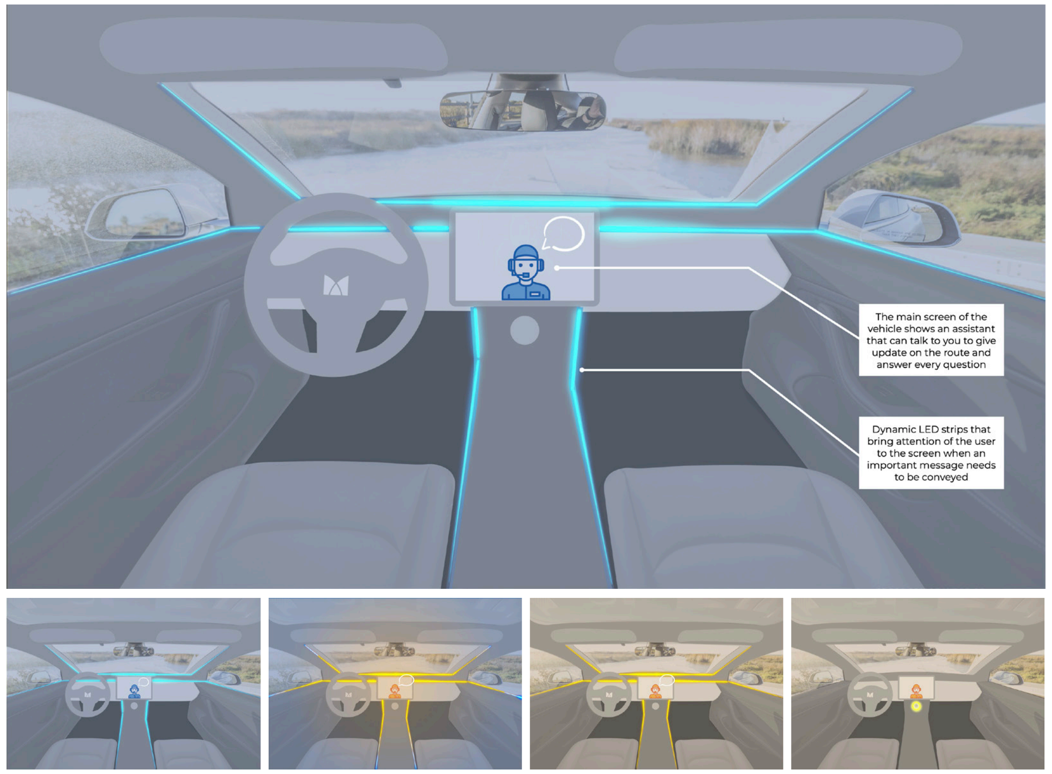


Figure 34 . Copilot concept

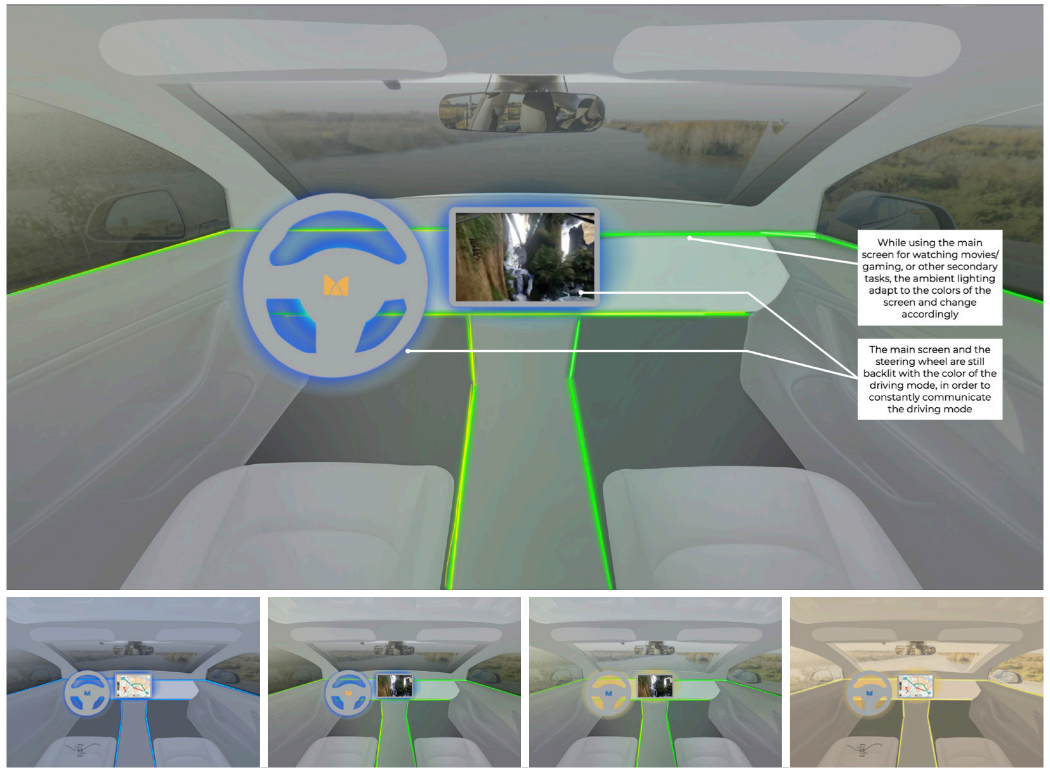


Figure 35 . Subliminal Awareness concept

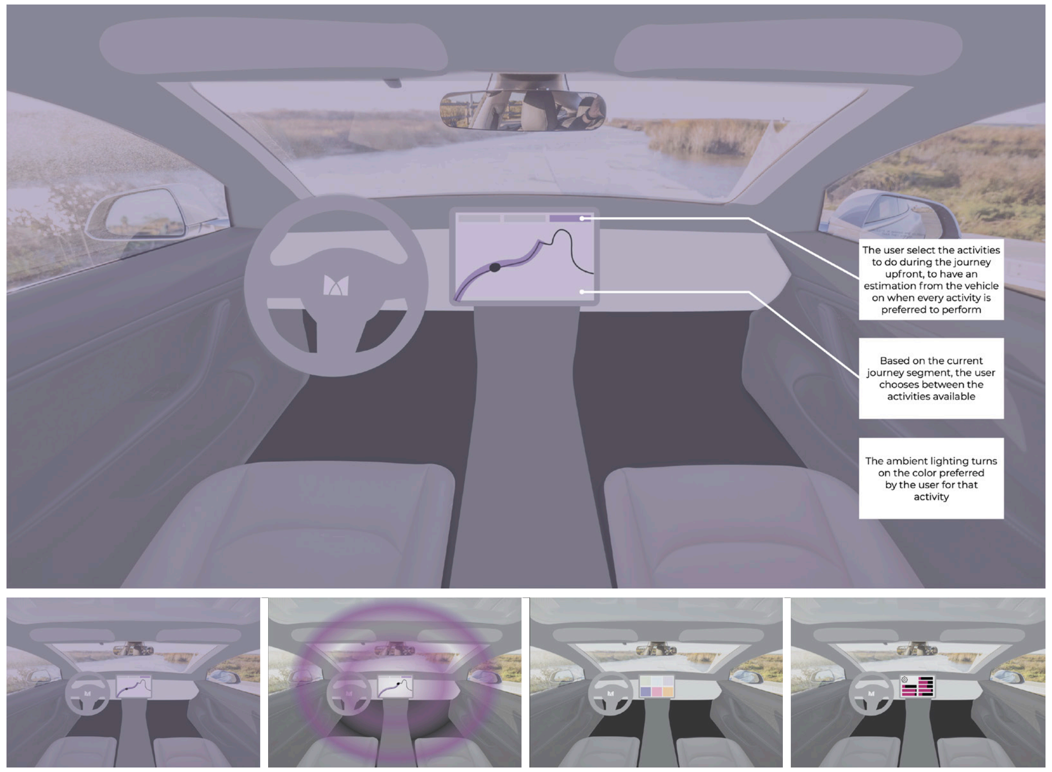


Figure 36 . Tailored Journey concep6

Evaluation Method

Eight participants took part in this concept evaluation test. People who have experience using PAD systems, especially Tesla owners (5 out of 8) and Volvo owners were recruited for this test to cover different age groups and a good balance between female and male participants. The three concepts were explained and discussed (changing the order of the concepts) through audio-recorded video calls showing the images of the concepts and evaluated with a Google Forms survey where they could express their opinion on the concepts through Likert Scales and PrEmo, and some open questions.

Discussion

The analysis of these first concepts led to some considerations about the emotions provoked, how to convey information during LOotL and SB, and finally about singular elements/ interactions' influence on the experience's perception.

First, the concept perceived as the most relaxing according to the participants was the Subliminal Awareness. A participant explained *"it gives me the right amount of information without being annoying"*, so this means it will probably also be the least intrusive communication among the three designs. On the other hand, during the idea generation, it was uncertain if the Subliminal Awareness concept could be understood and perceived as clear for participants because of all the "silent" modalities playing a role in this concept. However, according to the results of the questionnaire, Subliminal Awareness and Copilot were the concepts rated as the clearest in terms of driver's responsibilities and automation understanding, while Tailored Journey was evaluated as the least.

Copilot was evaluated as particularly easy to access with voice commands and visuals, and extremely supportive during the driving experience. The change of assistant was perceived as the clearest to understand the switch of driving mode, as a participant said *"it's another person with a different voice and different environment, so it's very easy to make the distinction for yourself, you don't really need to think about this, it's just clear that I am now in a different phase"*.

Nevertheless, some participants also mentioned Copilot has the potential to be annoying and intrusive in the long term and they lacked the possibility of personalization.

The Tailored Journey was the most criticized concept among the three. Participants appreciated some personalization options but they wondered if adjusting all preferences was too demanding and time-consuming, distracting from the actual important information. During the test, a participant even mentioned the possibility of having presets according to the mood/activity *"personally, I find it a lot of work to adjust something to my personal taste but I like to have like presets, so that I don't have to like to assign all this stuff myself"*.

However, many participants mentioned they really appreciated the route overview provided in this concept with the prediction of driving modes, so they can plan and prepare in advance their activities, *"I like the idea of knowing the confidence of different parts of the trip ahead of time. So if that's something that the car can predict and say "Oh from this time to this time, it's going to be questionable about you might have to take over", I think is really helpful. Then, maybe I could also make decisions about what to do according to that"*.

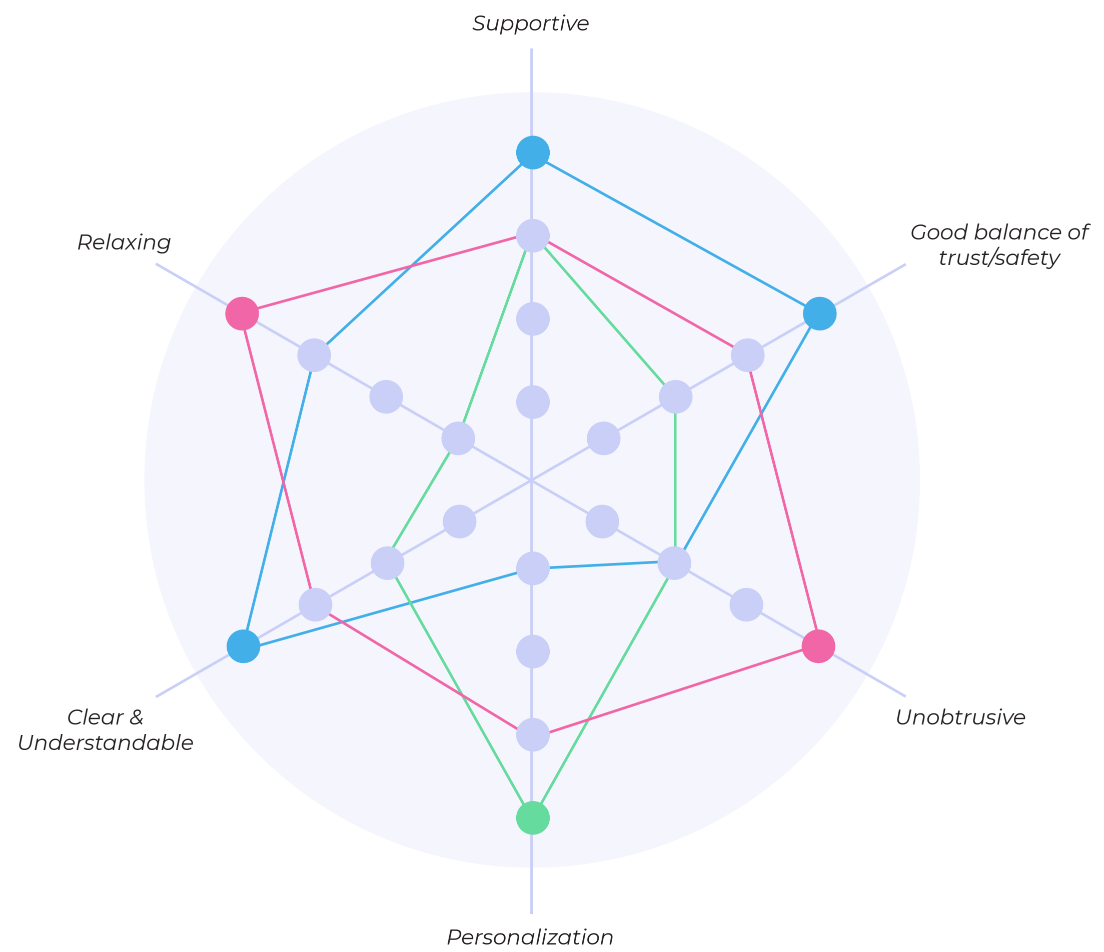


Figure 37 . Concept phase 1, evaluation overview

Takeaways

Based on the interview with participants and the components' evaluation (figures 34, 35 and 36), the three concepts were evaluated according to design criteria that the HMI should achieve for this project. The overview was drawn in figure 37. The concept Tailored Journey stands out only for personalization but it lacks the other criteria. The Copilot concept is the one evaluated as more supportive, clear and understandable and also having the best score for balance between safety and trust, however, it lacks in personalization and intrusiveness. The Subliminal Awareness concept certainly stands out for its relaxing and unobtrusive nature and all the other criteria are good enough not to have real failures.
For this reason, the Subliminal awareness concept is to be considered the most successful among the three concepts, considering that also the others have some elements that could make this initial concept more complete.

Finally, every concept has some features that are perceived as valuable for the design of a final concept, so figure 38 summarizes the design strategy approach to take into consideration this phase's concepts.

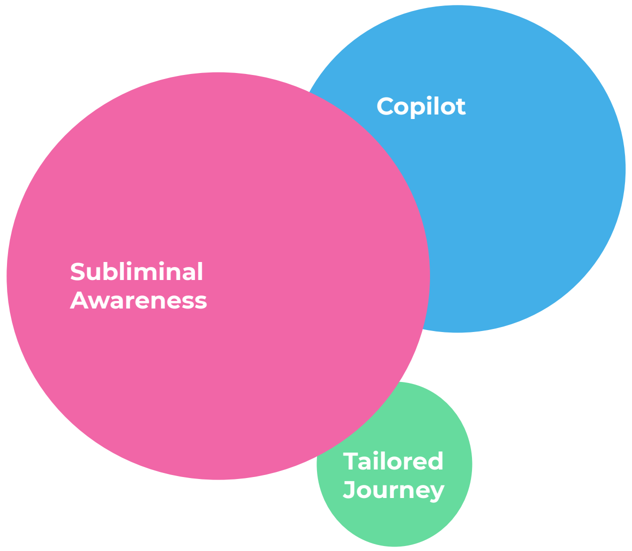


Figure 38 . Concepts' combination strategy phase 1

CONCEPTUALIZATION 2 - ATMOSPHERE & AMBIENCE LEVEL

After the first phase of conceptualization where the participants directed already the project towards certain directions, a second phase was conducted with the aim of investigating purely on the ambience and atmosphere level of the HMI.

