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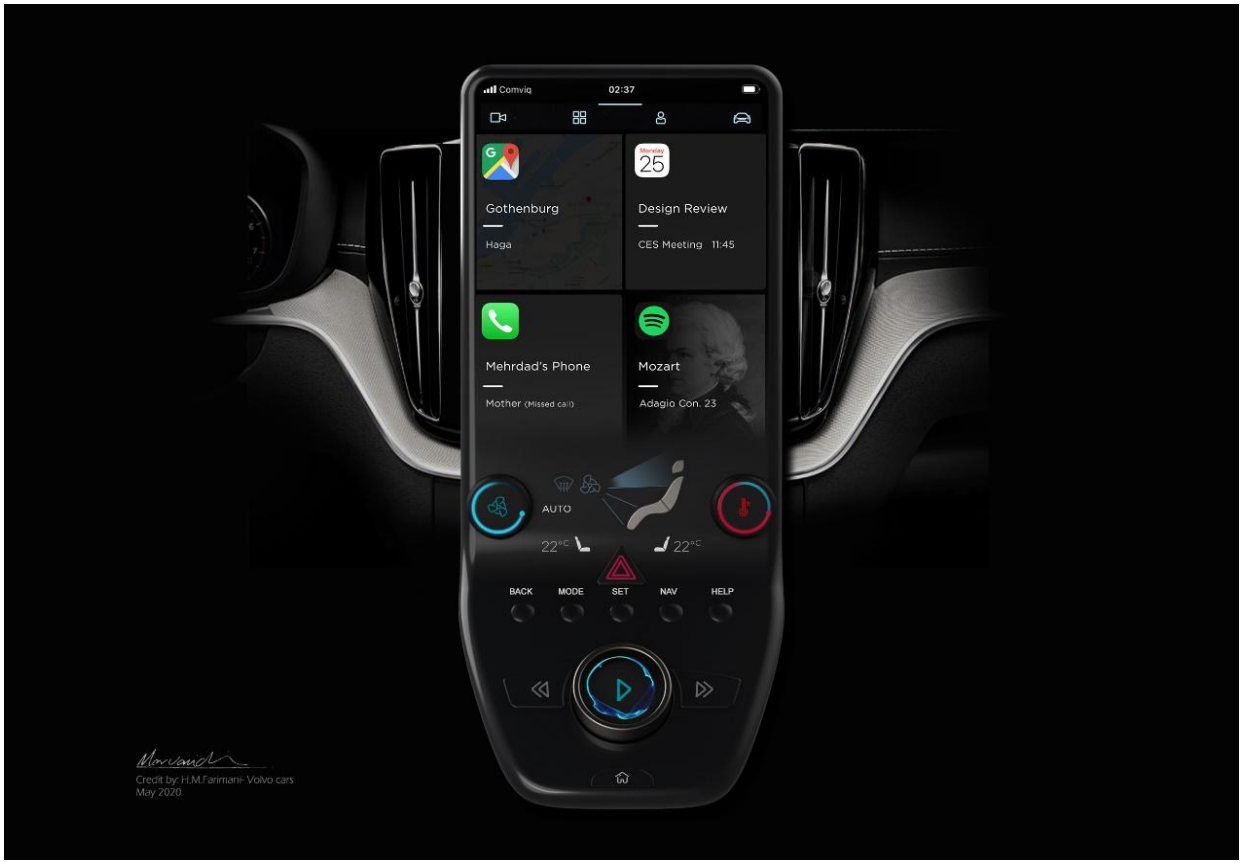

Investigating the User Experience of Physical and Digital Interfaces in Automotive Design

A Comparative Study of User Experience and Satisfaction in In-Vehicle Infotainment Systems

Master's thesis in Industrial Design Engineering

Hossein Morvaridi Farimani

DEPARTMENT OF INDUSTRIAL & MATERIALS SCIENCE
Division Design & Human factors

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Hossein (Mehrdad) Morvaridi Farimani, Gothenburg, 2020

Terminology

CSD	Centre Stack Display, a technical word which is used by practitioners.
Digital interfaces	Type of interface which consists of a touchscreen as the interaction device, and which usually has no physical controls.
Eyes off road	A term which is used when the driver's eyes concentrate on something else than the road when driving (primary task).
GUI	Graphical User Interface.
HMI	In this study, HMI is primarily interpreted as Human-Machine Interaction. The term can also be interpreted as Human-Machine Interface.
Impact map	A graph which represents different user behaviours and attitudes towards a specific subject.
Infotainment	The combination of information output and entertaining functions in an in-vehicle interface. This interface also contains convenient functions such as climate control.
IVI	In-Vehicle Infotainment, which refers to the in-vehicle displays.
Multifunctional displays	Term usually used for digital screens, such as a touch screen, which provides both input devices and output information in the same device
NHTSA	National Highway Traffic Safety Administration (USA)
OS	Operational system of electronic devices which (in this case) refers to operational system of in-vehicle interfaces.
Physical interfaces	Type of interface which provides dedicated physical controls in combination with a simple interface.
UI	User Interface of an electronic device

Abstract

With the continuous addition of new infotainment and driver assist features, In-Vehicle Infotainment systems (IVIs) are evolving to enhance convenience. However, balancing the system's output (information presentation) and input (vehicle controls) has become a major challenge for automotive companies. To address the complexity and information overload, many have shifted from physical controls to embedded digital touchscreens, raising questions about how far this transition should go.

This shift from physical to digital interfaces presents both benefits and drawbacks. On one hand, digital touchscreens can increase driver distraction due to the visual load and eliminate haptic feedback and muscle memory. On the other hand, they offer flexibility and modern aesthetics. The primary research question was: What are the pros and cons of physical and digital interfaces from a user perspective? The secondary question focused on how the context of use (driving vs. non-driving) impacts user experience with each interface type.

To explore these questions, this thesis investigated user satisfaction with both physical controls and digital touchscreens. Online user interviews and a literature review were conducted to assess the pros and cons of each interface in different contexts. The findings revealed that no single interface type is universally preferred. Users favored physical controls while driving, due to the haptic feedback and ease of use, but preferred digital interfaces in non-driving situations, due to their modern appeal and functionality.

The study also revealed that user preferences varied based on behavior and attitudes, with early adopters perceiving digital interfaces as more trendy, while conservative users viewed physical interfaces as more reliable. These insights led to the development of design guidelines and a hybrid interface concept, blending physical and digital elements. The concept was evaluated and deemed a better solution than existing systems, though some refinements were suggested. The results provide a foundation for balancing physical and digital elements in future IVI designs.

The design guidelines, developed from user needs and research findings, aimed to balance the strengths of physical and digital interfaces. These guidelines led to a conceptual UI design that combined physical controls for driving tasks with digital touchscreens for flexibility in non-driving contexts. The hybrid design was evaluated by both original participants and a wider audience, receiving positive feedback as an improvement over current systems. However, some aspects, like balancing ease of use with digital complexity, needed refinement. Overall, the guidelines, impact map, and evaluations represent progress toward more intuitive and user-friendly in-vehicle interfaces.

Keywords: User Experience (UX), Human-Machine Interaction (HMI), In-Vehicle Infotainment (IVI) Systems, Digital Interfaces, automotive safety

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1 Introduction

User-centred development and addressing user needs are part of every modern design methodology and toolset (Lee & Young Ju, 2018). For decades, understanding customers or users and their needs and requirements have been argued as a key success factor in new product development (e.g., Kern & Schmidt, 2009). The importance of this customer/user orientation is also evident in the automotive industry and in automotive design, exterior as well as interior.

In today's (as well as future) automobiles, in-vehicle infotainment (IVI) is an inseparable part of the vehicle's interior and thus also of driver experience. Automotive manufacturers are investing more than ever on its development. For example, Volvo XC90 has seen a notable change during the last ten years in the design of the IVI and driver interaction panel (Figure 1). The same transition can be noted in most of today's automotive productions. The classic interface with a number of push bottoms and knobs, (one dedicated per function), has shifted into a multifunctional touch screen. This transition is due to several factors, e.g. an increasing number of functions and information being handled through the IVI, the developments of in-vehicle navigation systems, smart phones, multimedia systems, and so forth.

Figure 1. IVI's transition in Volvo XC90 2006 (left) and Volvo XC90 2016 (right)

Given this development, several questions arise. Indeed, digitalized interfaces are more cost-efficient long term and easier to update but is digitalizing every interaction control in a vehicle the best solution for the user? What is lost in this transition and what is gained from a user and use perspective?

1.1 Aim and objectives

The overall aim of the thesis project was to investigate user experience, pleasure and overall user satisfaction with, on the one hand an interface design with dedicated physical controls and on the other hand an interface based on digital elements applied in an IVI system. By physical controls in the interface are meant the mechanical elements of a control panel (e.g. knobs, toggle, pushbuttons, etc.). The digital elements refer to touchscreen solutions for input and output/feedback in a single multifunctional digital display (Figure 2).

Figure 2. IVI with dedicated physical controls (Left- Infiniti), IVI with only one multifunctional touch display (Right-Tesla)

The fundamental question was: *To what extent should we change physical interfaces into digital ones?* To approach this question, the following research questions were addressed:

Research question 1: What are the pros and cons of each type of interface from a user and use perspective?

Research question 2: Does the context of use affect the user experience of the respective type of interface? If so, how?

1.2 Delimitations

The thesis project focused on IVI systems and user's/driver's interaction with such a system as a secondary and/or tertiary task (driving being the primary one). Only haptic and visual elements have been investigated since vision and haptics are the most relevant human senses in the context of physical and digital interfaces. The thesis project has not addressed other types of multi-modal interaction, e.g. voice commands, gestures or solutions such as head-up displays (HUD). In addition, the thesis project has focused on solutions for economy class automobiles and has not addressed luxury or sports classes. Most importantly, the type of cars addressed in this study are not autonomous/self-driving cars. However, some results can be applied to other classes of vehicles. Moreover, cultural and regional aspects were not the focus of this master thesis project.

1.3 Ethical considerations

Several ethical aspects have been considered during the thesis project. Volvo Cars works towards ensuring four of the seventeen Sustainable Development Goals adopted by the United Nations in 2015, more specifically numbers 3, 9, 11 and 13 (Volvo Group, 2019). The design guidelines that were produced during the thesis project have considered and have been steered towards ensuring these same goals. Use of sustainable materials, reducing unnecessary parts and informing users of their driving behaviours via IVI, are some of these considerations.

By improving the user experience and creating a more fluent and efficient stream of feedback (i.e. haptic feedback), the societal aspect of edging closer to Vision Zero, i.e. that there should be no fatalities or serious injuries involving road traffic, has been taken into consideration (cf. CityLab, 2014). Any change or improvement in the IVI system needs to bear this in mind and be directed towards achieving this goal.

GDPR and the protection of the data on participants in this study were considered as a priority in this project.

1.4 Project process

The process included several steps; defining the focus of the study, reviewing fundamental UX and HMI research, deciding on study design, conducting an explorative study (i.e. online interview), concluding on the results, formulating design guidelines, designing a new interface concept based on the guidelines and evaluating the final conceptual design (see Figure 3).

The thesis project was characterised as research through design (RtD), i.e. a combination of research, empirical studies and design creation, aimed to answer the research questions and, in the end, propose a design solution (or hypothesis) for the investigated problem.

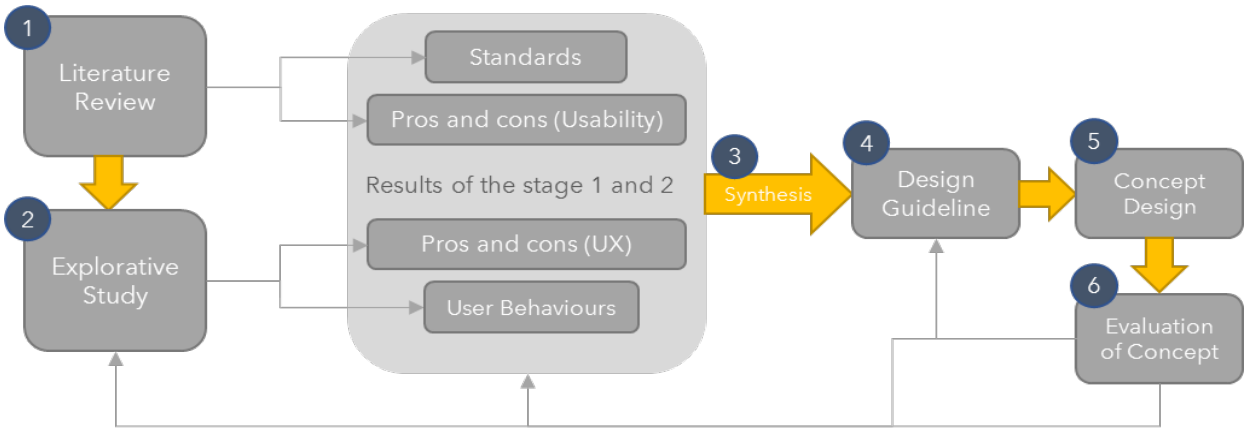

Figure 3. Overview of the stages of the thesis project

1.4.1 Literature review

The initial phase in the process involved a literature review. The Literature Review was an important part of the project and split into three sections (Figure 4):

- Understanding user experience. This meant addressing questions such as What is user experience? and How is it defined? and reviewing the concepts of sensory experience, temporality of experience, etc.
- Reviewing literature on human-machine interaction (HMI), general guidelines for user interface (UI) design, and concepts such as natural interaction, multimodal interaction, etc.
- Reviewing literature on (design of) in-vehicle HMI or IVI, as the main focus of this study. In addition, the timeline, the complexity and information distribution over time, the introduction of touch screens and finally, the pros and cons of the existing systems were investigated.

The synthesis of these topics provided the theoretical basis of the thesis project and the main resource for choosing the appropriate methods and tools for the empirical studies (i.e. explorative and evaluative interviews).

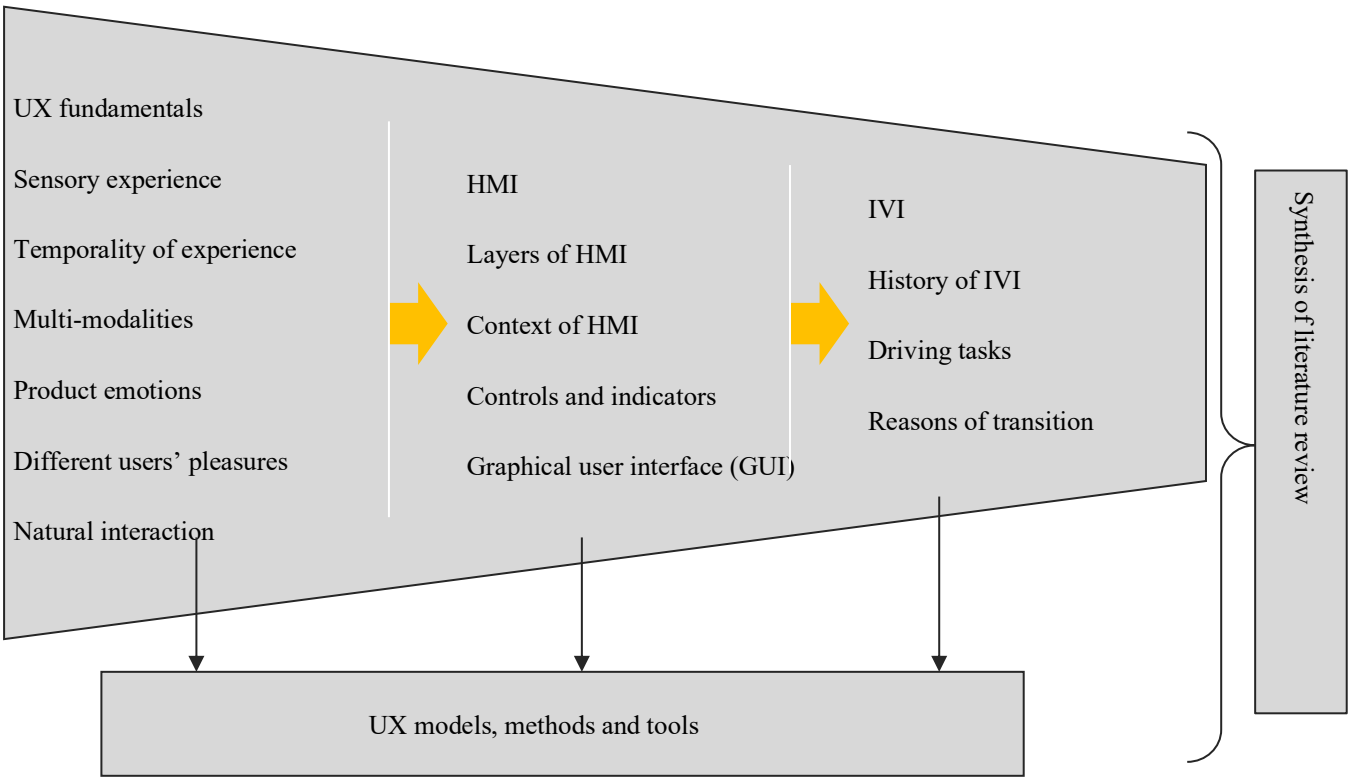

Figure 4. Overview of Literature Review

1.4.2 Driving simulator study

In order to answer the research questions, an experimental study was planned. This study was to take the form of a user test with participants interacting with a physical and a digital prototype of an IVI in a car simulator (some visuals are found in Appendix A). A substantial effort was made to find solutions to and produce comparable physical and digital prototypes in order to allow for a systematic comparison. However, the work as well as the user test had to be cancelled due to COVID-19 and an alternative method had to be sought.

1.4.3 Explorative study

The method decided upon was an online study as the main method for the empirical study of this thesis project. The online study was planned to answer questions regarding the anticipated and episodic experience of the participants when exposed to visual representations of physical and digital interfaces. The data collection method, interview questions, visual materials, process for recruitment of participants etc. were planned in this phase of the project.

The results of the Explorative Study were deducted and compared in the form of charts and comprehensive narratives. These results helped to answer the research questions and created sufficient input to the design guidelines. The users' experience of pros and cons of different types of interfaces and user types (i.e. impact map) form the main outcomes of this part of the process.

1.4.4 Formulation of design guidelines

In order to demonstrate the results of this project in action, a design had to be achieved. However, the link between the design and the empirical study and literature was implications for design and design guidelines. The design guidelines are the generalized implications of the study considering different personality traits and user types. The aim of the design guidelines is to act as an actionable framework for considering UX in physical and digital elements of an IVI system.

1.4.5 Applying the guidelines

A design methodology was required to create a design concept based on user experience. Therefore, a User Centred Design Approach was chosen as the most appropriate model for concept development. *Note though that this model does not only cover the actual design phase, but the whole development process!* (Figure 5).

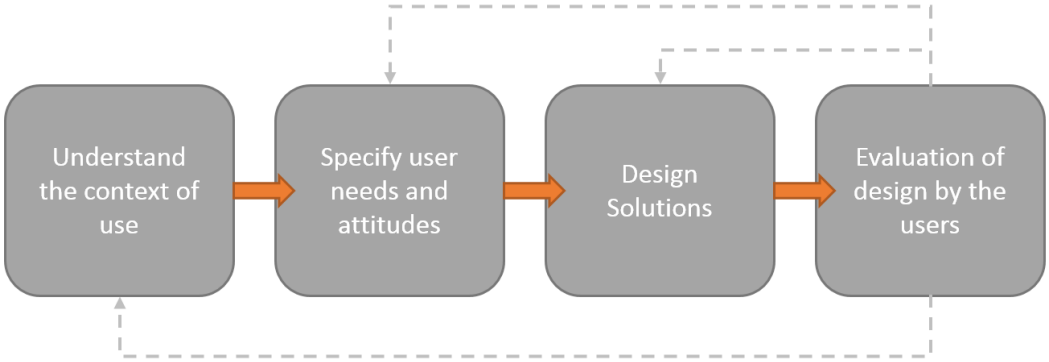

Figure 5. A user centred design approach (the content modified for this study)

The guidelines were used for proposing the new conceptual design of an IVI, which covers and tries to take into consideration the pros and cons of the discussed topics. This phase included ideation, concept sketches, detail sketches, UI design and 3D visualizations with the help of user centred design approach. Additionally, in order to prepare this design for the user evaluation, an animation of a performing system was created.

1.4.6 Concept evaluation

The final design concept was evaluated by the same participants who took part in the Explorative Study. In an on-line survey (i.e. questionnaire), participants, who fit the previously identified five types of users the best, were exposed to the visual representations of the final concept and answered a number of evaluation questions.

2 Literature Review

The section starts with a review of fundamental research on basic principles of user experience (UX), human-machine interaction (HMI), In-Vehicle Infotainment (IVI), natural interaction, etc. A short review of IVI systems over time and different trends are also presented. Literature is reviewed which describes research which has done similar or related studies regarding the haptics of physical, dedicated controls and touch screens.

2.1 User experience

2.1.1 The UX concept

In traditional human factors, the focus was on a system as the main core of the 'machine', whereas the operator or the user was treated as a resource to provide input to and control the machine (Noyes, 1997). However, during the last decades, the product development process has become more concentrated on users, specifically user experience as the main deliverable to the customers and this has contributed to increase product success in the market (Kleinschmidt & Cooper, 1991).

For a long time, the customer's concern was to satisfy needs at an affordable cost and the best availability and accessibility (Kumar & Whitney, 2007). However, with improvements in production systems, the customers faced a broad range of analogous, low-cost products. Now, it has become apparent that user's emotional responses to products and services, social use contexts, motivation for usage etc. are factors and concerns to be considered (Veryzer & Borja de Mozota, 2005). All these aspects can be included in the meaning of user experience or UX.