This time, three new concepts were generated and the ideation process was supported by the multisensorial approach and the Experience Map (Camere et al., 2015) that also helped to reflect on sensorial stimuli, see figure 39.

Figure 39 . Experience Map

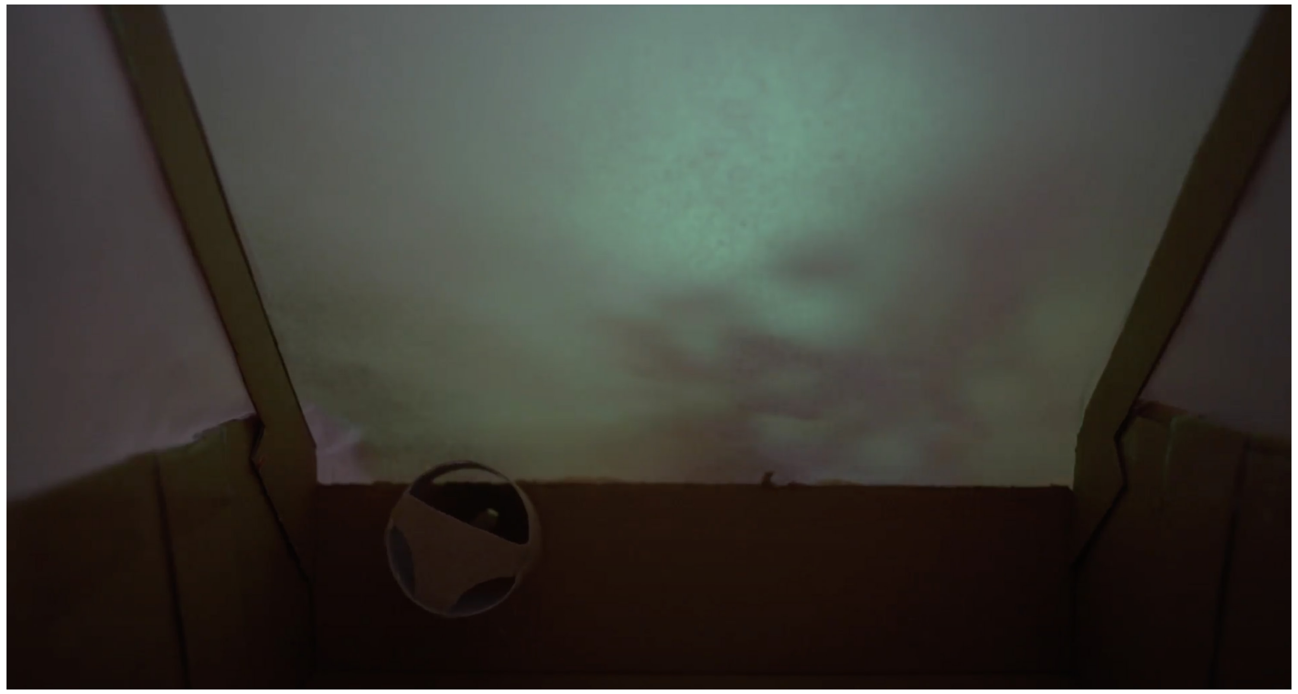


Figure 40 . Light-scape concept

Concept Light-scape (figure 40)
The ambience inside the vehicle adapts to the external landscape, suggesting driving modes and stimulating the driver's attention based on the external landscape.

Concept Motion-scape (figure 41)
The ambience of the cockpit adapts to the movements of other road users outside, informing the driver about the road situation around the autonomous vehicle.

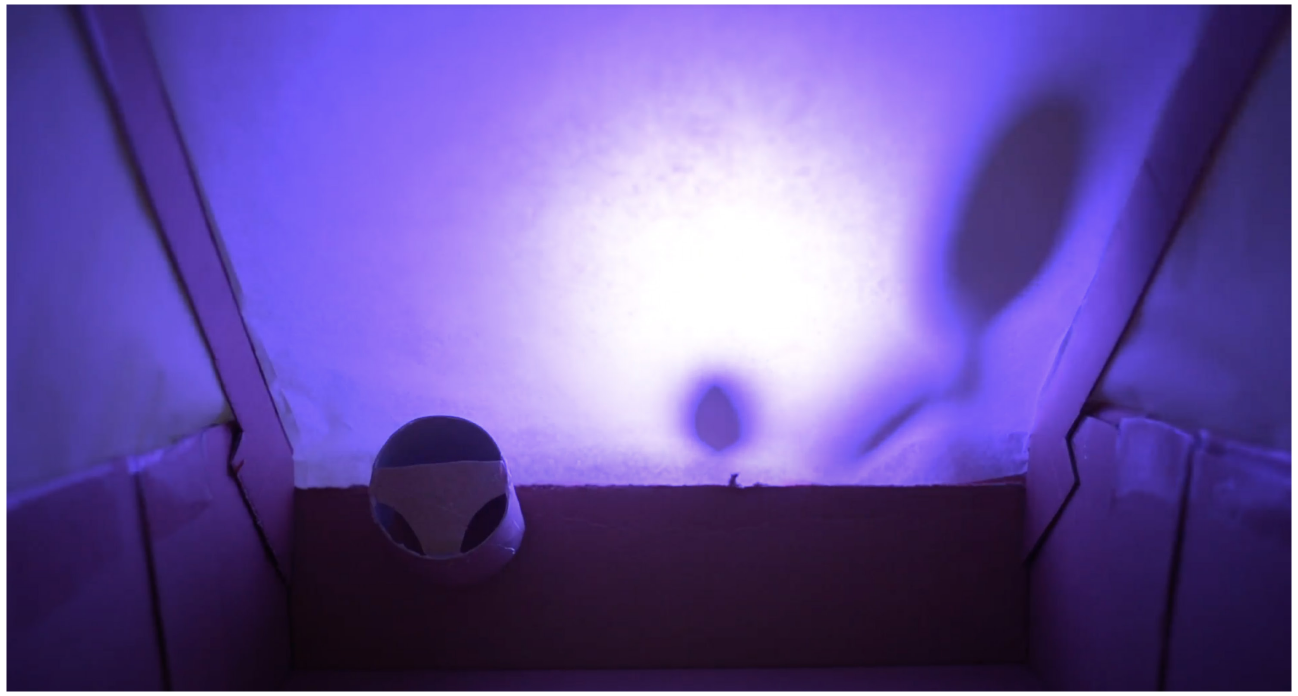


Figure 41 . Motion-scape concept

Figure 42 . Guided Attention concept

Concept Guided Attention (figure 42)
The ambience of the vehicle guides the driver to pay attention to specific elements of the cockpit, suggesting activities and moods.

The three concepts were evaluated with 10 participants remotely via Google Forms and videos reproducing the ambience of the vehicle made with a small scale cardboard model, lights and sound effects.
Participants with confidence using cruise control, representing a significant and heterogeneous sample were selected for the evaluation of this evaluation phase. The recruitment of the participants has been done through word of mouth.

Evaluation

The three concepts were globally appreciated and evaluated by the participants with Likert Scales questions, Pick a Mood (PrEmo), and open questions to understand the reasoning and logic behind the participants' answers.

The **Light-scape** concept was graded as the **most relaxing** among the three concepts in the Likert scale. However, the PrEmo showed contradicting results because 4 out of 10 participants picked negative emotions (irritated and tense) as we can notice from figure 43. Overall, this concept was the one perceived as less informing and more intrusive. Therefore, is less efficient for the goal of this project.

Total Score Light-scape: 19,2
(Intrusiveness: 4,2 / Relax level: 5,7 / Pleasant: 4,8 / Informing: 4,5)
A more extensive analysis results in Appendix 11.

Motion-scape concept was the one perceived as **least intrusive** among the three concepts, yet as informing as the Guided Attention one. Many people mentioned that this concept could **enhance their situational awareness**: *“the driver has a broader view of what is happening on the road”* or again someone else said, *“it can be a simple way to inform the driver of what is going on outside, related to other people and drivers”*. Although the emotions of the participants (figure 44) and the comments on this concept indicated that it could be perceived as annoying/unpleasant in the long term, someone stated: *“it would be useful to be able to increase or decrease the intensity of the feedback to adapt it to the needs of the passenger”*. However, this and concept Guided Attention were rated as the most informative, someone mentioned: *“It is very informative and makes you feel more in control of the situation”*.

Total Score Motion-scape: 22,3
(Intrusiveness: 5,7 / Relax level: 5,3 / Pleasant: 5,1 / Informing: 6,2)

Finally, **Guided Attention** concept was the one provoking the most positive emotions, in terms of **safety and intrusiveness**, as someone stated: *“this one, in terms of intrusiveness and safety, seems to be the most balanced for me”*. Moreover, no participants chose a negative emotion, but one person added “alert” and two people added “attentive” (figure 45), which seems to be perfect for the aim of this project. It was also defined as intuitive a participant said: *“I like this concept a lot. It reminds me of certain tutorials*

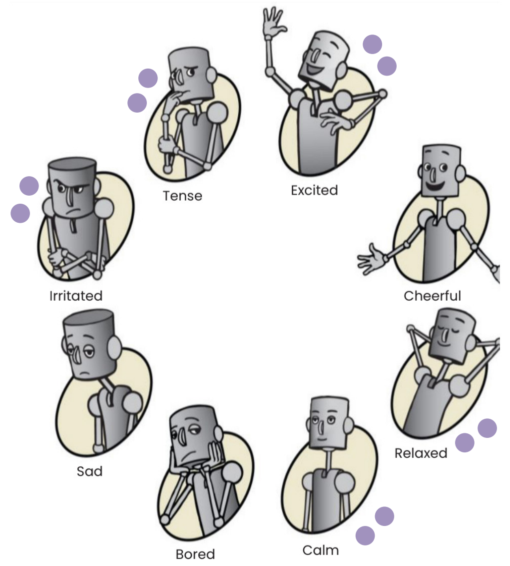


Figure 43 . PrEmo analysis concept Light-scape

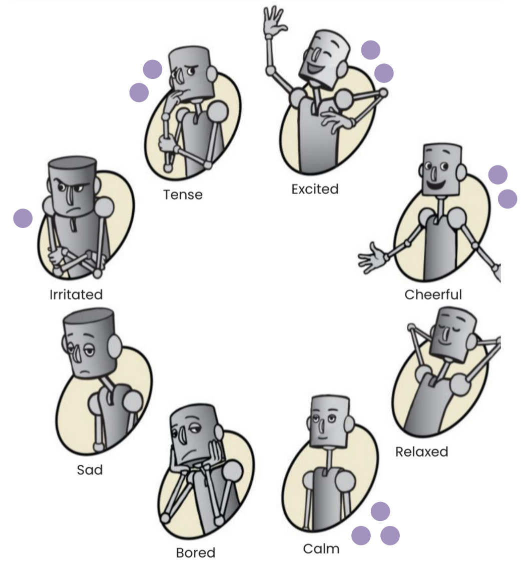


Figure 44 . PrEmo analysis concept Motion-scape

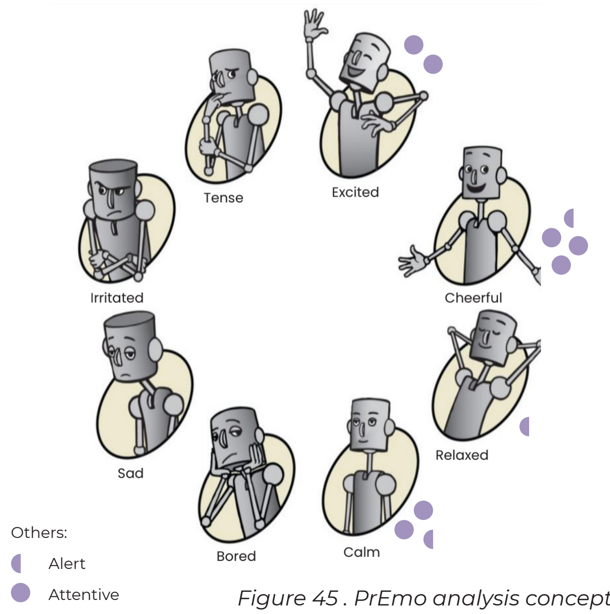


Figure 45 . PrEmo analysis concept Guided Attention

in video games where the UI guides the player to perform certain tasks for the first time. This will help with The reduction of onboarding times and teach the driver how to use the vehicle faster”.
This concept was the one graded as the **most informative** (same score as Motion-scape), and the **most pleasant**.
However, four participants mentioned that this concept could work better with a precise explanation on-display that clarifies the meaning of the light signal.
Despite small feedback on this concept, it seems to be the most promising (together with motion-scape) for in-vehicle ambient lighting as someone also mentioned: *“The main limiting factor of the human & machine interface is the amount of data that can be passed from machine to the human user. Adding another information “lane” via light is a great way convey information presented to users. Great idea!”*.

Total Score Guided Attention: 22,4
(Intrusiveness: 5,1 / Relax level: 5,3 / Pleasant: 5,9 / Informing: 6,1)

Limitations

This concept phase was the most critical one due to the limitations of the testing. The set-up of the vehicle and the accuracy of the information in-vehicle were really limited to the small scale model. The material used for the glass components of the vehicle was see-through enough to give a good lighting atmosphere idea, but not transparent enough to give a good idea of driving on the road and seeing what is happening outside the car. Moreover, including another light source giving the idea of the outside situation with a monitor would also mean not really being able to distinguish the outside with the concepts. Hence, it has been decided to only focus on the ambience and atmosphere effects. Some participants mentioned they would like to see what is happening outside, and the concepts were actually thought to have this possibility.

Takeaways

Both Motion-scape and Guided Attention concepts obtained really good results in terms of situation awareness, automation’s transparency and driver’s responsibility awareness. On the one hand, Motion-scape concept is able to bring relevant information about the road context in an unobtrusive way during SB and LOotL and its potential is to be tested further during NDRA and when the windshield is transparent or dimmed. On the other hand, the Guided Attention concept is a really powerful way to support the driver focusing on the right tasks during the driving experience. It is important to notice here, that this concept might be helpful in the transition from LOotL to SB, besides the other transition phases. The strategy for the final concept is to try to combine Guided attention and Motion-scape concepts into an ambience concept that also includes some relaxing factors of Light-scape concept, as shown in figure 46.

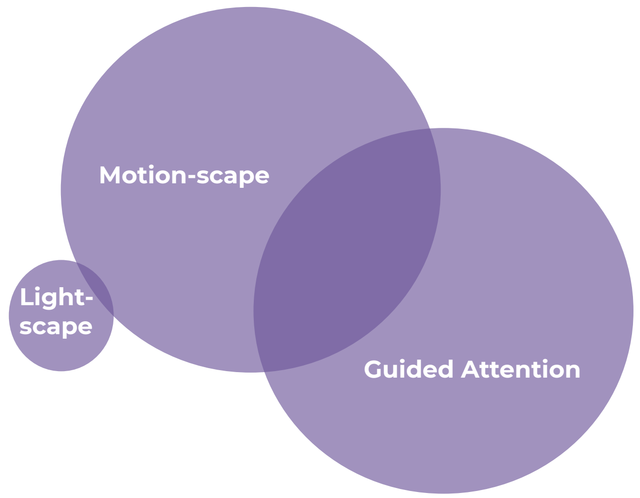


Figure 46 . Concepts’ combination strategy phase 2

CONCEPTUALIZATION 3 - SCREEN & DISPLAY LEVEL

The third conceptualization phase consisted of three more concepts about the visual **information on-screen to supplement the ambience** (investigated in the previous conceptualization phase).
Therefore, based on the results of the previous phase, the concepts “Overview Buddy”, “Sliders” and “Multitasking” concepts were generated to test different ways of displaying the information that needs to be explained on-screen, and cannot be conveyed only with the ambience and atmosphere level.