Fundamentally UX is subjective, affective and individual and should be understood as such (Forlizzi & Battarbee, 2004). There are numerous definitions of UX from different points of view including definitions by Forlizzi and Battarbee (2004), Hassenzahl and Tractinsky (2006), Norman (2004) and Jordan (2004) as well as the International Standard Organisation (ISO).

According to ISO, user experience (UX) is described as "a person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service" (ISO 9241-210:2010). According to Norman and the NN/group (2019), "User experience, encompasses all aspects of the end-user's interaction with the company, its services, and its products." Norman emphasizes the importance of distinguishing between UX and usability as usability defines the quality attribute of the UI and factors such as ease of learning, efficiency of use, being pleasant and etc. Norman (2004) encourages us to consider the total user experience as a broader phenomenon. Hassenzahl (2005) considers UX as a floating concept that varies between users and situations but also changes over time since it is dependent on and related to the users' skills, attitudes, personalities as well as the use context of the product, service or the system. In addition, referring to Desmet and Hekkert (2007), the user is the one who is 'living the experience'. Therefore, the user experience and user centeredness are highly dependent on each other in a design process and the users' personality traits should be considered as an important factor to consider in the evaluation of UX.

One of the important factors in user experience is the concept of temporality of user experience. Experience is not stable over time but may differ before, during and after usage (Karapanos et al. 2009; Kujala et al. 2011; Hassenzahl 2010). In addition, user experience cannot be understood merely

based a short period of use (Pettersson, 2016) and therefore user studies cannot only investigate the momentary experience of users. So, anticipated and episodic experiences should be considered together with momentary experience.

The definitions allow us to understand user experience as a dynamic concept which is based on the interaction between a user and an artefact (i.e., product, service and/or system) with different characteristics, in a specific context of use (Mahut et al., 2017). It is also important to be aware that user experience, perceived quality and aesthetics, are not separated from customers' understanding of usability and should therefore be considered as part of the whole (Wellings et al., 2010).

2.1.2 UX theories and models

2.1.3 Product pleasures

According to Jordan (2000), good human factors (e.g., ergonomics and usability) are no longer enough to reach good design solutions. Good human factors do not indicate an added value anymore, whereas their absence result in disapproval. Jordan argues his point with a hierarchical model of consumer needs, inspired by Maslow's hierarchy of needs. According to this hierarchy (Figure 6), the bottom layer of the pyramid is functionality, suggesting that a good design should offer appropriate functionality. The second layer of the pyramid is usability. Once the functional needs are satisfied, people start to look for a design that is easy for use. Pleasure is placed at the top layer in the pyramid. Jordan argues that people always seek for added value in their choices. Thus, after the usability concerns are satisfied, emotional benefits start to play a role in decision-making (Jordan, 2000).

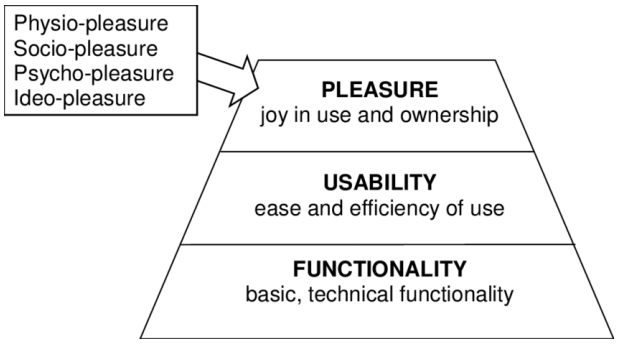

Figure 6. Jordan's hierarchical user needs model (Source: Jordan, 2000).

Jordan proposes four different product pleasures, i.e. Psycho-pleasure, Physio-pleasure, Ideo-pleasure and Socio-pleasure. **Psycho-pleasure** is interpreted to include aspects such as usability and functionality and **Physio-pleasure** is defined as elements which are related to human senses. Both these pleasures are considered important for this project.

According to Jordan (2000) *"…if the driver cannot reach the climate control functions easily, he/she will experience difficulties that might have consequences ranging from discomfort (e.g. if the driver is unable to set the climate) to danger (e.g. if the driver gets distracted from the road and result in an accident)."* The quote is a clear example of psycho-pleasure and physio-pleasure and their important

roles in user's satisfaction of interacting with and using a product. In other words, discomfort in a driving context can result in dangerous situations, hence, any difficulties in performing tasks will result in dissatisfaction and negative users' experience.

Ideo-pleasure and **socio-pleasure** are defined respectively as users' personal ideological point of views regarding the products and services and social aspects that influence the users and the artefacts. These aspects generate a more thorough understanding of the user's emotional responses to products or services.

2.1.4 Product emotions

Desmet and Hekkert (2002) proposed a model which is concentrated on evoked emotions and named it the 'basic model of product emotions' (Figure 7). The model represents four factors in user's emotional process: 1) product (as a stimulus), 2) concern, 3) appraisal, and 4) emotion (as a response).

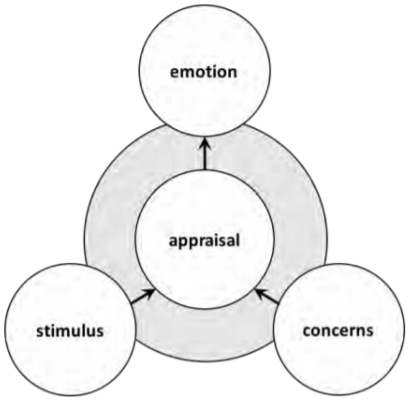

Figure 7. Desmet's basic model of product emotions (Source: Desmet & Hekkert, 2002)

According to Desmet (2003), emotions are the result of a relation between the person experiencing them and a particular object: e.g., one might be afraid of something, proud of something, in love with someone etc. Object, product, or artefact imply a **stimulus** in this model. However, the stimulus that evokes the emotion is not necessarily also the object of that emotion. In the present work, the stimulus can be a specific part of IVI (e.g. pushbutton or touchscreen).

Concern declares the hidden parts of every emotion. For instance, in the present study, if the car interface matches our concerns (e.g. safety, learnability, ease of user etc.) it is appraised as beneficial but if there is a mismatch with our concerns, it is appraised as harmful. The types of concerns that can be connected to the topic presented here are the motive for using the infotainment system, needs for being entertained in the car, goals to be reached by using car functions, and safety. However, safety declares as a more general concern and is not context dependent. Product is the object that is always involved in the relation between the person and the experience (Desmet, 2003). In this study, the product is considered as the IVI.

Appraisal refers to the fact that an emotion always involves an assessment - or appraisal - of the harmfulness or beneficial aspects of a product. This appraisal is a subconscious, automatic assessment

of the stimulus for one's personal well-being. Therefore, in the case of the stimulus being a product, there are three possible outcomes of an appraisal: the product is beneficial, harmful or not relevant for personal well-being. These three outcomes respectively result in a pleasant emotion, an unpleasant emotion or an absence of emotion.

Emotion is the human response and the outcome of the process. According to Desmet (2013), emotions are sometimes referred to as mood. However, there are two main differences. Firstly, mood has a long-term character whereas emotion is a short-term phenomenon. Secondly, emotions are intentional (i.e. in this context, emotions are the responses to the different aspect of the product) whereas moods are essentially non-intentional. Hence, mood is not included in Desmet's model (2013), or the studies presented here, since the user who are studied, are considered being in a neutral mood/affect at the time of the study.

Furthemore, according to Desmet (2013), product emotions can be classified into one of the following five categories: instrumental, aesthetic, social, surprise, and interest emotions (Figure 8).

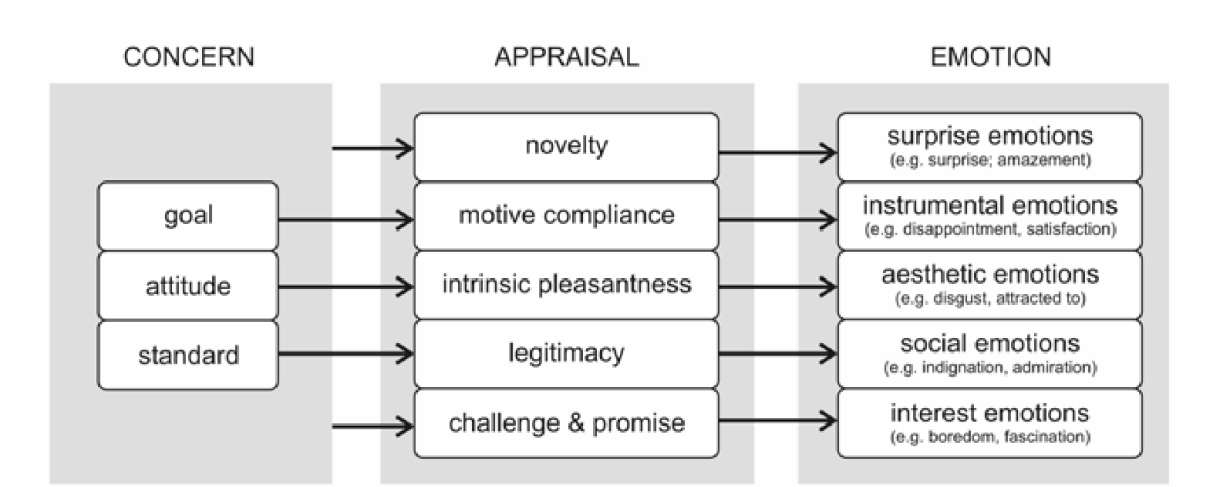

Figure 8. Classification of product emotions (Source: Desmet, 2013).

Although Desmet (2013) mentions that the five categories of product emotions do not cover all possible emotional responses towards a product, this model is still usable for the present project since it covers most of the aspects that are under investigation here.

2.1.5 Emotional design

Another model is proposed by Norman (2004). He introduces three levels of emotional design: visceral, behavioural and reflective levels (Figure 9), which result in delight (defined as enduring, lasting pleasure). These three levels explain the emotional responses of users to a product, before, during and after the usage.

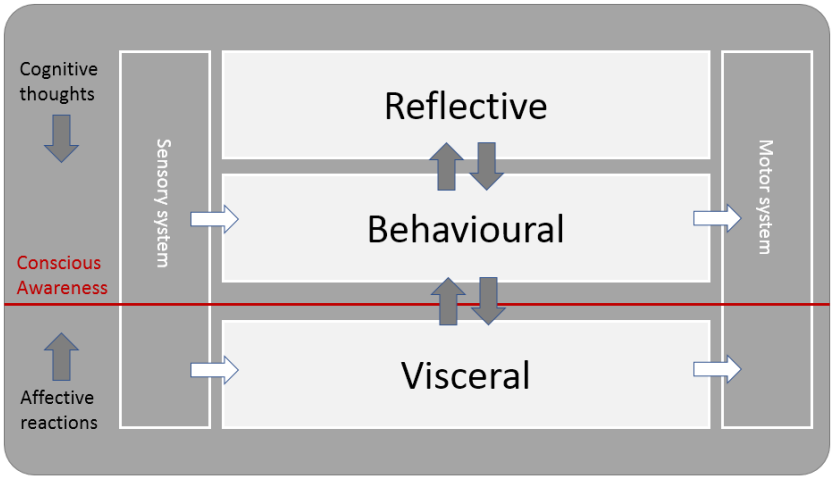

Figure 9. Norman's three levels of emotional design (Source: Norman, 2004)

The **visceral** reaction is triggered by an initial sensory experience. It is this first impression that sets the mood and initial framing for which one will explore everything else. The **behavioural** reaction is how the user feels as he/she is immersed in the product experience. It is how one reacts while interacting with a product and derives value from the products in use, also more commonly known as usability. **Reflective** behaviour refers to how the user remembers the experience itself and how it made him/her feels. It determines whether the user wants to try that experience again or not (Norman, 2004).