Concept Overview Buddy
Figure 47 illustrates concept Overview Buddy which consists of an avatar showing the progress and the status of automation, and according to the driving mode, displays some suggestions and advice for the driver to perform a safe trip. The function “talk to the assistant is also possible here”.

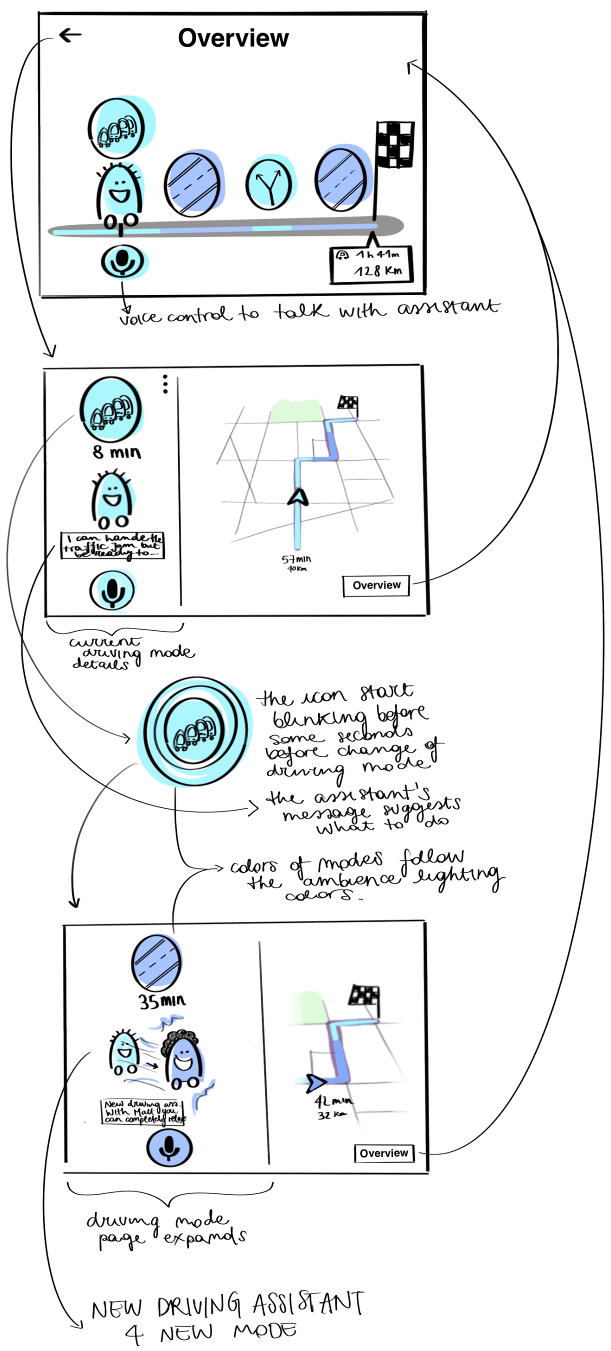


Figure 47 . Concept Overview Buddy

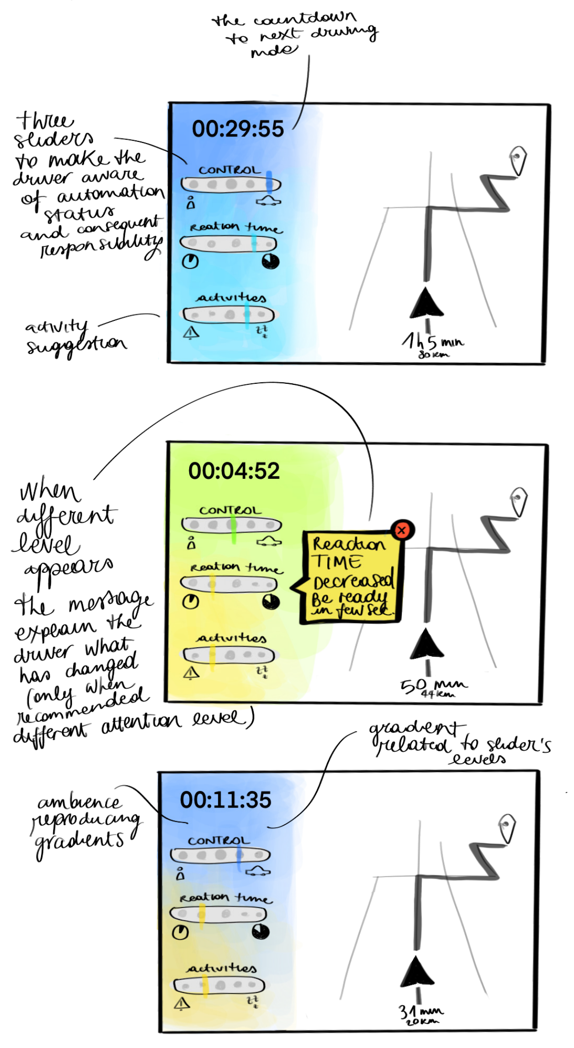


Figure 48 . Concept Scales

Concept Scales
In this concept, see figure 48, the automation status, driver activities, and reaction time required is represented through some sliders showing the current level available. Each level corresponds to a color that shapes the gradient shown on-display. The gradient color is reproduced also by ambient lighting.

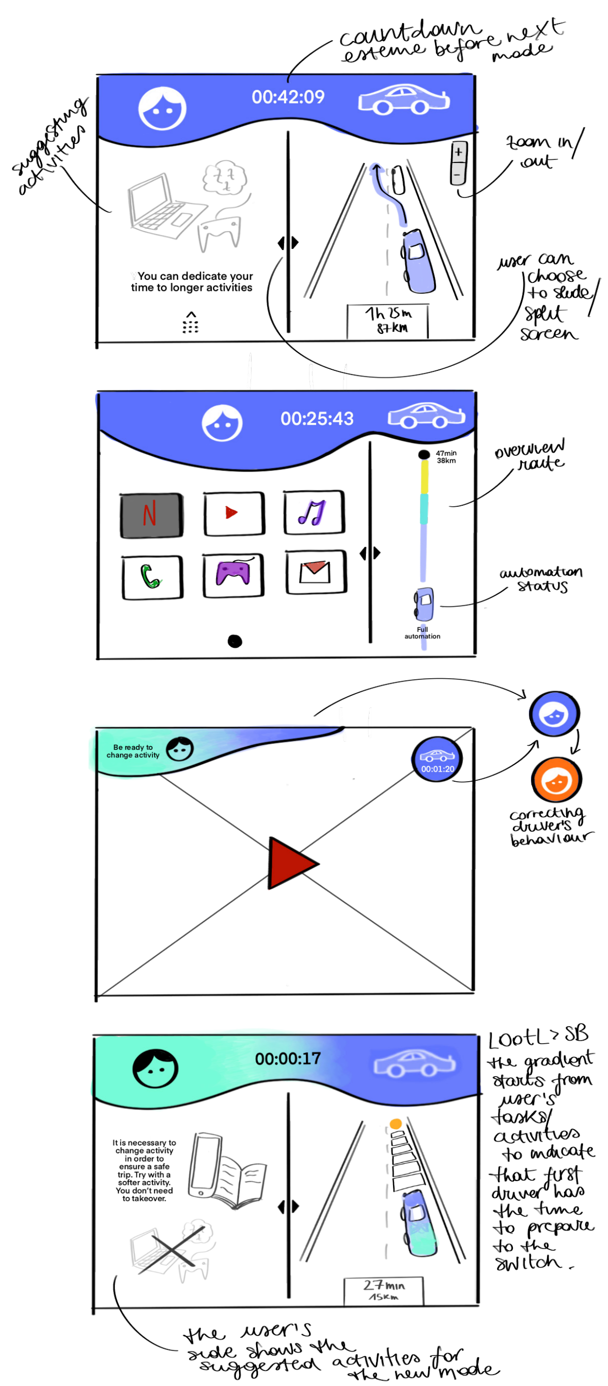


Figure 49 . Concept Multitasking

Concept Multitasking
The last concept wants to encourage multitasking, having the driver and the vehicle section that the driver can reduce/extend similarly to the iPad multitasking option.
In this way, the information which is necessary will always be on display (and represented in ambience) but the driver can choose the level of information and also see which activities are recommended for that driving mode.
The colored bar on top starts fading into the new driving mode color (as well as ambience lighting) when few seconds before the change from LOotL to SB.

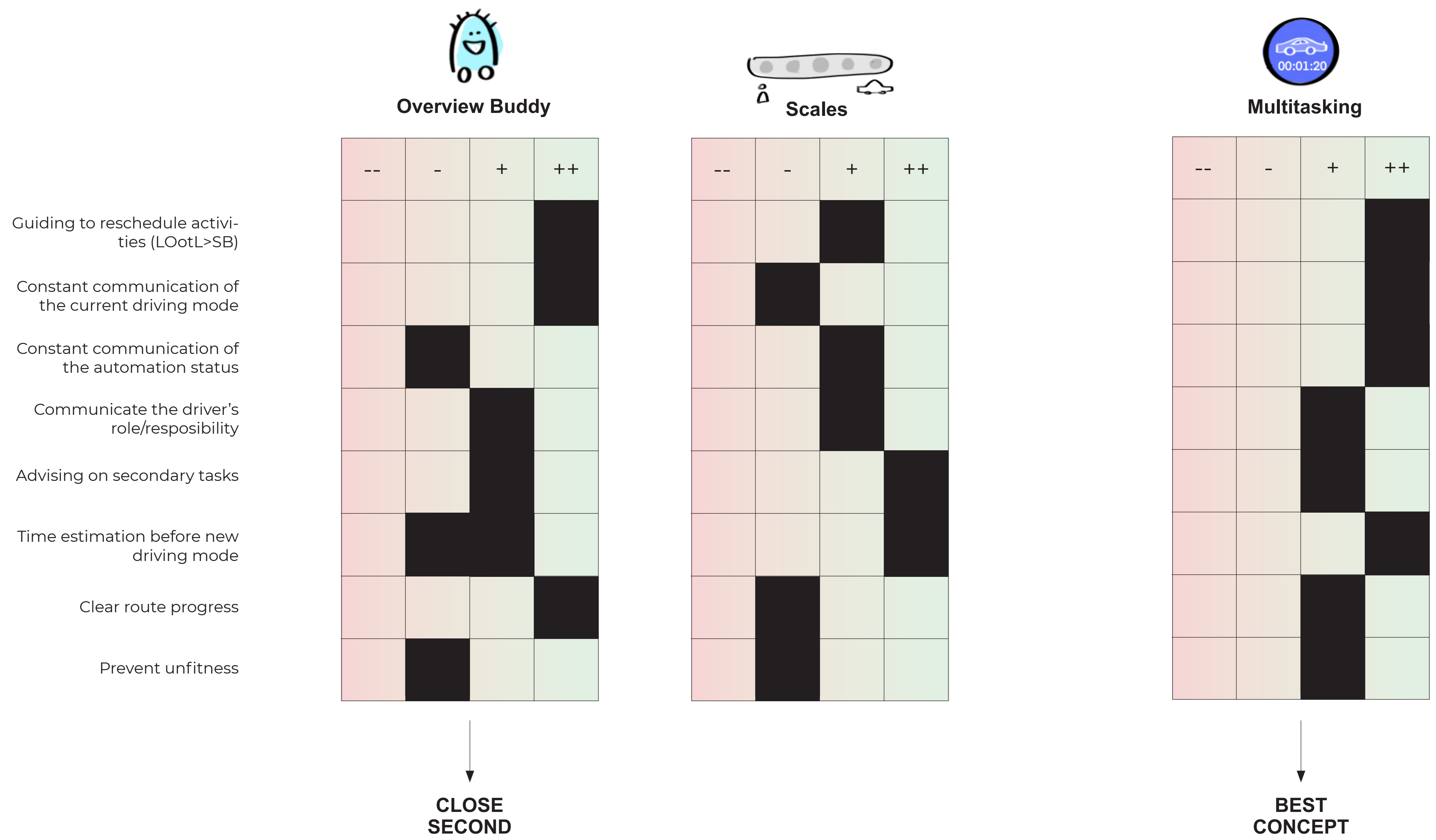


Figure 50 . Harris profile evaluation concept phase 3

Evaluation Method

The three concepts were explained and discussed with around six people into automotive or designers, who expressed informal opinions about the concepts. The drawings were shown to the six participants in order to make them understand the stage of the project and give them the freedom to change and build on ideas.
The evaluation method used for this phase is called Harris Profile (Delft Design Guide, 2017), a table per concept that represents strengths and weaknesses in order to evaluate those concepts based on design requirements and user perception. This method is used to help decision making on concept selection during the design process.
Harris Profile makes the evaluation explicit and easy to understand. The criteria used for the Harris Profile evaluation correspond to the design requirements for the display/screen visual information explained in Figure 50.

The countdown element works especially if it is located on the top part of the screen, and in a big size and clear font, giving a clear idea of time left before the next driving mode and driver's responsibility. Both Overview Buddy and Multitasking concepts were well perceived for the understanding of the driving mode because of the constant communication of the information with the colors used and of the Buddies exchange. Probably in the case of Multitasking, the change of driving mode should be assisted by another feedback modality to make the switch even more clear. The status of automation was particularly appreciated in the Multitasking concept because of the gradient starting from the driver's side, making the transition at the automation later, that helped understanding better the automation phases and the consequent driver's responsibility change. However, the overview estimation of the driving modes in the whole route present in the Overview Buddy concept was really appreciated and considered as crucial to plan secondary tasks. The strengths of each concept will be included in the design of the final concept, as summarized in figure 51.

Discussion & Takeaways

Despite Multitasking concept was the most complex, it was indicated by participants to be the most complete and clearest among the three concepts, especially for supporting the driver to change activity and to correct secondary tasks during full automation driving modes. However, the concept that better indicated the right secondary task to adapt based on the current driving mode and automation status, seems to be the Scales concept that leaves the driver the possibility to interpret the activity scale based on the automation.

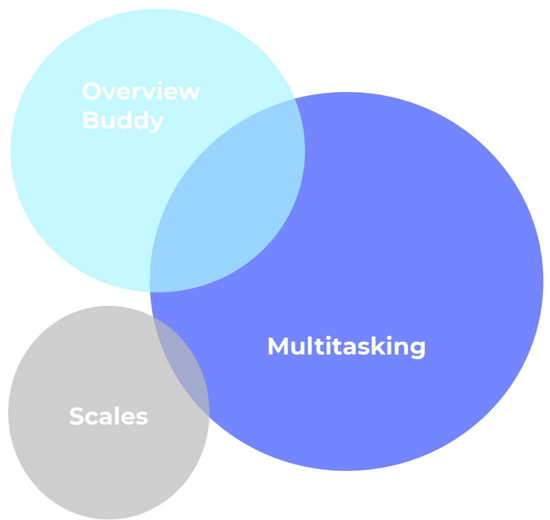


Figure 51 . Concepts' combination strategy phase 3

FROM CONCEPTS RESULTS TO CONVERGING STRATEGY

The data collected and the results from the analysis of the three conceptualization phases helped to define a direction for the final design idea to further test and evaluate. The best concept for each conceptualization phase was used as a starting point for the holistic final design for this project (Subliminal Awareness for phase 1, Guided Attention for phase 2, and Multitasking for phase 3). Yet, components of other concepts that achieved excellent results will be taken into consideration and incorporated during the ideation of the holistic experience.