Norman's model is connected to four aspects of human cognition. First, an emotion-memory link, and the notion that our emotionally charged events persist in our memories beyond the product's functional values. Second, an aesthetic-usability effect, which is related to the fact that aesthetically pleasing experiences empower usability and increase the user's urge to learn and adapt. Third is persuasive emotion or gut feeling, which is related to the decision-making process through emotions. Moreover, there is an ownership effect which expresses the fact that users value experiences where they feel a sense of personalized ownership (Norman, 2004).

2.2 Human-Machine Interaction (HMI)

In order to establish positive UX in an automotive context, firstly we need to consider the term Human-Machine Interaction (HMI) as a key part of the driver's (and passenger's) interaction with the vehicle.

The development of HMI is an interdisciplinary, complicated challenge (Bader & Fallast, 2012). Besides the technical aspects, the development of the HMI needs to consider cognitive principles so that the design matches the user's mental model and interaction patterns. Interaction as a 'multidimensional', 'subjective' and 'affective' phenomenon is the core of UX, and the notion of temporality is critical in understanding how interaction occurs (Mahut et al., 2018). The term 'affect' is also important here and is defined by Demirbileck and Sener (2003) as *"a customer´s response to the perceptual design details of the product"*.

The implementation of the HMI in today's automotive industry has become more and more complex, but there are basic principles to be considered in order to fit the scope of the present project.

The first in-vehicle HMIs were literally mechanical, and the purpose of the functionalities was to fulfil the driver's requirements regarding information on speed, gas level, lever guidance etc. Later, the driver and the passengers needed to be entertained while driving so other functions including radio, music, navigation and phone pairing were added progressively and integrated into cars as part of automotive development. A system which provides information together with entertainment facilities is called 'Infotainment' system (Bosshart & Hellmüller, 2009) – in an automotive context it is referred to as the In-vehicle Infotainment (IVI)[1] system which is mostly concentrated to the centre stack dashboard/display (CSD) and steering wheel area (Meixner, 2017).

At the beginning of the 21st century, the automotive industry faced a substantial raise in the complexity of the driver-vehicle interface which is the result of widespread introduction of advanced computers and communication concepts (Barfield & Dingus, 1998); (Burnett & Porter, 2001). Therefore, the increased number of IVI functions in modern cars, such as high-end audio, video, phone pairing, etc. has a direct impact on the complexity of the HMI since the driver has to manage more information while driving (Meixner, 2017) – in addition to other technological functions in the automotive context such as: collision warning system, navigation system, infrared pedestrian warning system, etc. which were invented in order to support the driver to achieve a safer and more comfortable driving experience (Wikman, 1998; Wittmann, 2006).

Several researchers emphasize that the time spent on secondary and tertiary tasks (Kern & Schmidt, 2009), is also time for 'eyes-off-road' which can result in serious unawareness by the driver (Tsimhoni & Green, 2001). Since undivided attention and awareness are necessary in driving as a primary task (NHTSA, 2016) some researchers recommend implementing a multimodal HMI which could provide a safer and a more 'natural interaction', especially when users can choose which type of modality to use (Oviatt, 2000). Valli (2008) proposes the following definition of natural interaction:

"*Natural interaction can be seen as mean of communication that allows individuals to interact with technology in the same way as we are used to with other people in everyday life."*

Multimodal HMIs are the result of a synthesis of different modalities in a meaningful and understandable way in order to support a usable, efficient and satisfying interaction. It is declared that multimodal interfaces are easier to learn and use (Oviatt et al. 2004), at the same time they are more engaging and pleasurable, and in addition distribute the cognitive load (Oviatt et al. 2003).

In a study based on the idea of 'basic interactions', Karlsson et al. (2019) investigated participants' preferences in multimodal interaction and what modality was considered the most 'natural' when performing different operations. The majority of participants declared that the modality that they were used to, or familiar with, was also what they experienced as the most 'natural' and in addition, *"some participants even expressed a dislike to modalities that they were unfamiliar with"* (Karlsson et al., ibid.). Therefore, familiarity and former experience have a great impact on the user's choice of preferred modality and what is considered as natural interaction. Users also preferred consistency between modalities and operations and might be reluctant to switch between different modalities, in particular in relation to certain tasks (Karlsson et al., ibid.).

[1] Central stack display (CSD) and head unit are also common terms for this system.

Ng et al. (2017) conducted a study in order to evaluate three different interactive controller methods with a touchscreen interface in a real-world driving context. The results showed that directly selecting items on a list-based graphical user interface (GUI) available on a touch screen was the quickest method. Using a physical controller or on-screen buttons as input controls to the GUI took more time but resulted in higher accuracy. Ng et al. (ibid.) recommended designers to consider the context of use and the level of integration of the modalities in each design project. It is for example important to consider if 'speed' or 'accuracy' is the more important factor while mapping the physical controller or touch-based infotainment applications.

It is also reported that there is no optimal interaction device for all the tasks but the best solution for the specific task needs to be sought (Rogers et al., 2005; Karlsson et al. 2018). Users require a sufficient level of feedback (which is reported by different studies), and even if the users do receive visual and auditory feedback, they still require some levels of haptic feedback (Pitts et al. 2009).

2.3 In-Vehicle Infotainment Systems

During the last decades, recent developments in the automotive industry spotlighted HMI more than any other time as an inseparable part of a vehicle why automotive manufacturers have been willing to invest more and more in this area (Gkouskos & Chen, 2012). More functions are added to the car day by day and in order to integrate all the functionalities in a car dashboard without changing the size of the cluster of displays and centre stack, there is a trend among manufacturers to merge all the functions into an embedded, multifunctional interface (Burnett and Porter 2001; Rydström et al 2012; Breitschaft et al. 2019) which results in an elimination of physical pushbuttons and knobs. In order to track the design transition of IVI systems, a brief history of IVI's development is necessary.

Many practitioners and researchers have emphasized the importance of IVIs, as mentioned by Gorden Wagener, chief design officer for Daimler AG (2017):

"*The screens are the window to the digital world… screens are new horsepower. Multifunctional displays are becoming the main interface for the driver and passengers with the outside world, we are witnessing an increase in the use."*

The history of infotainment systems can be traced back to the 1930s with the launch of the AM car radio (Figure 10). These started off as a taste of luxury for well-off motorists, but by the end of the decade, push-button AM radios became a common feature in most cars (Dressekie, 2019).

Figure 10. Early radio and music display systems

As more and more car users came to expect music players as standard in their cars, manufacturers worked hard to develop new and exciting in-vehicle music and radio technologies that aligned with how people were consuming music at the time. Some of the most notable innovations of the previous century include in-car record players, 8-track cassettes, car stereos, and in-built MP3 units (Figure 11).

Figure 11. Multifunctional display Toyota 1998 (Left) Nissan 2001 (Middle), BMW 2001 (right)

The satellite-based Global Positioning System (GPS) was first developed by the US military in the 1970s to provide geolocation and time information to a GPS receiver anywhere on the globe. The first car to boast an in-built navigation system was Toyota's 1981 Celica model. Dubbed NAVICOM, the system was controlled by a microcomputer, which continuously displayed graphs showing direction and distance to a pre-coded destination (Figure 12). In 1990, Mazda introduced the first ever GPS system for automotive navigational use. Since then, GPS technology has advanced significantly and again has become standard in many new cars in 2019 (Dressekie, 2019).

Figure 12. Early car's navigation systems, Toyota 1987 (Left) and BMW 1994 (Right)

The transition of Volvo cars' IVI interface over the past twenty years is a clear example of the history of IVIs. This transition is the result of technological developments and user needs which affected both interior design and user experience. Figure 13 shows the shift from an interface with physical controls into multifunctional displays. The same transition can also be seen in most of the today's cars but with differences in details. In order to analyse the transition and provide a new solution for the possible problems that the users may face, it is necessary to have a clear understanding of the history of these changes.

Figure 13.Transition of Volvo cars' IVI over twenty years (Image source from Volvo cars, graphical image by the author)

In order to cope with centre stack size issues and increase the number of functions on offer, some automotive manufacturer (such as Tesla) introduced a single touch screen as an interaction device for their multifunctional interface (Figure 14), (Budiu, 2019). Some other manufacturers (such as Audi and BMW) chose another approach and have instead used a rotary knob control as an input device for user interaction (Figure 13) (Rydström et al., 2012). Other companies have developed a touchpad surface (the same as the ones in laptops) as an interaction device. This type of device did not get much positive attention in consumer reports (CR. Barry, 2019) but is notable since haptic feedback was considered in this system (Pitts et al., 2009; Serafin et al., 2007), (Figure 14).

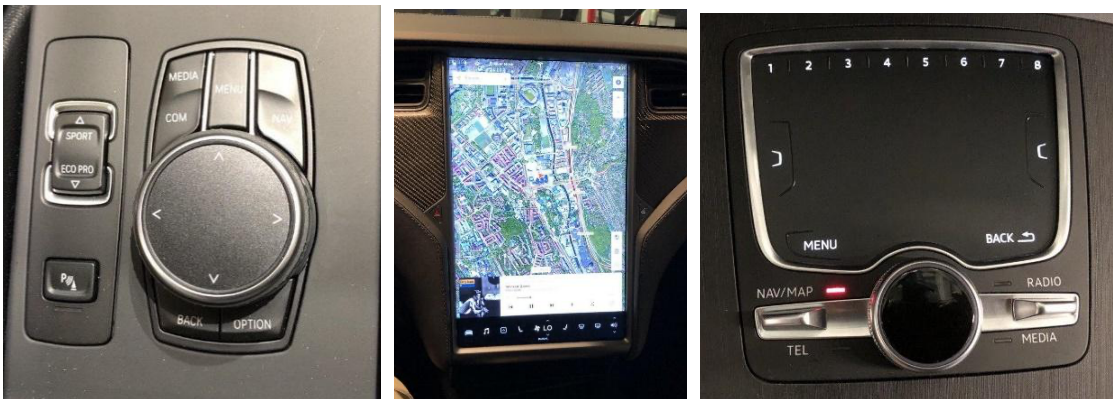

Figure 14. Left: Rotary knob by BMW, (Middle) Tesla multifunctional screen, Right: touchpad surface by Audi (Photos by the author)

The current main trends of IVI designs can be defined as:

- To integrate the system input and output devices in one touch screen (such as Tesla that uses the least number of physical input controls).

- To keep the system input and output devices separated; the output device is mainly the touchscreen, but the input device can be any physical device (e.g. conventional pushbuttons and knob controls or a rotary knob as in BMWs).

The major trend, however, is to shift into a surface which integrates controls and displays, and which demonstrates a seamless surface as an interaction device. A good example of this can be the development of BMW infotainment controls over a period of only three years (Breitschaft et al. 2019). This rapid change in design can be seen in Figure 15 from (A) mechanical separated push buttons with a rotary knob (BMW Group, 2015) through (B) surface integration buttons and multifunctional knob (BMW Group, 2017) to (C) seamlessly integrated UI-surfaces (BMW Group, 2018) (Breitschaft et al. 2019).

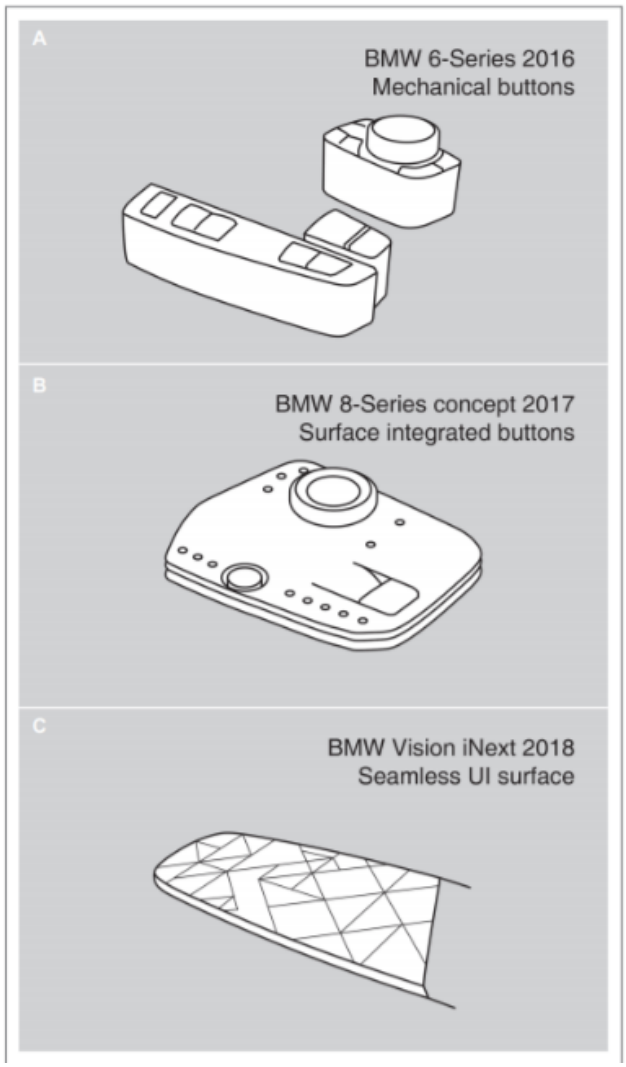

Figure 15. (A) Mechanical separated push buttons with a rotary knob. (B) Surface integration buttons and multifunctional knob. (C) Seamlessly integrated UI-surfaces (Breitschaft et al. 2019)

Another trend among manufacturers (e.g. Jaguar, Figure 16) is to distribute the information on multiple (usually two) displays, something that is not recommended by several researchers since it requires more visual scanning which results in distraction and also increases the cognitive load of drivers (De Waard, 1996; Bao et al, 2002; Noy et al., 2004; Wittmann et al., 2006). In these solutions,

the upper display is usually used for information presentation and output (i.e. navigation map, music list etc.) and the lower display is used as a dynamic input device.

Figure 16. Distribution of information in two displays by Jaguar

In addition, regarding multimodality[2], speech and voice command as an interactive mean could increase usability and flexibility. However, several researchers have shown that it can result in frustration, and reluctancy to use after some time. For instance, the user may have problems to find the exact word to control a specific function. Furthermore, users may be reluctant to switch between different modalities due to a perceived increase in cognitive load (Karlsson et al., 2019).

Moreover, several automotive manufacturers still keep the physical push buttons and knobs. They believe that this is a better interactive mode for their consumers, it fulfils the notion of 'familiarity', and it creates a better user experience. For example, Mike Novak, marketing manager for Fiat Chrysler Automotive (FCA) says:

"*We decided to keep buttons and knobs for frequently used utilities (such as volume and tuning), rather than replacing them with touch control, as some automakers have done. Novak explains that FCA's research shows that drivers prefer buttons and knobs over touch controls because they can be found by feel and can be used in cold weather when the driver is wearing gloves*." (CR by Keith Barry 2019)

Several articles on HMI and IVI have focused on the design and development of the GUI of the displays, primarily visual and/or auditory aspects (e.g. Creusen and Schoormans, 2004). However,

[2] The focus of this study in only on vision and haptic and addressing other modalities is only in the case of explaining the trends and is out of the scope of the project.

there are still some critical issues related to system input and output of the interfaces (see e.g., Burnett, 2000).

Naturally, driving is mainly characterized by the primary task of driving, and hence "eyes on road". Even when the driver's attention is not on the road, the driver's eyes are still focused on the primary task related information sources, such as rear-view mirrors and instrument cluster. However, the time watching the road is reduced when performing secondary and tertiary tasks. This can be any other activity such as setting air conditioner or music setups or dialling a phone number. Looking away from the road for two seconds or more can multiple the risk of accident or near crashes (NHTSA, 2016). Therefore, as touchscreen IVIs became more popular in automotive industry, researchers investigated in-vehicle touch-based interaction (e.g., Kern & Schmidt, 2009) as there was an increasing concern regarding the distractions and safety issues of the displays. These concerns increased at the same time as manufacturers started to eliminate the physical controls and the driver's entire interactions became limited to touch-based interaction (Ng et al. 2017; Tsimhoni and Green, 2001).

Some studies, such as one by Pitts et al. (2009), introduced touch feedback on screens as a solution for the mentioned problem but there are still some issues with touch screens regarding overall task completion time since simple functions might be available deep down in GUI layers (Ng et al. 2017). Moreover, the muscle/spatial memory is no longer usable in dynamic touchscreens interfaces (Burnett & Porter, 2001).

In addition, Tesla cars (as a typical example of the transition from dedicated physical buttons to touch screens) faced objections. For instance, Budi (2019) declared:

"Tesla is an example of a weak interaction design which did not follow most of the conventional and well-known HMI principles of usability and human psychology and one of the reasons can be lack of dedicated physical controls."

Regarding usability, Wittmann et al. (2006) investigated the consequence of display positions on the driver's behaviour and found out that the placement of the display plays an important role in user's interaction with the system. In addition, some other researchers showed the importance of accessibility on IVI positioning. This research also showed that the problem with using only one display as an interaction device, is that it needs to be positioned low to be reachable and easy to access but this position is in conflict with the optimal display position from a visual perspective (i.e. to have the least eye travelling from the road to the interface), which should be high at the centre stack (Wittmann et al., 2006).

There is a substantial number of references that emphasizes the importance of 'haptics' but overall it seems as though haptics have been 'under-researched' as having a role to play as a customer satisfaction element which results in an overall 'enjoyable hedonic experience' (Burnett & Porter, 2001). It is also declared by Forbes magazine that *"Haptic can be among the ten things that will change the way we live"* (Ely, 2006). In addition, Pitts et al. (2009) concluded that haptic feedback makes touch displays more easy and 'pleasurable' to use. Moreover, Rydström et al. (2017) proposed that use of tactile controllers gives users a feeling of being 'in control'. Karlsson et al. (2019) also mentioned touch/haptics as one of the easiest ways to complete an operation. Furthermore, Prynne (1995) gave insight on the use of haptics in automotive interiors.

"*It is apparent that many car dashboards are designed more for the eye than the hand". and furthermore "The sense of touch can only be used when a person has established direct physical contact with an interface, there is a natural emotional 'closeness' to the interaction*".

Furthermore, regarding the importance of haptics and any hedonic effects, Sallnas (2000) declared that the addition of haptics to an interaction experience when people are collaborating in an operation, brings the feeling of 'togetherness' and improve 'user acceptability'.

Another topic that is discussed a lot among researchers is multi-modality and the effects of experience on the choice of modality in IVIs. For instance, regarding the user's preferences on choice of modalities, Karlsson et al. (2019) found an interdependency between preferred modality and different, so-called 'basic operations' in multimodal interaction. A study by Rydström et al. (2012) suggested that unimodal interaction and the freedom of choice in selecting modality in a 'redundant multimodal system' are favoured interaction modes and perceived as 'easier interaction'. The studies by Rydström et al. (2012) and Karlsson et al. (2019) suggested further that there is no one perfect input device (or modality) that covers an entire task, and which is always the best choice. Certain interaction devices need to be considered for certain kinds of tasks. Some examples can be touch to increase/decrease (something, e.g. sound), speech to search (for something, e.g. a tune), gesture to navigate (e.g. between screens) etc. Also, regarding the effectiveness of multimodal interaction, the study by Rydström et al. (2012) proved that to 'skip steps' and getting directly to the desired function is an advantage for the users. For example, speech is a modality eligible for direct task accomplishment.

Yet another subject that is important in HMI research is 'context'. A driving compared to a non-driving context affects the user's preferred choice of modality. In the context of driving as a primary task, the preferred modality is proposed to be the one that has the least effect on driving the car safely, e.g. speech (Ekman & Johansson, 2017).

While driving, the driver needs to have access to several sources of information and data simultaneously. Many researchers suggest different guidelines and frameworks to design an IVI for a better information and controls distribution. For instance, Budiu (2019) emphasizes that, in a car interface, the most used functions should be designed in a way that made them easy to reach.

Rydström et al. (2012) studied the effects of interacting with touch screens versus rotary knob and concluded that a touch screen interface is more efficient for 'alphanumeric' input functions while a rotary knob performs better for continuous adjustments and scrolling a list. In addition, Rogers et al. (2005) declared that "*direct devices are generally best for discrete, pointing and ballistic tasks whereas indirect devices are better for precision tasks or repetitive tasks*."

Much research has investigated different aspects of usability of current IVI systems but few the pleasurably of the interaction. Nevertheless, relying on user experience is perceived as a key success factor for new products (Veryzer & Borja de Mozota, 2005). Many guidelines exist for the design of the controls and interfaces but most of them are out of date and/or not specifically applicable to a driving context with all the limitations that follow (Burnett & Porter, 2001). Even if they do apply, they are all about usability and effectiveness, and almost none exists which also involves the emotional aspect of the IVIs.