The design process has been illustrated in Figure 52 in order to test a complete experience based on the results of fragmented interactions tested singularly in the conceptualization phases. After the evaluation and analysis of the final holistic design experience, the reflections on the design process will follow and will be discussed. The challenges and tensions that emerged in the process of combining those concepts in a holistic experience are summarized on the next page and solved with the final concept presented in the next chapter.

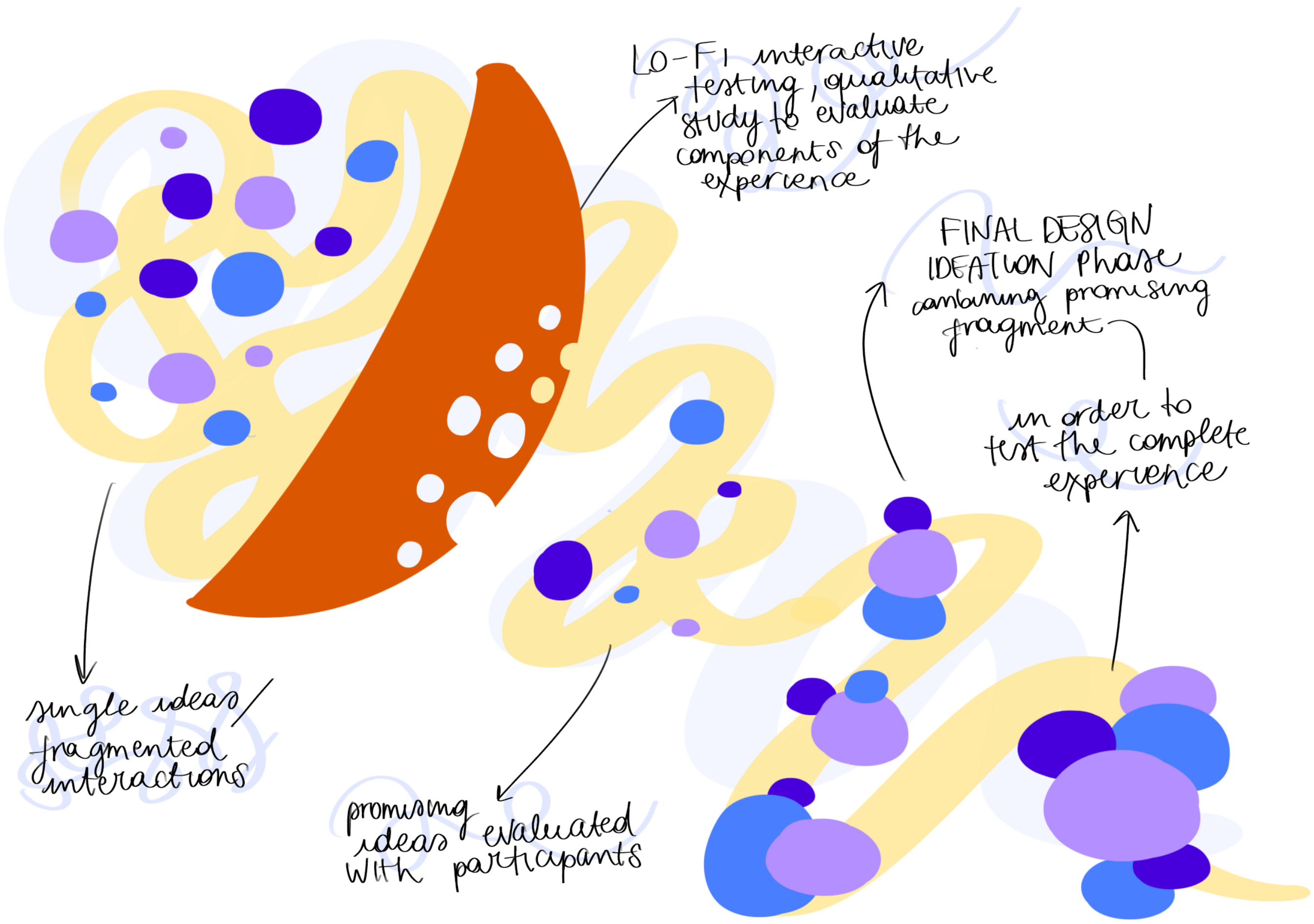


Figure 52 . Visualization of conceptualization converging strategy

SILENTLY INFORMATIVE

Ambient lighting is a good way to convey information from another sensorial lane to drivers. However, it might not be enough to deliver a clear and informative message if the signal is not recognizable or introduced before with other communicative channels.

RELAXING ALERT

In driver StandBy mode, since the driver needs to be aware of its responsibility change compared to Lond Out of the Loop, the conflict of being attentive to the road context without necessarily monitoring the situation should be solved with ambience elements that prevent the driver's unfitness. Moreover, it needs to be clear to the user which activity is or is not allowed in this phase, correcting the driver's dangerous behavior.

GUIDED INTERPRETATION

Drivers need to have the "freedom" to interpret the driving modes in terms of activities and secondary tasks they can perform. An icon to indicate a group of secondary tasks is too limiting for users to understand what they can or cannot do. They should be "free" to experiment knowing that if they are performing activity which is not recommended, they will be warned by the system.

ADJUSTABLE SAFETY

The system should ensure safety and personalization at the same, so what's better than machine learning and artificial intelligence? The system could understand the driver's behaviour and shape the system based on the activity or mood of the passengers.

DIGITALLY AND PHYSICALLY CONNECTED

The center console, which should be the main source of information and control for the driver during autonomous driving, loses its effectiveness when the driver is performing other tasks, especially when using other devices. That's why both the ambience and the devices in-use should communicate crucial information to driver to ensure safety.

CHAPTER AT A GLANCE:

- *Final Concept*
- *User Test Set-Up*
- *Concept Evaluation*
- *Discussion*

07 FINAL CONCEPT & EVALUATION

This chapter describes the final holistic design concept, a combination of previous ideas and interactions. The concept includes ambient lighting, the Around Me effect, the haptic seat, and digital elements collected on the central display. Here, it is included the concept developed into a mock-up test and the final evaluation with 9 participants.

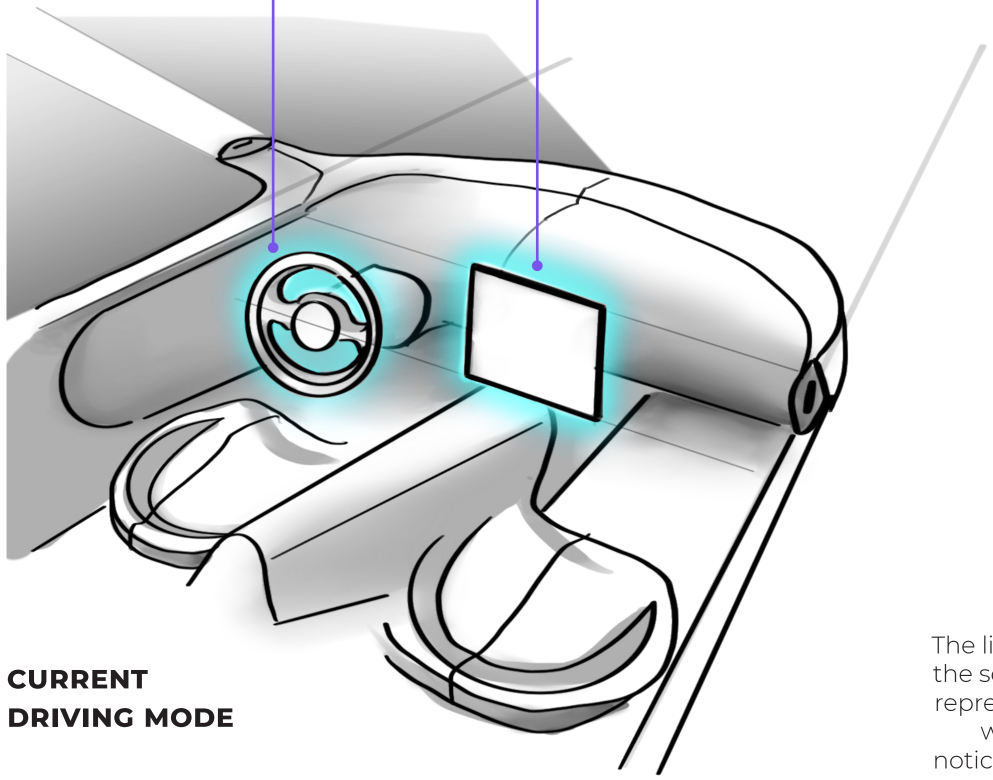
FINAL CONCEPT

Embracing criteria

The final concept incorporates design elements from the three conceptualization phases, in order to create a holistic driving experience through the ambient lighting, sensorial feedback, and the digital interface. The new driving experience during LOotL/SB driving modes and the transition between these two modes is based on the design research and the iterative concept phases.

The final concept aims to unobtrusively inform drivers about automation status, driving mode and their responsibilities during autonomous driving mode through the HMI, while the driver is performing non-driving related activities. The final concept is shown and described in the figures below.

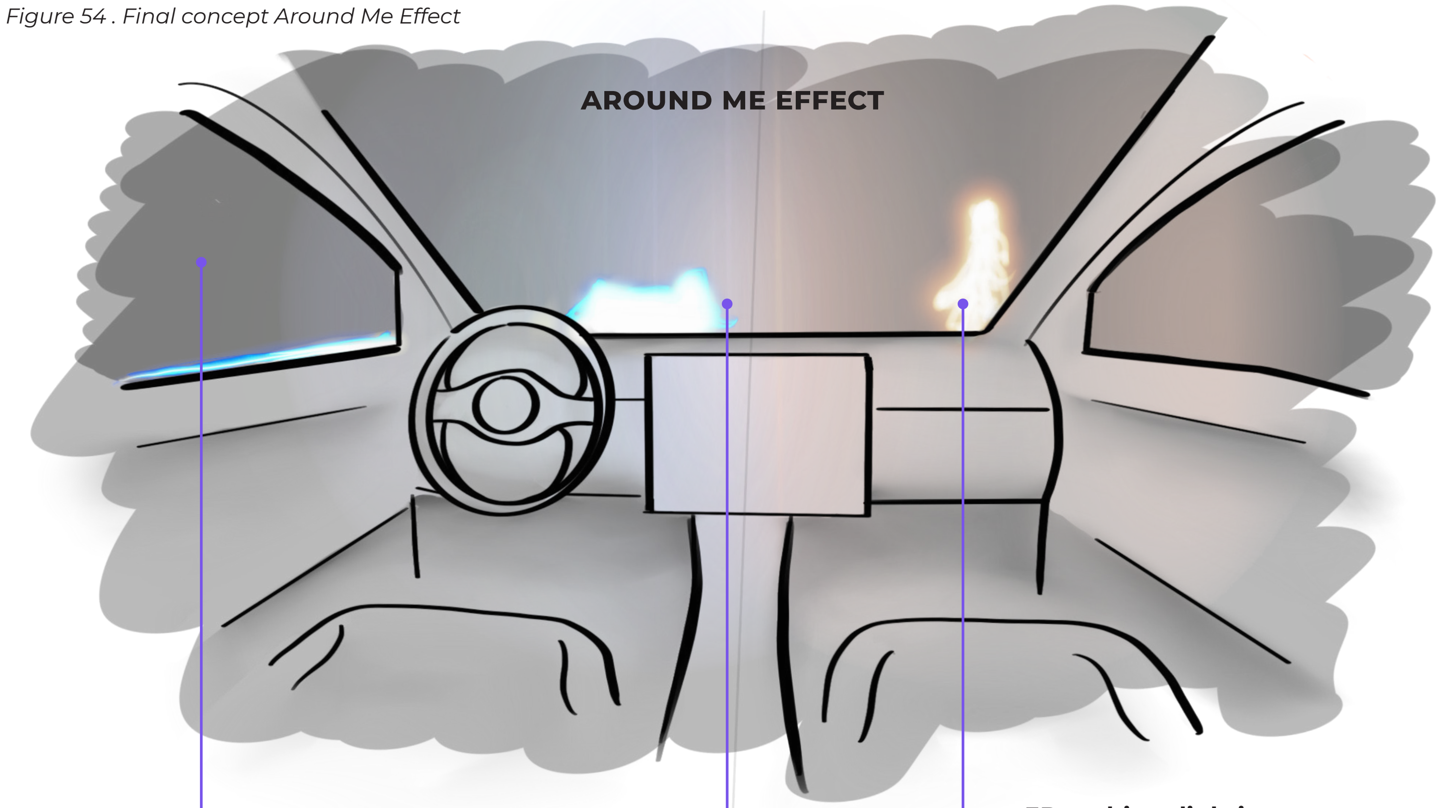
Ambience Lighting: the backlit steering wheel and screen
The autonomous vehicle shows its driving mode with the color of the light behind the steering wheel and the center console screen. This diffuse effect contributes to set the atmosphere of the mode informing constantly the driver about the status of the automation



The light coming from behind the screen and steering wheel represents a strategic location where the possibility to be noticed is higher compared to other parts of the vehicle.

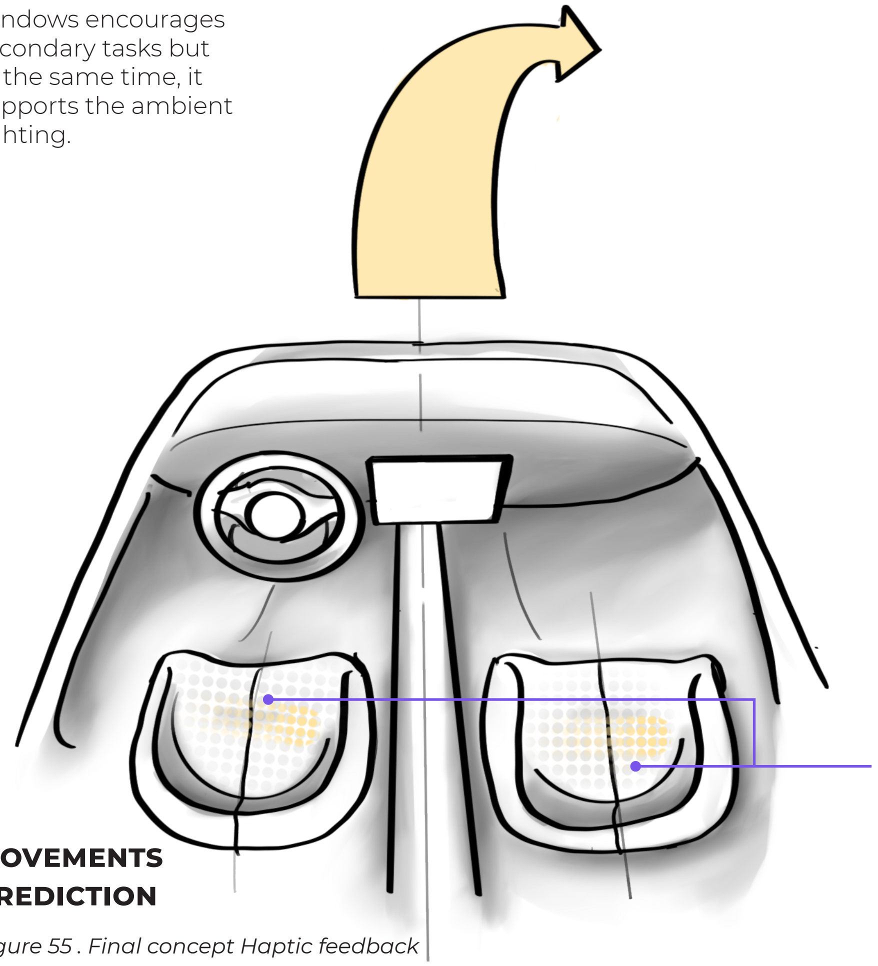
Figure 53 . Final concept Ambience Lighting

Figure 54 . Final concept Around Me Effect



Dimming windshield and windows
The dimming option of the windshield and windows encourages secondary tasks but at the same time, it supports the ambient lighting.