2.4 Summary and Implications

The overall aim of the thesis project was to investigate user experience of different interfaces based on pleasure and overall satisfaction. Based on the reviewed literature, functionality and usability were judged to play the main roles for user experience and satisfaction of IVIs. This was due to the close connection between these factors and (traffic) safety. Jordan's hierarchical model was therefore considered the basis for the further work.

Taking Desmet's model into consideration, in this study the product (stimulus) is considered to be the HMI of the IVI. The assumption was that if the design of a car interface matches the user's concerns (e.g. for safety, learnability, ease of use etc.) it is appraised as beneficial and if there is a mismatch with the concerns, it is appraised as "harmful". The types of concerns that can be considered in this study are driver's needs for safety and reliability, motives to be entertained, goals to achieve by using car functions, and values which can be social trends or personal preferences. However, safety declares as a more general concern and is not considered context dependent. Moreover, the passengers also need to be considered as users of the IVI.

From Norman's model, it can be concluded that users' attachment to products creates a more sustainable positive experience of use. So, the attachment or 'reflective' concept, which was described by Norman, can be used in this study to create a more long-lasting, positive experience for the users.

Natural interaction is a complex and multidisciplinary phenomenon and implementation of natural interaction requires a deep understanding of the user's needs and preferences. This highlights the importance of a seamless and accurate integration of modalities.

Many articles discuss the importance of an effective and efficient integration of different modalities in an HMI. In addition, several articles introduce different pros and cons of each type of interface and modality. As a summary, the proposed gains and losses in the transition from physical to digital interfaces are presented in Table 1.

Much research declared that there are advantages and disadvantages with different types of interfaces. In addition, the transition of interface designs from physical to digital interfaces has been studied by different researchers, primarily by taking usability and safety into consideration. The thesis project intended to fill the knowledge gap regarding the advantages and disadvantages of this transition from the user's (experience) point of view with the help of theoretical user experience models.

A number of questions had to be asked; Do users experience the argued pros and cons of digital vs physical interfaces? What do they consider as the pros? What do they consider as the cons? Does it matter to them? In planning the initial user study, it was assumed that users could discuss these questions without being exposed to a tangible representation of different types of interfaces and rely on his/her anticipated (based on earlier experiences) and episodic experience (based on earlier experiences). However, to go deep into the users' user experience, it is necessary to run a study that targets users' momentary experience.

Table 1. The proposed gains and losses in the transition from physical to digital interfaces based on Literature Review.

	What is gained with a digital interface?	What is lost?	Anticipated consequences
1	More information can be presented	Driver needs to process more information while driving	Driver distraction (negative)
2	Bigger output display	Elimination of physical controls due to the lack of space	Less clutter for better aesthetics (positive) Loss of haptic controls (negative)
3	Integrated touchscreen (touch screen acts as both the control panel and display)	Multimodality (touch is the only way of communication)	Increase in eyes-of-road time (negative)
4	Minimal and clean surface	Less differentiation in tactile surfaces and buttons	Less clutter for better aesthetics (positive) Loss of tactile/haptic feedback (negative)
5	Flexibility (dynamic interface)	Muscle/spatial memory is no longer usable since the location of the functions is dynamic	Increase in eyes-off-road due to not being able to use spatial memory (negative)
6	Novelty	Familiarity with conventional systems	More difficult/longer time to learn how to use (negative)
7	Direct selecting/targeting	Lack of feeling of control due to less accuracy in touch screens in comparison with physical controls	Less control over the system (negative)

3 Explorative Study

3.1 General approach

As was concluded in the Literature Review, there is limited research on users' emotional response to and experience of digital versus physical interfaces. Therefore, the user study intended to explore the explicit experience of users and the pros and cons of physical and digital interfaces, as perceived by user, by conducting user interviews. This Explorative Study made use of a combination of models and tools to explore the experience of the users.

The main challenge of the study was to find the appropriate methodology to study user experience and explore users' actual feelings towards the interfaces, i.e. to find the method(s) needed to enable an elicitation of the user experience. According to Mahut et al. (2017): *"Research on user experience and interaction leads to a deeper consideration of the subjective perception rather than objective dimensions."*

It was furthermore essential to use different theories in order to be able to analyse the data and evaluate the results from different perspectives. Several theories and models exist regarding user experience and hence what and how to evaluate. At the same time, there is no unified model that is relevant to all studies and evaluations of user experience. All frameworks aim to describe the hedonic quality of products (Hassenzahl, 2005). For example, in Jordan's hierarchical user needs model, 'pleasure with products' at the top of the hierarchy is defined as ''*the emotional, hedonic, and practical benefits associated with products''* (Jordan, 2000). For the analysis of the data from the Explorative Study, Jordan's (2000) 'hierarchical user's need model' and Desmet's (2003) 'basic model of product emotion' and 'classification of product emotions', were considered.

One single *data collection method* could not answer everything, why a combination of models and tools was selected (Table 2). Interviews (Wakasa, 2019) including simple rating questions were used for collecting the data. To analyse data and to draw conclusions, it was important to have the conversations recorded and then transcribed.

User interviews as the main empirical method were chosen due to the limitation of the study. Although user interviews as a method is not enough to explore observable, tacit user experiences, interviews allow investigation of a user's thoughts, preferences and behaviours. It is possible that it could have been more effective to explore the actual user experience in an experimental user study including a setup of different types of interfaces, but the downside is that the users might then make judgements only based on the represented setup (i.e. interfaces).

Table 2. Different topics, corresponding methods and tools, and theoretical models

Section of the Explorative Study	Methods and Tools	Models
Identifying pros and cons	Interview data, thematic analysis	Desmet's model (emotions)
Understand hierarchy of the importance of pros and cons	Categorisation of usability aspects	Jordan's product pleasure model
Validation of pros and cons according to Literature Review	Rating scales	
Creation of user types	Impact map	

Also for the *analysis* different methods and models were used. A thematic content analysis (Rucker, 2016) was performed on the interview data. In addition, a classification of product emotions also known as multi-layered model (Desmet, 2003), the hierarchical user needs model (Jordan, 2000) and impact map (based on a model developed by Volvo cars AB, Domingues, 2017) were used in different stages of the analyses.[3]

The main reason that three different models were used in the analysis, was how they contributed to the topic. In this study, there were different challenges to answering the research questions. More specifically, the study broke down into three main challenges: 1) Specify the pros and cons of physical and digital UI respectively, 2) Understand the hierarchy of pros and cons, and 3) Present the priority of pros and cons. The categorisation of usability aspects supported the design phase, and the multi-layered model of product emotion helped specify the significant emotions related to each user's concerns. It was important to explore the different aspects of emotions to find the pros and cons. In addition, the hierarchical user needs model enabled understanding the pleasure behind each theme (e.g. the repetitive pattern).

In order to extract the best possible data from the interviews, a combination of Jordan's hierarchical model and Desmet's product emotion model was considered as the main models. The choice of model was based on the requirements posed by each phase of the project. Desmet's model helped towards understanding the user's emotions and identifying pros and cons. However, it does not provide any input regarding the hierarchy of needs and preferences. In addition, the types of actionable data which are desired to create the design guideline cannot be extracted from this model. Thus, Jordan's model was used to create a hierarchical set of user needs and behaviours. However, Jordan's model does not clarify different users' behaviours and attitudes so, this aspect was addressed in the impact map (Domingues, 2017).

[3] The evaluation of the concept was conducted and analysed by the same approach as the Explorative Study. The evaluative study is described in section 5.

3.2 Purpose

The purpose of the study was to identify and discuss the pros and cons from a user experience point of view and to explore the associated emotional reactions and responses.

3.3 Method

Online interview sessions were designed in order to understand the way that users experience the interaction with physical and digital IVI systems, respectively. The interview consisted of different questions considering the pros and cons of each type of interface. The respondents were exposed to sample images of each type of interface and were asked to explain and argue their responses based on the images (Figure 18; Figure 19).[4]

3.3.1 Participants

The interviews were conducted with twelve participants, via Skype or Zoom. Among the respondents were five woman and seven men, aged between 25 and 65 years. The invitations with a screener form (see Appendix B), were sent to a sample which was randomly drawn from a list of car owners, mostly in Sweden. The sample group fulfilled the following criteria: 1) in possession of a valid driving licence for at least five years, 2) minimum 5000 km/year driving experience, 3) not being a professional/commercial drive, 4) owning a car equipped with the new type of interfaces and having experience with physical interfaces, and 5) not being an expert in the field of design and UX. The screener form was sent to the participants beforehand, and it was stated that the personal information would be handled according to the GDPR guidelines (see Appendix C). Some additional information was asked from the participants to be used for the further analysis. This information identified their current car model, manufacturing year and year of obtaining their driving licence.

In order to avoid any possible disclosure of information and reveal any user's demographics, the participants were coded into groups based on their age group (the range 25-65 divided into 4 groups), gender (M/F) and then a specific number for each user. An example of user codes is as follows: 3M-09.

3.3.2 Data collection

The material and facilities included; 1) a videocall platform (Zoom or Skype) with the possibility of sharing the screens and 2) a PowerPoint presentation containing visual representations (mainly images) of each type of interface and interview questions (see Appendix D). The participants were asked to arrange the videocall with a laptop to ensure good quality of the presented images and texts.

[4] Although It is considered feasible that the users can discuss interview questions without being exposed to any prototype interface and rely on their anticipated and episodic experience, it is recommended to continue the study in the future in a real-world context to also understand the users' momentary experience.

The order of the interview questions was randomized to prevent any possible order biases. In addition, in part 2 (see below), the statements were randomized for physical and digital interface-related questions.

The interview aimed to collect data to answer the research questions by going deep into the user's experience and thoughts regarding different types of interfaces. Besides, the data was to be used as a basis for the design phase. Each interview session lasted overall thirty minutes. The first five minutes were spent on communicating the study goals and agreeing on GDPR, the following three minutes on the procedure and definition of the terms, e.g. infotainment, digital interface, physical interface etc. and answering the respondents' possible questions. The remaining time was spent on the interaction between the respondents and interviewer considering the presented content.

In order to make the interview output clearer for the later analysis, the interview questions were separated into three parts. The first part intended to provide an understanding of the respondents' (i.e. users') thoughts and experiences regarding the interfaces. The second part consisted of rating scales and was probing the extent to which the respondents agreed/disagreed with the pros and cons that were argued in the Literature Review (Table 1). The third part concerned the transition of interfaces from physical to digital and the way that users had experienced this. The three parts of the interview are elaborated on with examples below.

Part 1: The participants were asked to freely discuss and elaborate on the pros and cons of each type of IVIs (physical and digital), based on their episodic experience. At the same time, they could see images of different types of interfaces. The context of use was also discussed. The format of the two questions posed in this section is presented in Figure 17 and Figure 18.

Figure 17. Interview question section 1, Digital interface

Figure 18. Interview question section 1, Physical interface

Part 2: In the second part of the interviews, both quantitative and qualitative data was collected with the intention to validate the respective pros and cons that were argued in the Literature Review. Therefore, the participants were asked to consider a number of Likert statement and rate the degree to which they agreed or disagreed with each statement for each type of interface (Figure 19). The respective statements that the user was exposed to (see example in Table 3) were extracted from Table 1 which is a summary of the Literature Review. Other relevant questions were also posed.

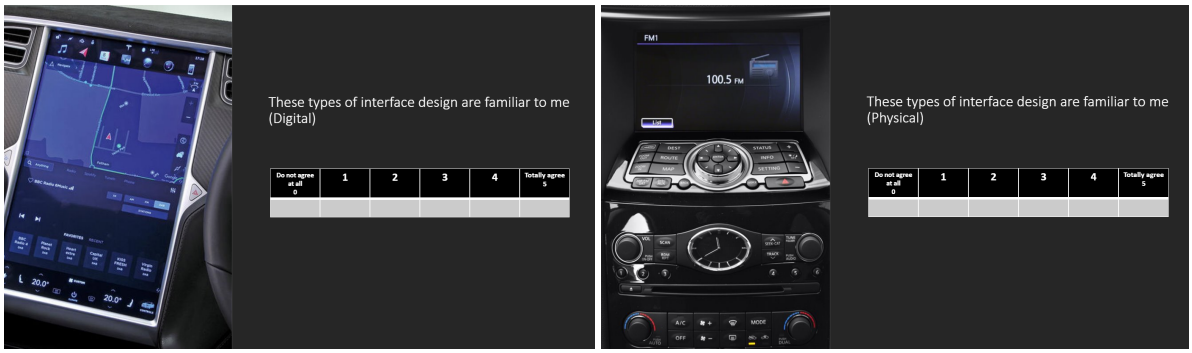

Figure 19. Presentation format of interview questions of section 2

The statements were formulated as follows:

- "This type of interface design is familiar to me" (Digital/Physical).
- "This type of interface can draw attention from the road when driving" (Digital/Physical).
- "Using this type of interface is most often a positive sensory experience" (Digital/Physical).
- "I can use this interface while driving without looking at it" (Digital/Physical).
- "I feel more in-control while using the type of interface" (Digital/Physical).

The rating scales ranged from 1-5 where "1" meant “Do not agree at all” and "5" meant "Totally agree" with the stated argument.

Table 3. Example 1M-01: "These types of interface design are familiar to me" (Including an image of the digital interface)

	Do not agree at all (1)	2	3	4	Totally agree (5)
These types of interface design are familiar to me					

Each of these statements were followed up by the following questions:

- How does (familiarity) affect your experience of using digital/physical interfaces?
- In what way does a digital/physical UI contribute to your experience in term of familiarity?

Part 3: In part 3, the transition of Volvo Cars’ IVI over twenty years was presented to the participants. The question was how they experienced this transition and how positive or negative they appraised it. Additionally, in this section, the respondents were usually discussing other issues and inputs that were considered relevant to this topic.

The interview session ended with asking the participants for additional comments and thoughts and, at the very end, appreciating his/her for participation in the study. The whole interview was audio recorded and transcribed for further analysis.

3.3.3 Data analysis

The collected data consisted of both qualitative and quantitative data. Although the qualitative data was the focus and the basis of the user experience study, the quantitative data was collected to validate the respondent’s answers in a numerical form. In the following, the data analysis of each type of data are described.

3.3.4 Qualitative data analysis

The qualitative data, which focused on user experience, was extracted from the interviews, more specifically parts one and three of the interviews. Besides, the interviewer's (the author's) understanding of, and side notes taken during each interview were considered as subjective data resources.

After the interview sessions, all twelve interviews were transcribed, and the transcripts analysed using a thematic content analysis method (cf. Rucker, 2016). The procedure is as follows (see also Appendix E):

1. **Getting familiar with the data** (reading and re-reading): The transcript of each interview was reviewed many times.

2. **Coding (labelling) the whole text**: The example below (case: 3M-09) represents the coding of a transcribed interview: the green label or highlight represents cons, and the purple label or highlight represents pros of each type of interface.

   "I think with digital I may not be able to see everything on the screen if the sun or light reflects on the screen. Second, which worry me the most is how to operate while driving I am really scared when I have my eyes off the road and last, it scares me if I make a damage the screen and how much would be the cost to replace. I am not sure how much is the cost to damage the physical but usually they do not break easily.

   But digital is very impressive, looks modern and technologically advanced. Also, it gives the option to customize the menu. like how many smart phones are the same? You see some differences in everything. That gives you some chances to change. (Customization)

   Physical: of course, it is more reliable. Easy to use without looking at them. Even in Porsche there are lots of buttons there, but it is enough to remember the location and this advantage cannot be achieved with the screen."

3. **Searching for broader themes and patterns of meaning**: In order to unify the user's experiences, each item from each interview was listed in a table according to different themes. For the interviewee case (3M-09), the example below (Table 4) shows the broader (or generalized) themes.
4. **Reviewing themes to make sure they fit the data:** In Table 4, the left side of the table lists the desired data for this study and the right side of the table is one interviewee's input, organized into patterns (according to theme).

6**. Identify broader themes patterns (categories), defining, and naming themes**: In this step, the themes were clustered into usability categories in order to make it more meaningful and general. It is apparent that many of the themes can be placed in two or several general categories but in this table, the one category considered the closest in character was chosen. This step was directly connected to analysis part.

The themes were clustered into five usability categories, which were used as a basis for comparing the data with the theoretical models, i.e. the multi-layered model of product emotions (Desmet, 2003) and the product pleasure model (Jordan, 2000) (Table 4).

Table 4. Interviewee case (3M-09). Broader themes with pattern of meaning. This table is specifically for one participant.

Digital Pros	Bigger screen size More options and functionalities Similarity with other devices Navigation friendly More information Access to internet (google assist) Aesthetically pleasant Customizable Access to phone apps Learnability Cleanability
Digital Cons	(Lead to) Eyes off the road Visual demanding (Lack of) robustness Light reflections on screen
Physical Pros	Safety Feeling of control Ease of use Haptic feedback Quick locating and recognition Specific tasks (climate control with physical) Reliability
Physical Cons	Crowding of buttons Confusion Cleaning
Context	When not driving, the digital in preferred
Additional comments	Combination of both is preferred. Voice commands are desirable. Using the phone for most of the functions is preferred. Prefer to have basic functions on the steering wheel

3.3.5 Linking qualitative data and theoretical models

One of the user experience models considered useful for analysis was the model of **product pleasures** (Jordan, 2000). This model was used in a second analysis phase for categorising the participants' statements. This model explores the pleasures behind a product or elements of a product and was useful to identify the type of pleasure (i.e. physiological, psychological, sociological and ideological) that users associated with (interacting) with interfaces.

The second model was the **multi-layered model of product emotions** (Desmet, 2003). This model was the main model used to explore the pros and cons of the respective types of interfaces from the users' point of view. Moreover, it specifies the user's emotions as a result of the appraisal of the

stimulus (i.e. interface) against certain concerns (goals, attitudes and standards and novelty). The user's emotions as a result of a particular appraisal are summarized in Appendix F and the stimulus is considered (the pros and cons of) the digital and physical interfaces. The 'intersection' between the user's concern and the stimulus results in a specific appraisal. Figure 20 is an example of this. The remaining data is found in Appendix F. Concern, appraisal and emotion correspond to the temporality of experience elements (i.e. anticipated, momentary and episodic experience). However, in this study the users were not exposed to functioning prototypes of the interfaces over time, so an analysis based on the momentary experience of the users was not possible.

During the interviews, the respondents usually talked about a concern (e.g. *"I want to use the interface with gloves")* and then connected it to their experience or their anticipated experience with each type of interface. This pattern of conversation enabled using the basic model of product emotions for the analysis. However, in some case, one statement that contained the concern and the emotional response aimed at different aspect of emotion model. As an example, a minimal and clean look can be also interpreted as a social trend and this fact can change the emotional response. The other challenge in analysing the subjective data according to the model of product emotion was the similarity of statements. As an example, many users discussed the familiarity of interfaces during the interview, but since the emotions were not clearly recognizable, it was challenging to judge their actual concern related to familiarity. In this case, familiarity can be interpreted as a description an interface, which has been around for a long time, or an interface, which is similar to the ones in other available devices. The two statements can be interpreted in different ways, and thus also the appraisal and resulting emotions.

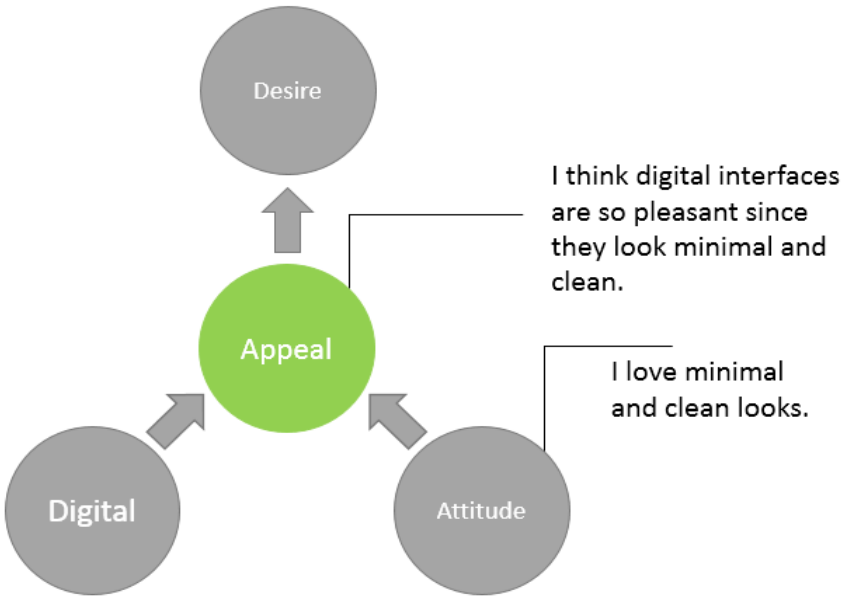

Figure 20. Basic model of product emotions (case from participant 3M-07)

3.3.6 Quantitative data analysis

The respondents' level of agreement with the Likert statements was analysed. First each individual's agreement with each statement considering a physical or a digital interface were obtained. Average values for each statement were then calculated.

3.4 Findings

Since the data was analysed using different models and tools, it is important to present them in a unified manner to be used for a joint result. It was argued in the literature that the user experience models can be compared in terms of their elements, however, a comparison might not be meaningful and even not possible. Nevertheless, in order to unify the results, for this study it is important to have a common understanding of usability, pleasure, and emotions.

3.4.1 Quantitative results

Table 5 shows the individual participants' responses to each Likert statement. The statements were targeting different aspects which were claimed in the Literature Review as the pros and cons of the physical and digital interfaces. The participants were asked to rate their agreement or disagreement with the statements. Each statement was asked separately for physical and digital interfaces.