3D ambient lighting system
The ambient lighting on the windshield and windows represents the outside context, reproducing the movements of other road users with lights and dynamic effects. This feature activates automatically when eyes are detected to be potentially distracted from the road context and immersed in other activities



Vehicle's behaviour haptic feedback
The seat offers anticipation of the vehicle's behavior (vehicle turning, overtaking, braking, etc.) via haptic feedback. This will enhance situational awareness while the driver is immersed in secondary tasks.

Figure 55 . Final concept Haptic feedback

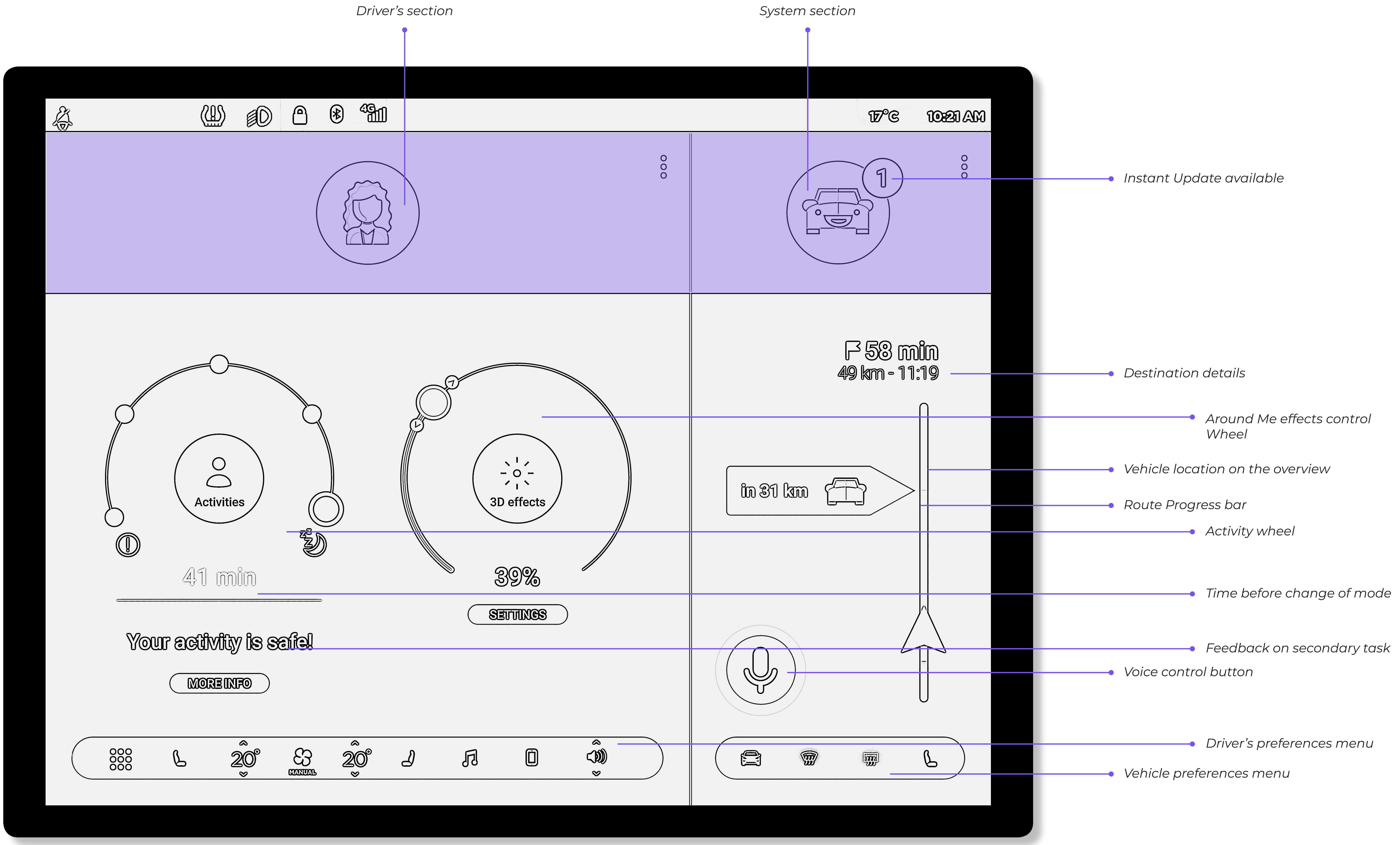


Figure 56 . Final Concept, Digital Interface

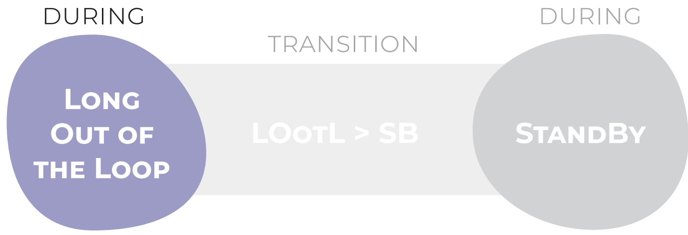
DIGITAL INTERFACE - CENTRAL CONSOLE

The digital interface, designed to be tested on the same screen of the central display can be seen in Figure 56. There are two main sections, one about the User on the left, one about Automation on the right. The User section is composed of the Activity wheel which shows the user's current level of NDRA and the recommended one in order to be safe. Under it, the time before change of mode (and activity) is shown on the same color of feedback (green, yellow, or red) depending on the match between activity detected and recommendation. Next to this wheel, there is the Around Me effect wheel, where users can regulate the level of intensity (0-100%) of the dimming and 3D effects on the windows. The Automation section shows the route overview bar with a cursor indicating the progress and the destination details. In the overview, the estimation of the time budget is made explicit for the whole journey, providing the prediction of driving modes to change in advance. Moreover, the voice control command gives the driver the opportunity to communicate to the system anytime.
During the final user test, each component understanding and intuitiveness will be evaluated by participants.

STORYBOARD FINAL CONCEPT

The following images illustrate and explain the storyboard from LOotL mode, passing through the transition “switch-down” till the SB mode. The digital interface of the center console will be discussed later, showing in detail the elements that interact with the physical sensorial experience.

The *Around Me Effect* emulates the movements of other road users or crucial elements in the surroundings with different colors and shapes depending on the type of user/element (cars, pedestrians, bikes, traffic light, etc.). The effect is supported by the dimmed windshield and windows. The shade of the dimming and the intensity of the lighting system depends on the daylight level and the driver's preferences.



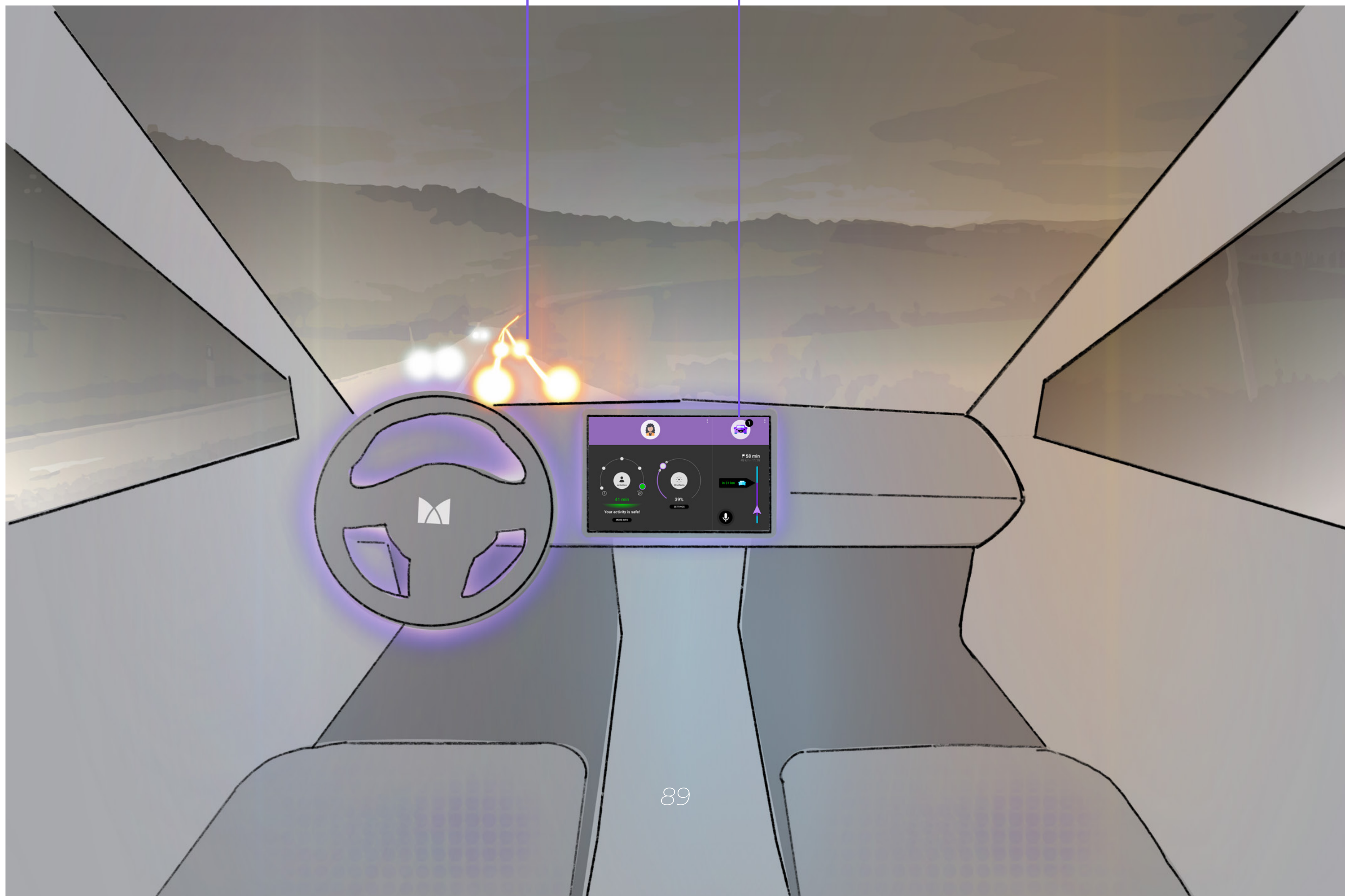
Within the driving mode LOotL, the *Around Me Effect* enables the user to focus on secondary tasks while having a 3D ambience emulating the outside context. The effect's intensity is adjustable according to the user's preferences.
The driving mode is indicated with lavender colored backlit which helps to relax and calm the nerves.
Within this mode, the haptic feedback in the seat is almost imperceptible (but still adjustable according to the user's preferences).

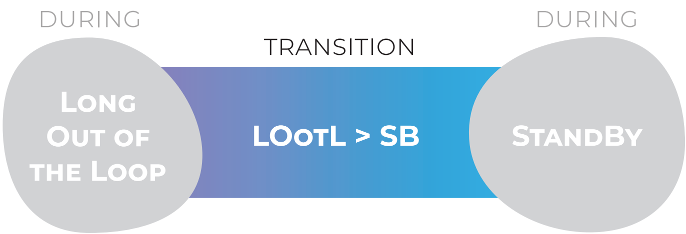
Center control screen:

- Route progress and overview
- Button for instant update
- Voice control option
- Buddy on detailed level
- Activity bar
- Time left before next mode

More details on the center consol interface at page 110.

Figure 57 . Final Concept, LOotL driving mode





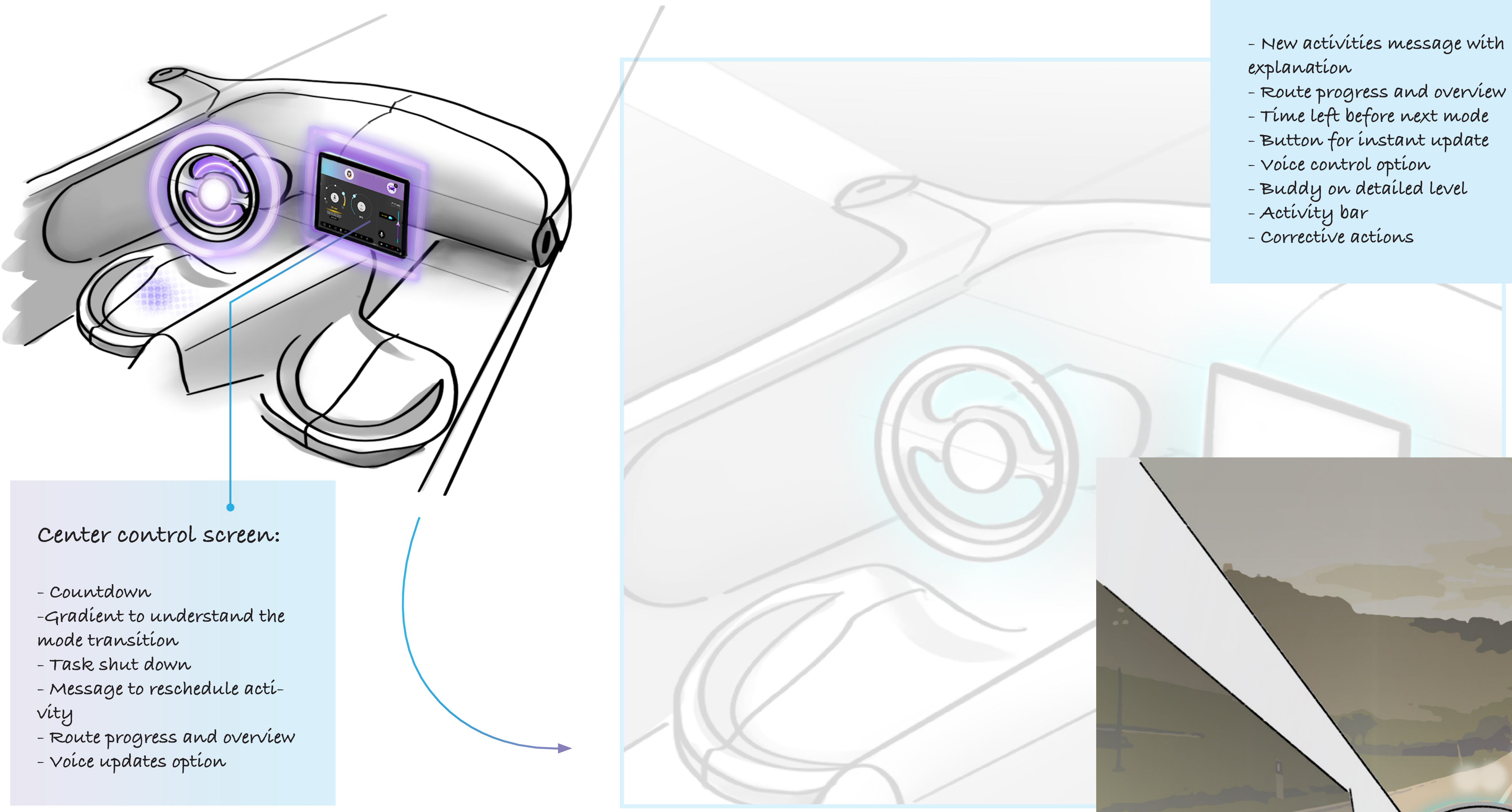
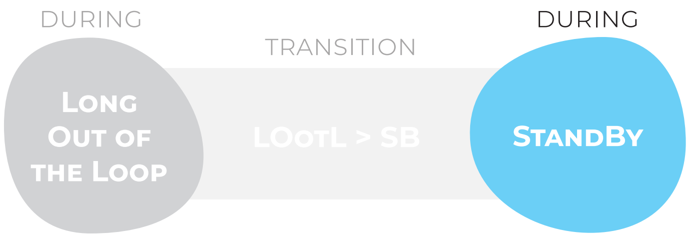


Figure 58 . Final Concept, transition between LOotL and SB

During the transition between LOotL and SB modes, the switch of driving mode is indicated with purple backlit color blinking (while in the screen the driver's responsibilities are already changing) and then changing color to light blue, which attracts more attention compared to the previous one.
In addition, the transition phase is also defined multimodally by a sound and a distinct triple time vibration on the seat haptic feedback.

Clearly, the transition is different if the user is napping or sleeping. In this case, the system recognizes the driver's activity and it prepares to enact an awakening action before enough to ensure that the user is ready to change his activity to a less intense one.

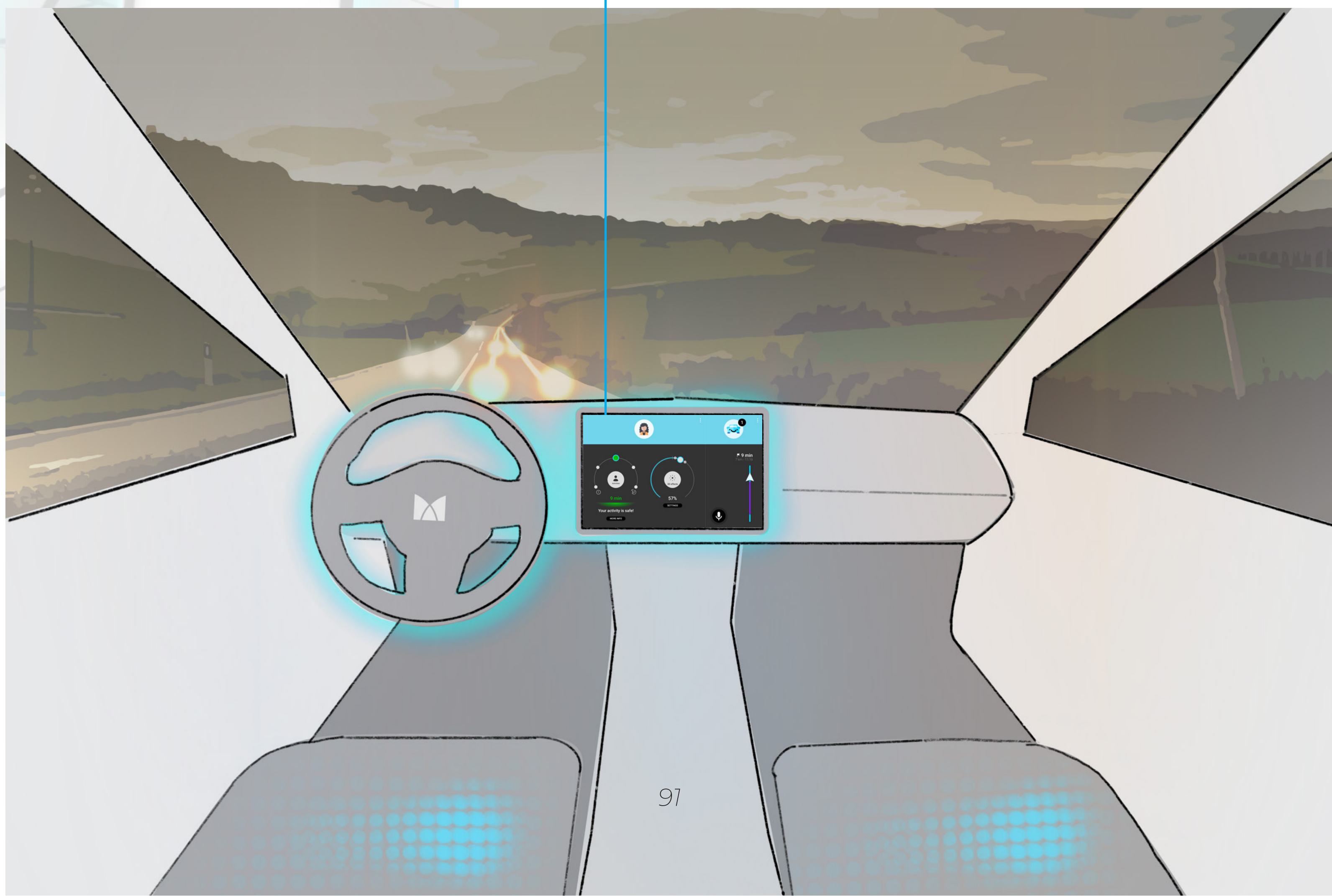


Center control screen:

- New activities message with explanation
- Route progress and overview
- Time left before next mode
- Button for instant update
- Voice control option
- Buddy on detailed level
- Activity bar
- Corrective actions

Within the SB driving mode, the *Around Me Effect* still enables the user to focus on secondary tasks recommended by the activity wheel on the interface, while having the 3D ambience emulating the outside context. The effect is in this driving mode more crucial to enhance situation awareness. Its intensity remains adjustable according to the user's preferences, but with some constraints.
The driving mode is indicated with light blue which attracts more the driver's attention and encourages productivity.
Within this driving mode, the haptic feedback in the seat is crucial to understand the automation's behavior and status, so compared to the previous LOotL, here the vibration is stronger.

Figure 59 . Final Concept, SB driving mode



During the steps of the storyboard described before, the interface changes and reacts to the user's activities and according to the journey progress, it shows different information about different driving modes and information about the road context.

During LOotL driving mode, the mode bar turns purple, in combination with the ambient lighting, see figure 57.

The Around Me effects are now turned on, at 39%, it is still possible to see the road indeed, but the atmosphere is dimmed and aims to be relaxing.

The activity wheel shows that "sleeping" is supported and safe for 41 minutes.

The progress bar shows that the current mode will last for other 31 km and then it will change to light blue, the SB mode.

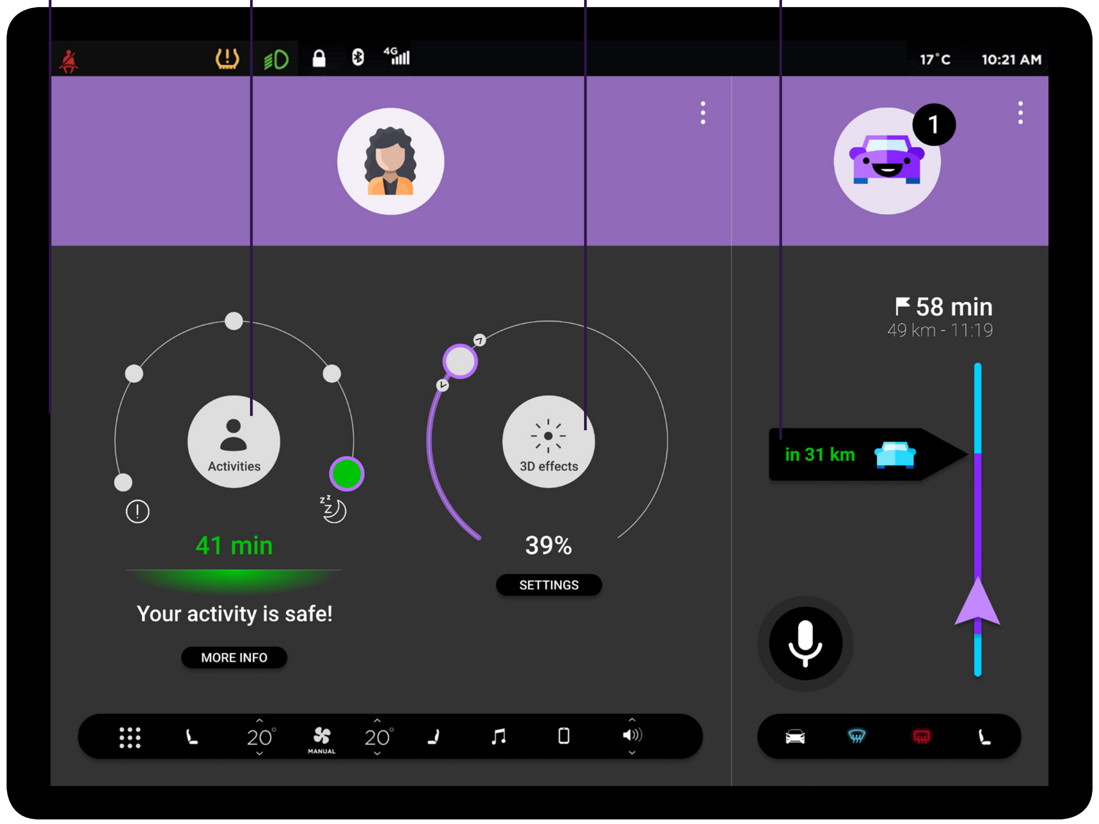
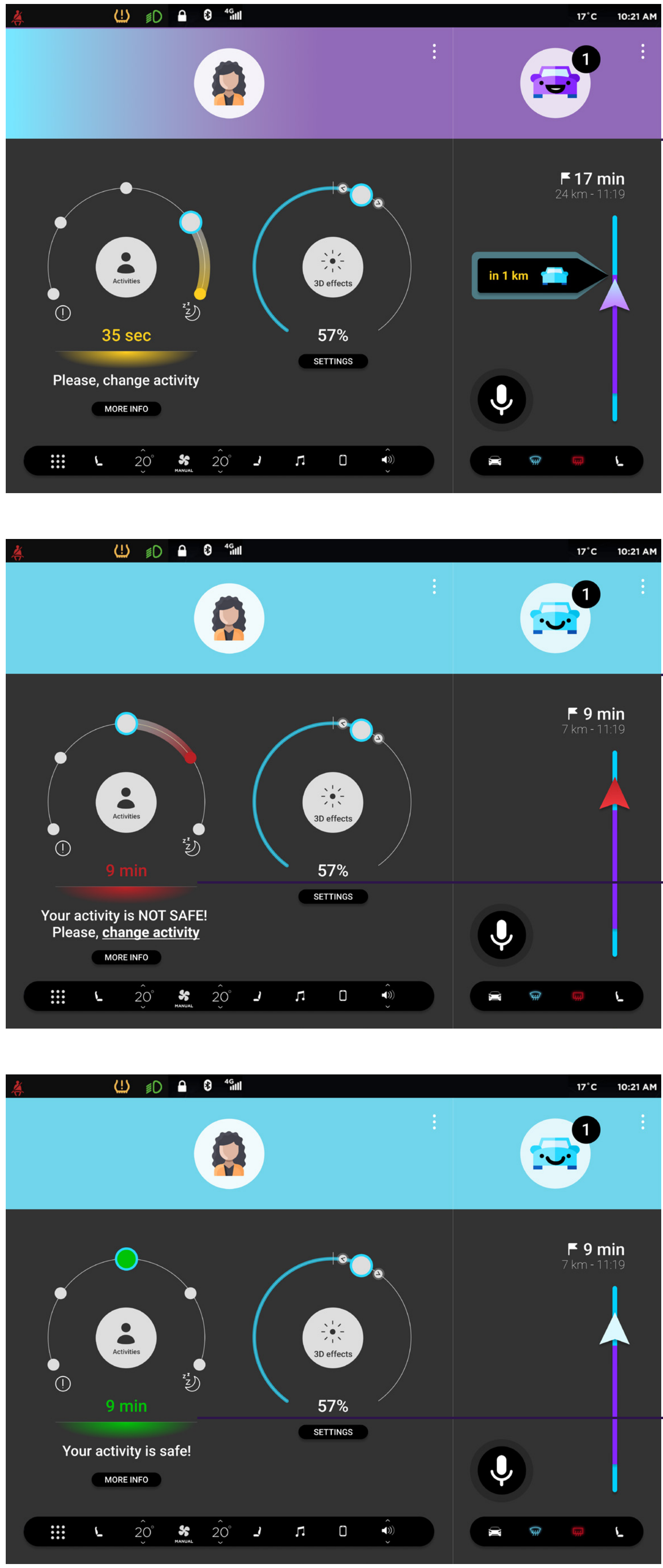


Figure 60 . Final Concept, interface during LOotL



In the transition between LOotL and SB mode, the mode bar starts turning light blue, mimicking the ambient lighting, see figure 58.
The activity wheel indicates that the current activity is not supported by automation anymore, and it recommends to change activity.

During SB driving mode, the mode bar turns light blue, in combination with the ambient lighting, see figure 59.

If the driver's activity becomes dangerous in relation to the road conditions, the interface turns red to report it to driver and make him change activity.

When driver's acrivity matches the level of intensity of supported activities, the interface shows green color as positive feedback.

Figure 61, 62, 63 . Final Concept, interface during LOotL transition between LOotL and SB

USERS TEST SET-UP

METHOD

The aim of the final user test is to evaluate the quality of the interactions between users and the elements of the holistic concept, to define strengths and weaknesses, checking the fulfillment of the design goal and requirements. The table 9 below shows the research questions for this User Test and the correlated testing-evaluating methods for each question, not to leave any question unanswered.

Participants

For this experiment, 9 people were recruited to participate in the online sessions (M=66.7%, F=33.3%). People with different levels of experience with PAD systems were selected in order to have a heterogeneous sample. The sample also covered as many age groups as possible (33.3% between 26-35 y/o, 22.2.% between 18-25 y/o, 22.2% between 36-50 y/o and 22.2% between 51-65 y/o). In the recruitment, it was made sure by asking potential participants to describe themselves as drivers, that both LIP and HIP users groups were covered and therefore Autonomous Vehicles variety of drivers would be represented. However, due to convenience sampling (recruitments via the researcher's social circle, online forums and social networks), the participants might not be representative of the whole population sample.

Digital prototyping

Based on the core experiences previously described, a digital prototype (video) of the holistic concept has been created to be able to test it with participants remotely due to the Covid-19 restrictions. Figure 64 shows the car interior where the ambience lighting effects of the concepts were created and filmed. Moreover, to be able to answer the first research question, a second video of the prototype was created removing the ambience lighting and the surrounding effects. In this way, people could evaluate and compare the two situations and give an opinion on perceived information purely from the central display or together with the environment of the car. The dimming glasses and 3D effects were reproduced in the editing of the video, as well as a better view of the central display and the steering wheel. The road view integrated into the prototype represents the journey from Utrecht to Amsterdam and has been added to the prototype in the editing of the video.

RESEARCH QUESTIONS:

- How do ambient lighting and surrounding effects contribute to fill the knowledge gaps and to satisfy the design goal? (modalities)

- What do people understand the automation logic and behavior? (transparency)

- Would people understand their tasks/ roles during the different driving modes? (mode confusion)

- How are the new information perceived in terms of load? (information overload)

- Which are strengths and weaknesses during the two driving modes LOotL and SB and in the transition phase between these two modes? (usability)

INTERVIEW

HUMAN FACTORS QUALITY SCALE (HFQ)

PREMO

SUS USABILITY SCALE

Table 9 . Test research question and moethod for data collection

Figure 64 . Car interior setting to film the video prototype

Test environment

The users' test sessions took place online via video call (see figure 69) or in-person, as shown in figure 68, (but still testing the same digital prototype), depending on the availability, health condition, and location of participants. The sessions were recorded through the laptop web-cam to be able to listen to the session again and note insights afterward. Participants were well informed in advance about data protection and privacy. The environment sounds of the vehicle and indicators were recreated to generate a convincing setting.

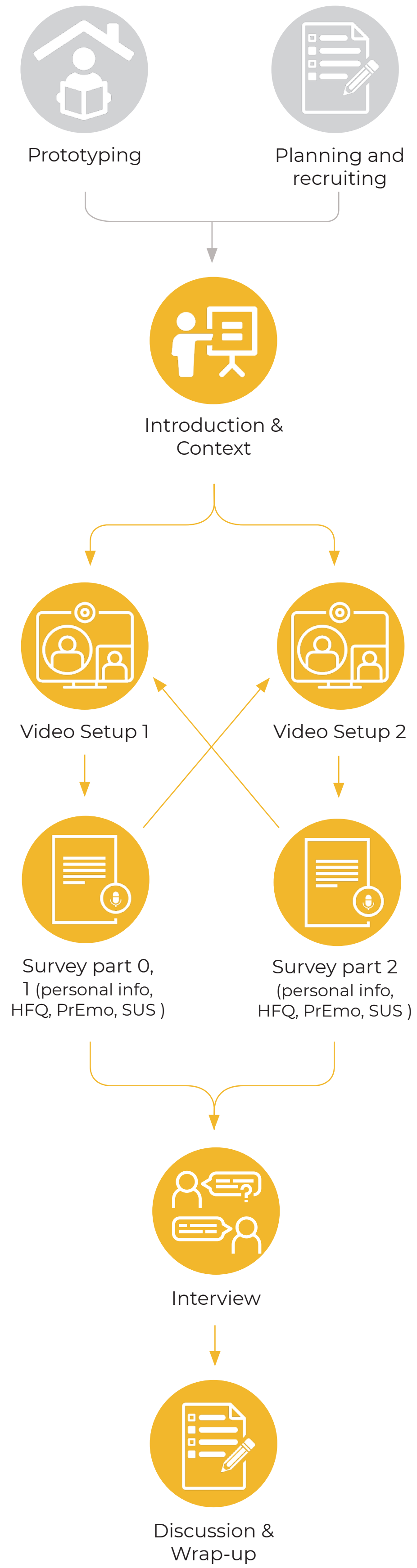


Figure 65 . The procedure of the Users' Tests

Figure 66 . Frame 03:24 from Video Setup 1, only central display, top picture
Figure 67 . Frame 03:24 from Video Setup 2, central display, ambient lighting and Around Me effect, bottom picture

Procedure

After being welcomed to the session and briefly introduced to the project, if the participants did not returned the informed consent before the session they were informed about privacy and data collection. Then, the 5 levels of autonomous driving were introduced, and the type of vehicle they were testing in the session was presented, introducing also some features of the design (manual and automation modes, getting familiar with the screen before testing).
Before watching the two videos, a short guided fantasy was conducted to immerse participants into the context of the test and the journey (commuting from Utrech to Amsterdam on a working day).
The video started with manual driving to then change into autonomous mode when approaching the highway. Participants were asked many times what they were undestranding about the interface and how it made them feel. Moreover, during LOotL people were asked to play a game (Snake) or watch videos to simulate the NDRAs.
During the test people were allowed to reflect aloud or ask questions anytime.

After each video participants filled a Google Form survey and they were asked to give reasons in order to understand the logic and the profile of participant better. After the two video setups were evaluated, the researcher asked questions about additional features of the concepts that were not possible to test in that session to have an opinion from them and finally to share more insights or thoughts about what they had experienced during the tests.

Figure 68 . Testing in person with a user

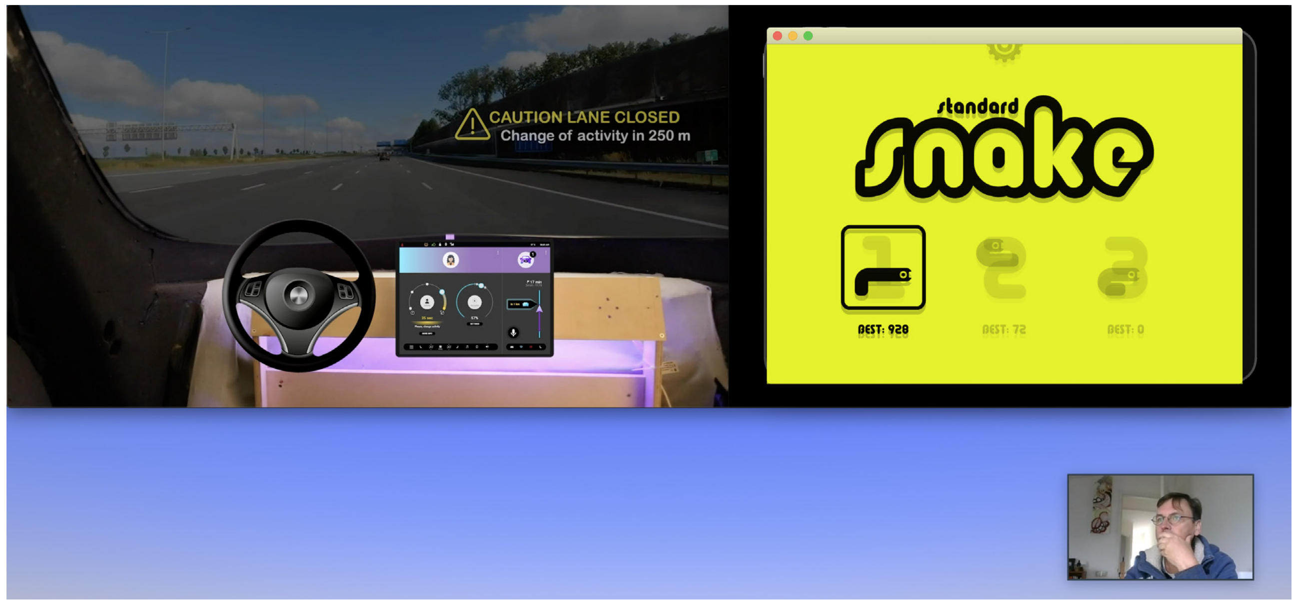


Figure 69 . Testing online with a user

CONCEPT EVALUATION

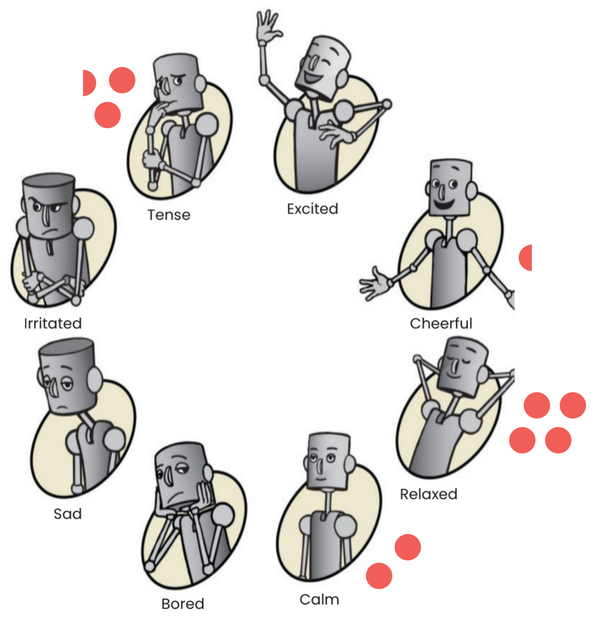
Results

Generally, the tests showed really positive results in favor of the holistic concept. The Interaction Quality scale and the PrEmo evaluation highlighted the differences from the comparison between central display design baseline set-up (Figure 66) and complete holistic experience set-up (Figure 67).

PrEmo (figures 70 and 71)
The first setup was perceived by three people as a tense situation, they mentioned that they did not feel sure that automation was on for the first seconds, while in the second setup where the whole environment changes and adapt to their potential activity, they understood the change of mode more clearly and consequently they felt calmer and under control.

Someone stated: *"With these effects I would feel more relaxed and calmer than before, the distinction is more clear and in the long term I think I will trust the system more"*.
Two people mentioned they would feel more focused on their current task thanks to the dimmed effect and at the same time aware of their responsibilities on the road situation. Every participant said that in the holistic situation they would feel safer and less tense.

Human Factors Quality Scale (HFQ)
The differences between the two setups result even more visible from HF Quality scale. All the criteria were rated more positively in the holistic concept setup than the display-solo setup, as shown on the next page's graphs.



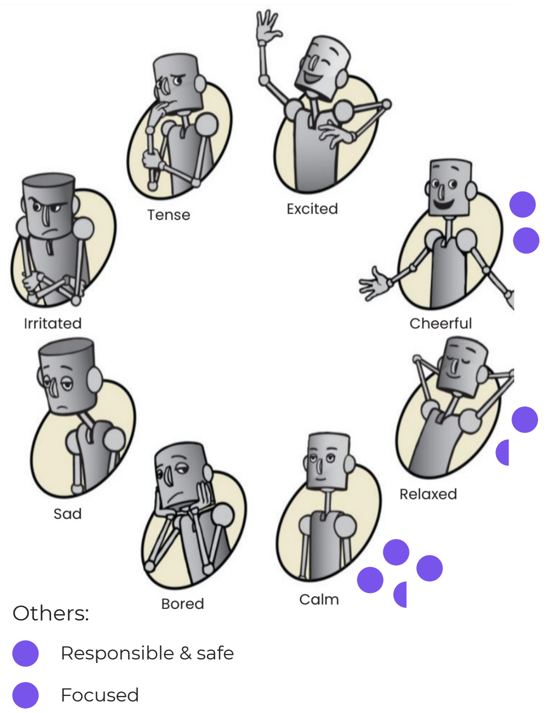
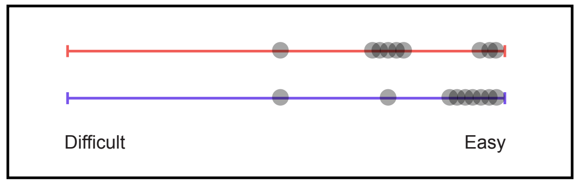


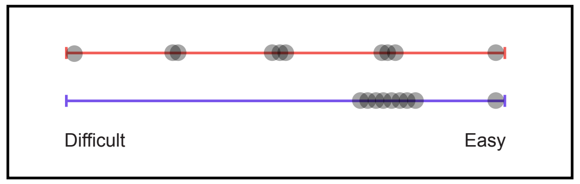
Figure 70 & 71 . PrEmo evaluation of baseline setup (left), and holistic design setup (right).

Central display design baseline set-up
Holistic experience set-up

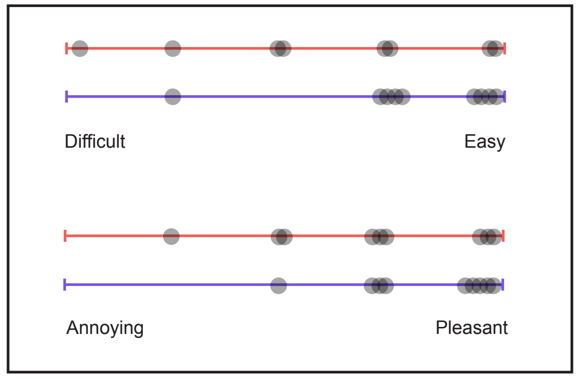
• Understanding the status of the automation would be:



• Understanding the driver's tasks and responsibilities would be:



• Understanding the road context while performing non-driving related activities would be:



While the opinions are quite dissimilar about the screen-only setup among participants, the answers about the holistic design setup seem to be more homogeneous. Everyone thought the automation status and the driving mode was easier to understand thanks to the ambient lighting of the vehicle. Eight participants rated 4/5 their tasks and responsibility understandability. Also, the understanding of the road situation when performing secondary tasks increased considerably thanks to the Around Me effect on the windshield. Finally, this effect was perceived as pleasant by everyone especially because they are free to change the level of intensity themselves, as someone stated: *"I'd feel more relaxed with this environment but maybe it would distract me from the game or other activity I am doing. It is like there is something on the peripheral view that attracts my attention. However, the fact that I can adjust it myself is good, I like that I can change the intensity depending on my activity "*.

System Usability Scale (SUS)
The sus score (81.7) demonstrates that the holistic concept is considered by participants as easy to learn and use, consistent and that it integrates the functions in a good way. However, people with no experience with PAD systems found that the support of a technical person is necessary to be able to use this system the first time and they had to learn how to use the system before getting the confidence to perform secondary tasks. On the other hand, people with PAD systems experience thought the new experience of this design was really fast to adapt and to their view of level 3/4 automation, as someone mentioned: *"The system seems to be aligned with the direction of automotive industries. It really makes sense to me. I think people won't have to radically change their habits or learn too much. This system looks exactly the little step of innovation that we need to make. It is the right amount of innovative information"*.

Element-User Evaluation Overview

Figure 72 represents the overview of participants' opinions about singular elements and core experiences of the holistic concept design. This overview is the starting point for the adjustments for a future design that takes into consideration the perceptual and cognitive problems found by users in this holistic design testing session. The overview was determined while reviewing and analyzing the video recordings of the sessions.

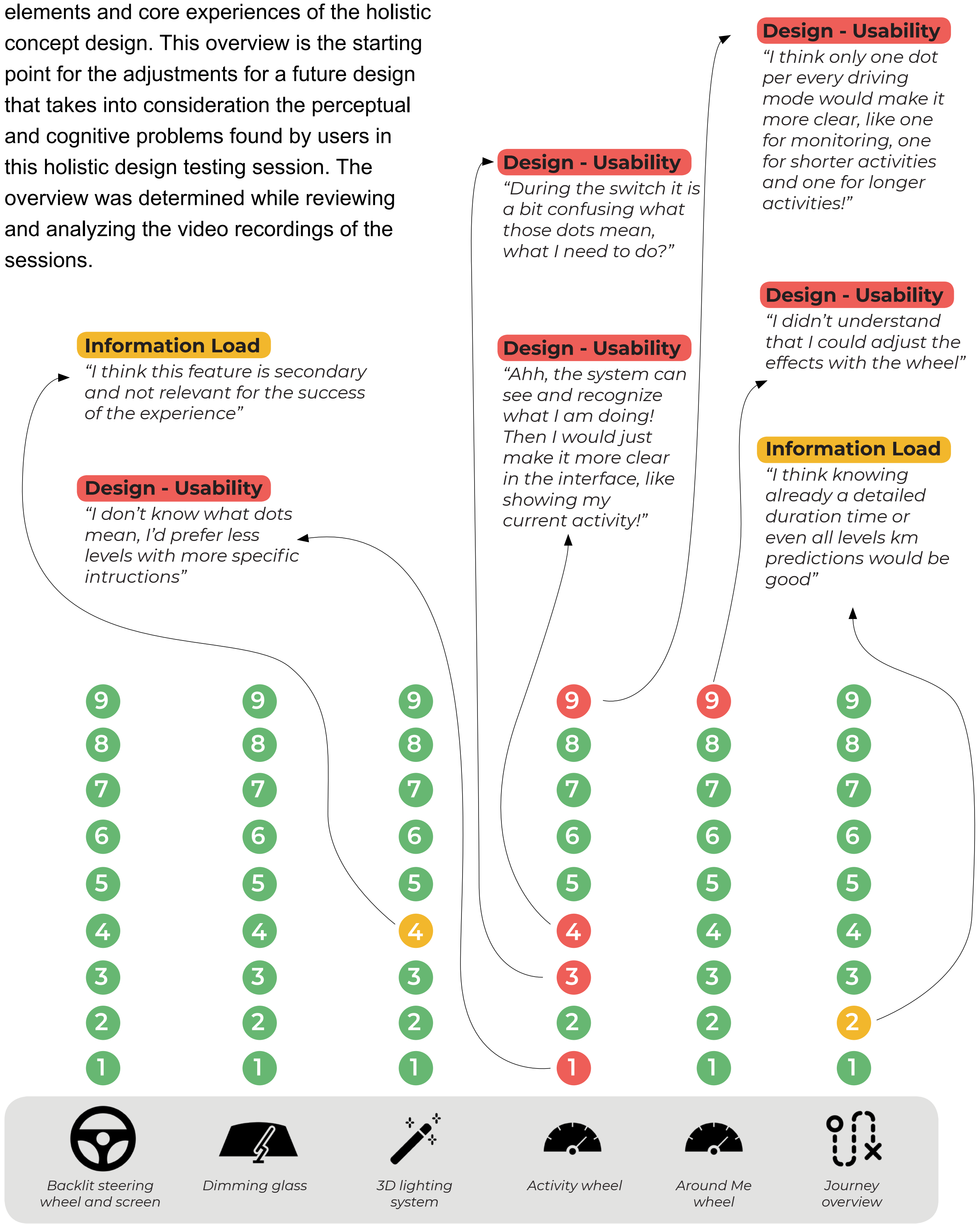


Figure 72 . Element-User evaluation overview

Frame-Specific Problem Overview

Table 10 shows the problem overview of the holistic design in relation to specific driving modes (LOotL, SB) and the transition between them, and the implications for each problem. It should be noted that the digital activity wheel was not perceived as clear to communicate the current activity (1.1) and the visual feedback on driver's dangerous activities has not been noticed by every participant (1.2). These critical problems were found both in the baseline setup and in the one with ambience effects. However, while in the first setup participants were more confused about their tasks, in the second one, the ambience helped to set a more alert mindset after the transition to SB mode. Another crucial problem was identified to be the intensity of the Around Me effect during SB (3.1). Therefore, participants expected that the shorter and lighter the secondary task suggestion is, the more visible the road should be. A couple of participants also pointed out that important messages on the HUD were not notified in advance enough (2.1) and they could have missed the reason for mode transition or important notification on the road context.

Frame		Problems	Implications
1. Long out of the loop	1.1 ●	Activity wheel is not clear to communicate current activity and allowed activities	*- 3 activity dots in automation mode (monitor, short and long task)* *- Add illustration to communicate driver's current activity*
	1.2 ●	The feedback on the driver's dangerous activity is not visible enough	*- Add color feedback on mode ambience or add sound signal to attract driver's attention on the notification on display*
	1.3	Time to stay on the current mode is not clear enough	*- Position on the journey overview next to the km indication (users noticed it immediately)*
2. LOotL > SB	2.1 ●	The messages on HUD about switch or important things are not notified in advance enough to be able to read them	*- Indicate in advance with a sound the message* *- Indicate in advance with light dynamic the message*
	2.2	Change of activity on the wheel is perceived as unexpected	- Add notifications about change of activity in advance
3. Standby	3.1 ●	The Around Me effect is expected to decrease its intensity in this level, to gain awareness of the road context	*- Around Me effect only possible 0-50 on SB* *- After transition, make Around Me effect still -20% than before*

● Critical Problems

Table 10 . Element-User evaluation overview

DISCUSSION

The results gained from the Users Test underline both the positive and negative aspects of this first holistic design concept. Overall, as shown in the previous problem overviews of the holistic design, most of the problems were found in a Usability level, while only a few problems were found on a Cognitive and Understanding level. The users (both PAD experienced and unexperienced) could immerse themselves in the future scenario imagining themselves in a level 3/4 vehicle and they found the interface and the ambient supporting their activities and satisfying their needs of information, as a participant stated: *"I really like this atmosphere, the ambience seems supporting what I am allowed to do, very nice!"*.

Driving mode & driver's activities
Everybody understood that activating the autonomous driving mode means being able to perform longer or shorter activities non-related to driving, especially thanks to the change of environment. ***The ambient lighting of the vehicle helped trigger a relaxed and calming mood that makes them feel they can trust the automation and focus on other activities.*** However, the activity wheel designed for the central display was not a clear way to display information about activity opportunities for the driver. Some participants thought that the wheel was pointing out activity in use at the moment, two people asked *"Am I sleeping now?"*, not understanding the indication of the dot. All participants showed confusion about the five dots' meaning, and they would have preferred to have an introduction or description of each step.

Through the interviews, 3 people mentioned that the wheel has some potential to give the right freedom to drivers, not limiting their activities, but the fact that there are currently many dots makes it more complicated to understand the meaning of each step.
The change of the ambience color from purple to light blue was immediately noticed by participants and they understood that the road conditions did not allow them to continue their activity (gaming) anymore.
The ***blinking ambience did work well for bringing the driver's attention to the screen.*** However, few participants noticed the message about the change of activity on the HUD too late to understand the reason for that change and they looked confused because they did not know what was going on. Those participants mentioned they would have preferred an audio message/sound or indicator that could deliver the message before, in order to get ready to change their mood/activity. On the other hand, people who noticed and read the message on HUD understood what was happening and they were very open to assume back some control by changing their activity to a lighter one.
Another significant insight came from the difference of reactions from people with and without experience with PAD systems.
People inexperienced with PAD thought they had to takeover or resume control on the pedals/steering wheel in this transition, while participants with PAD experience understood the light blue mode as changing to a shorter activity having more awareness of the situation. This factor indicates that the transition between these driving modes would put too much alert on those people causing mode confusion.
According to participants, the confusion does not derive from the color of the ambient lighting but from their unfamiliarity with the system and from the message on the HUD and the sound feedback perceived as a dangerous situation (and not wrong activity). Therefore, it would be interesting to investigate deeper the sound signals during this transition phase.

Transparency
Overall, participants really enjoyed the ***Around Me effect*** (both the dimming option and the 3D light effect on the windshield) and they found it useful for different reasons. First of all, to set a different driving mode, as described before. Second, ***they realized that the vehicle could detect other road users around, crucial for building trust in the system.*** Third, they thought the ***glow effect could work to understand the road situation better when engaged in an NDRA, enhancing situational awareness and consequently understanding the behavior of automation on the road***. The 3D light effect on the HUD could also help to distinguish different kinds of road users, dangerous behavior of those users using different colors and shapes for the effect. Moreover, ***the message before the switch was considered very helpful to trust the transition between LOotL and SB mode***.

The participants were also informed about the idea of implementing subtle haptic feedback on the seat that anticipates the movements of the car. Everyone seemed enthusiastic about it, so it will certainly be something to develop and test further because it could have a great potential to increase transparency between user and automation.

Information Load
In these testing sessions the two categories of users, HIP and LIP, occurred again. The success of this concept was also due to its adjustable nature. Some participants, for example, mentioned that they would like to be able to see the road especially during their first rides with this car to get familiar with the system, so the fact you can regulate the effects was really positive. Someone else found this really useful to adjust it according to their activity or mood. Therefore, ***this interface gives the freedom to personalize your vehicle and environment adjusting the information load***.

Another good result was that three people mentioned that this interface presented the ***right amount of information to implement in an existing vehicle without learning too much***, ***but still enough to make sense of the new system***. None of the participants stated that the information on this interface was too much to handle and process. However, this concept has not been tested together with all the elements that are normally found inside a vehicle, so, it is to be validated again.

Limitations
It is important to mention the limitation of this testing session. First, the digital set-up condition could influence the results because people feel more relaxed thinking they are not really in danger or testing a real prototype on road. The context does not imply a full real-context mindset.
Secondly, the interface of the prototype was not responsive to people's activities. A more advanced prototype that detects eyes or activities of participants and changes accordingly could have worked better to investigate the efficiency of the activity wheel on the central display and the trust level with the system.
Lastly, the sensorial aspect of the design has not been tested in a physical way due to Covid-19 restrictions. The ambience, the glow effects on the windows, and haptic feedback proposed in the holistic design need to be tested physically in a vehicle to evaluate people's physical reactions to those new elements.

CONCLUSIONS & RECCOMENDATIONS

The final user testing aimed to evaluate the holistic design concept generated from the previous design research and iterative conceptualization phases. The goal of the test was to validate the final concept's value for Mediator project from the users' point of view, investigating if the design could fulfill the knowledge gaps of transparency and mode confusion taking into consideration the information load and trust in the system as criteria for the HMI.

Conclusions

Project Research Questions

*"What information should be communicated? When sh*ould this i*nformation be communicated? And, how should this information be communicated?"*

During autonomous driving modes LOotL and SB, some information should always be communicated in order to create an environment that guides and supports the driver's activities. The transition between LOotL and SB instead should communicate information to make the driver change or adapt the current activity to an adequate one.
The ***automation status and current driving mode*** should be constantly and unobtrusively be communicated to the driver in order to make them "feel" it even while they are performing other activities. With this design project, it has been validated how ***the potential of the ambient lighting communicates that information and helps to set the right mood for the driving mode.*** Therefore, a change in the ambience contributes to creating a relaxed atmosphere rather than calling users' attention to prevent the driver's unfitness or during the transition between LOotL and SB.
The role of the driver should also be communicated clearly by showing them which activities are recommended to perform based on the driving mode. In addition, ***the route progress absolutely contributes to the activity planning action of drivers and the understanding of time budget,*** so it is crucial to have an estimation overview of the driving modes available for the whole route.
The time before a change of driving mode should also always be accessible to drivers to make them plan their time in advance and reminding them of the time left on the same range of secondary tasks. Moreover, automation's decisions and actions should be accessible but not intrusively. Important ones should always be communicated in advance to not let drivers doubt the logic of the automation, enhancing the user's trust in the system.

User Test Research Questions

It has been discussed in the previous section how the research questions have been answered and the concept has been evaluated, however, below a summary of each research question is provided.

1. How do ambient lighting and surrounding effects contribute to fill the knowledge gaps and to satisfy the design goal?

Ambient lighting has been evaluated to be a good way to constantly and unobtrusively communicate the current driving mode and different modes changing the color of the ambience. Moreover, dynamics in the ambient lighting attract the driver's attention and it can be a good way to overcome the driver's unfitness.
On the other hand, ***the glow effects recreated on the windshield seem to make use of the driver's peripheral view during NDRA engagement, generating more situational awareness of the road context.*** This also helps to maintain a good balance of trust in the system, providing feedback and limitations when information is communicated in advance.

2. What do people understand the automation logic and behavior?

Transparency has been obtained from the final concept both from the HUD information that explains the automation's logic by showing important information about the road conditions. The haptic feedback on the seat supposed to be part of this concept could not be tested in this session but the idea has been approved and appreciated by every participant.

3. Would people understand their tasks/roles during the different driving modes?

The activity wheel and the time estimation on the central display helped users understanding the change of responsibility and eventually changing their current activity. However, the activity wheel gave too much freedom of interpretation and participants felt confused about which activity they could perform in SB mode. ***The wheel should have specific task division based on the driving modes and resposibility difference.*** Nevertheless, the ***ambience transition and change of color supported efficiently the change of task and responsibility awareness***.

4. How are the new information perceived in terms of load?

The information presented in this HMI concept was not perceived as too complicated or too much in terms of load. The more familiar the participants were with automated systems the more confident they were with this concept. Yet, even the more inexperienced participants found the interface ***easy to learn and pleasant*** at the same time. The Around Me effect was accepted and appreciated especially because the user can set their own preferences and still have some reference to the road context.

5. Which are strengths and weaknesses during the two driving modes LOotL and SB and in the transition phase between these two modes?

Table 10 at page 101 shows the problem overview of the concept related to usability and the meaning of the interface that summarizes the weaknesses of the final design. The strengths of the HMI proposal are all the elements that contributed to recreate different environments according to the driving mode in use: the ambient lighting to communicate driving mode and automation status, the Around Me effects that dims the windows and shows road information and messages about automation decisions and logic.

Recommendations

During this master thesis project, not every important or marginal argument that emerged during the research or design phase had space or time to be studied in-depth or tested with users. For this reason, the question marks still left unanswered are exposed in the recommendations below.

Ambient Lighting
Since the study conducted for this thesis brought positive results about the effect of ambient lighting on the perception of driving mode and driver's responsibilities, further investigations about this topic can explore psychological effects on people in the short and long-term exposure. For instance a deeper study on ambient lighting colors and dynamic's perception to set a certain mindset or mood for the driver but also for the rest of the passengers of the vehicle.
Another study could investigate the possible consequences of excessive illumination on the eyes retina and its relation to this design considering the presence of ambient lighting and glow effects on HUD.
However, it is to be considered that the ambience lighting tested in this concept was located on the front part of the vehicle, while in a real context the ambient lighting would still be in proximity of the steering wheel and the main screen but also around the user, inside the vehicle, according to the car brand's choices.

Around Me effect
A further investigation could take into consideration the night version of the Around Me effect because this study was limited to the daylight version. It would be interesting to test the dimming windows and the glow effects when the road's visibility is already more difficult to see.
Nevertheless, the Around Me effect has not been explored in order to understand the feasibility of the concept in terms of a technical and financial perspective. The investment needed for those technologies is still unknown at this stage, and it is definitely something to investigate deeper.

Activity Tracking & Machine Learning
Another interesting result from this project's testing session was the extremely open approach of participants to a smart system that "observe" drivers' behavior, detect their activities, correcting dangerous behavior. A couple of participants even mentioned the possibility of integrating Machine Learning into this system to optimize the interface and predict user's preferences according to the activity. This very trendy approach to technology is certainly interesting to test further.

Central Display components location
The digital components on the same interface screen of the central display were grouped on the same screen to facilitate the interactions with the digital prototype. The purpose of the final user testing, indeed, was to test all the successful components of phases before, together. However, although this worked quite well for the aim of the test, each component of the screen has to be positioned in a more logical location inside the Central Display or even in separate locations. For instance, the activity wheel and the Around Me effects knob will be positioned in different sections of the dashboard/menu, according to each car brand design. Else, the overview of the journey and the route progress is more likely to be shown together with other road information, for example, the map always being accessible to the driver.

Mediator's Use Cases
Finally, in order to verify other design opportunities for ambient lighting and the other core experiences, it is recommended to further investigate their role in different Mediatio's use cases, for instance during the transfers of control and in manual driving.

REFLECTION & AKNOWLEDGEMENTS

This project started as a challenge.
I have been able to handle the project in the most tragic historical period I have ever experienced and still being able to be motivated and enthusiastic about what I was learning and what I was discovering, and that was the first success. Moreover, this project brought to my life a lot of positiveness, and this is why I chose this career in the first place. The hope for my future self is to approach many other projects with the same enthusiasm, always learning something new from people around enriching myself every day.

As a designer, dealing with a structured methodology is always a challenge. The double diamond process helped to follow guidelines for the project and not getting lost in diverging or converging phases. Personally, it has been a lot messier and articulated than a double diamond process but I am happy to discover, project by project how this process takes different shapes and different choices in the future. For now, I am happy with the choices made in these months and the obtained results.

Sometimes it is very hard to deliver everything in time, to have everything under control, to manage people, data, participants, methods, and creativity at the same time. But those kinds of challenges are the main reason I am in love with this profession, making me feel anything but flat. During this project, I also had the chance to understand myself better and to improve myself and my confidence. Today I am grateful and satisfied with my work and the skills obtained during this experience.

Thanks
Gradually entering the heart of the project, I found myself becoming a 'car-obsessed', spotting every Tesla on the road and spying the EV charger in front of my house expecting some cool cars to approach it.
I empathized with people and users in this project, feeling part of it and taking care of people's experiences.
I had the chance to collaborate with a friendly but very professional graduation team, the chair Elmer, the mentor Sylvia and the company supervisor Diane, thanks for everything you taught me and all the positivity you transmitted to me, it was a pity not being able to meet in person during these months.

I would like to thank all the people that have been supporting me during this project, especially Jani, Franci, Ale, Mari, Priya, Titi, Andre, Maira, thanks for the encouragement and every moment we spent together.

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To my boyfriend Tommi, thanks for being always by my side, choosing me every time, even 1300 km away from me. Thanks for never giving up on us and for always making me reflect more on things I have been too instinctive about, although respecting my choices, my times, and my space. I will always remember these two years as a way of growth for us too.

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Benedetta Grazian
Delft, October 2020

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