- Familiarity: "These types of interface design are familiar to me" (Digital/Physical).
- Distraction: "This type of interface can draw attention from the road when driving" (Digital/Physical).
- Touch experience: "Using this type of interface is most often a positive sensory experience" (Digital/Physical).
- Using without looking: "I can use this interface while driving without looking at it" (Digital/Physical).
- Perceived control: "I feel more in-control while using the type of interface" (Digital/Physical).

Table 5. Quantitative data according to gender and age groups.
Table Guide: D=Digital. P=Physical. Fml: Familiarity. Dst: distraction. Tch: Touch feel. Lk: using without looking. Ctrl: Perceived control. Trans: Transition from physical to digital.

Age	Gender	User Code	Fml /D	Fml/ P	Dst/ D	Dst/ P	Tch /D	Tch /P	Lk /D	Lk/ P	Ctr l/D	Ctrl/ P
25-35	M	1M01	2	5	4	1	1	4	3	2	2	4
	F	1F02	5	4	4	3	2	4	1	3	3	4
	M	1M03	3	5	4	2	3	3	1	4	4	2
	F	1F04	2	3	4	3	1	3	4	2	2	4
36-45	M	2M05	5	1	3	1	5	2	1	4	5	2
	F	2F06	3	4	5	1	1	4	4	2	2	4
	M	2M07	4	5	4	2	4	3	3	5	2	4
	F	2M08	2	5	3	1	2	4	1	5	1	5
46-55	M	3M09	3	4	4	3	4	3	1	4	4	2
	M	3M10	3	5	4	3	2	4	1	3	3	3
56-65	M	4M11	3	4	4	3	5	2	4	2	5	3
	F	4F12	5	1	5	1	5	1	5	1	5	1
Average			3.3	3.8	4	2	2.9	3	2.4	3.2	3.1	3.1

The first statement, which was considering the "familiarity" aspect, was mentioned in several articles. On average, the participants mentioned that they were more familiar with physical interfaces than digital interfaces which proved the points argued at the Literature Review. However, the average response for familiarity with the digital interface was 3.3 (of 5) while the same number was 3.8 for physical interfaces. This small difference can have various reasons. For example, regarding familiarity some people might consider digital interfaces more familiar since it is similar to their smartphones.

It was argued in the literature that digital interfaces are more distracting than physical interfaces. The averages responses on the "distraction" scale (Dst/P and Dst/D) shows that the majority of the participants perceived digital interfaces as more distracting than physical interfaces. The respondents were also asked for their agreement with statements regarding the "touch feel" (Tch) and "using without looking" (Lk). Sensation of touch (i.e. haptic aspect) can include both the sensory experience and the muscle memory. Interaction with a UI without looking involves the use of muscle memory which results in time with eyes-off-the-road. The majority of the participants mentioned that physical interfaces are both pleasurable and usable.

Perceived control (Ctrl) was another aspect that was discussed in the Literature Review. It was mentioned in some articles that users feel more in-control while using physical interfaces. However, in this study, the average result re perceived control was similar for both types of interfaces.

3.4.2 Qualitative results

3.4.3 Themes and usability categories

Based on the content analysis, Table 6 presents the identified themes, the usability categories to which they were considered to belong, and the definitions of the usability categories.

Table 6. Themes, usability categories, and their definitions

Themes	Usability Category	Definition
Familiarity **Robustness** **Perceived safety** **Cyber security** **Feel of being in control**	Trust	Relates to the level that the users trust the system (IVI) or the level of reliability of the system. Usually there is more trust in the analogue (isolated) systems and less trust in digital (cyber) systems. Familiar systems are perceived as more reliable.
Minimalism **Trendiness** **Clean look** **Novelty in GUI design and look**	Aesthetics	Relates to the look, how trendy, and how pleasant the appearance of the system is perceived to be. It can be the physical design of e.g., buttons, or the design of the graphical user interface.
Eyes-off-road **Quick locating and recognition** **Learnability** **Accessibility** **Visibility vs reachability** **Ease of use** **Haptic feedback** **Dedication of controls** **Cleanability** **Targeting accuracy** **Updating**	Performance	Performance is associated with the functionality and usability when driving. It relates to the performance of the functions based on user's expectation. This category is also relevant to psycho-pleasure (cf. Jordan 2000), which is associated with usability, the pleasure and effectiveness of use.
Haptic/tactile feel **Crowdedness of interface** **Unorganized sections** **Visual complexity**	Sensory experience	Relates to every HMI element that involves any of the human senses. Regarding the delimitations of this study, haptic and visual are the highlights. Sensory experience is associated with physio-pleasure (Jordan 2000).
Big screen **Similarity to other devices** **Access to phone apps and net** **Customization of features** **Flexibility** **Day/night mode** **Environmental aspects**	Convenience and Added values	In this category, some extra features are covered that are added to the IVIs to make it more enjoyable and entertaining for the users. Most of the users did not prioritize these features above those of safety and usability. However, users prefer to have the features in their cars since nowadays they play an important role in users' satisfaction.

3.4.4 Four-fielder matrix

The themes, identified using a thematic content analysis, were placed in a four-fielder matrix. The horizontal axis represents the physical and digital interfaces respectively and the vertical axis contains the pros and cons of the respective interfaces (Figure 21). For instance, haptic feedback is assessed to be better represented in physical interface and identified as one of the most significant advantages of physical interfaces.

The matrix shows the priority of themes and patterns based on the usability categories. The prioritization is concluded from iterating between users' inputs and the data extracted from the literature and standards such as NHTSA (2016).

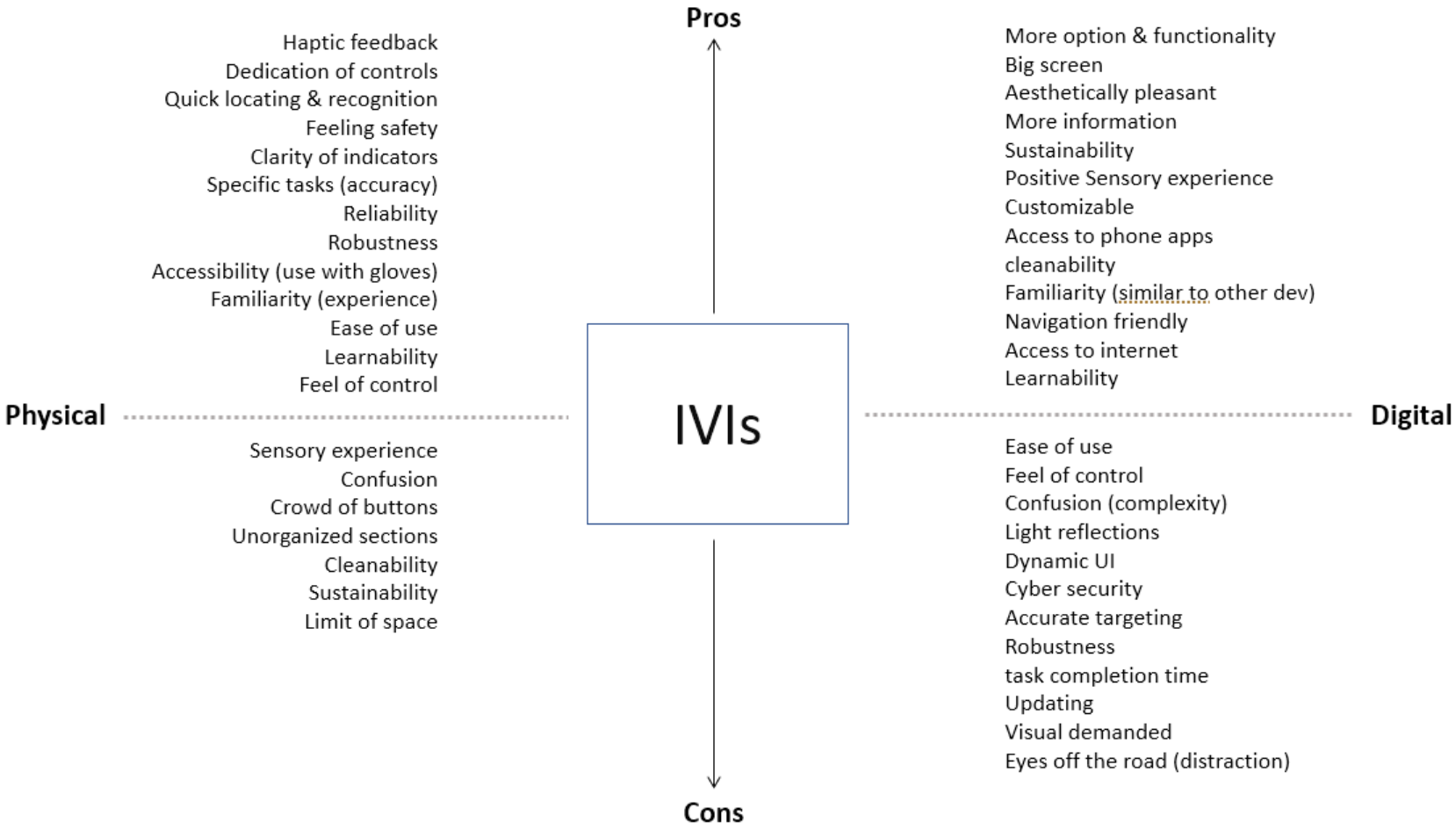

Figure 21.Four-fielder Matrix of themes' pros and cons regarding each type of interface

3.4.5 Linking empirical data and theoretical models

Table 6 describes the elements that the participants identified as pros and cons of physical and digital interfaces from a usability, a pleasure, and an emotional point of view. The table shows the integrated analyses based on Jordan's product pleasure model and Desmet's emotional design model.

Table 7 shows the user inputs (i.e. concerns) categorised according to Jordan's and Desmet's models. Several findings could be extracted from Table 7. Firstly, that there is a match between the identified elements and pleasures and emotions respectively. However, there are some items, e.g. personalization and cyber security, which both can be linked to ideo-pleasure but also correlate with concerns such as standards as well as novelty. The relation between performance, psycho-pleasure and goal is obvious. In addition, aesthetic and sensory experiences, which are parts of attitude (like/dislike), fit quite well with physio-pleasure.

Table 7. Combination of Desmet's and Jordan's models in the analysis stage

Pleasures	Usability category	Theme (user concerns towards digital and physical interfaces)	Emotional response
Psycho-Pleasure	Performance	Eyes-off-road (Digital cons)	Satisfaction/Dissatisfaction (Goal)
		Quick locating and recognition of functions (Physical pros)	
		Learnability of the new system (Digital cons)	
		Accessibility to different function quickly (physical pros)	
		Ease of use (Different opinions)	
		Dedicated controls for specific functions (Physical pros)	
		Cleanability (Physical cons)	
		Targeting accuracy (Digital cons)	
		Updating (Digital cons)	
		Haptic feedback (Digital cons)	
	Convenience	Access phone applications (Physical cons)	
		Flexibility of the interface (Physical cons)	
		Big screen (Digital pros)	
		Day/Night mode (Digital pros)	
	Trust	Familiarity with or having experience of the interface (Different opinions)	
		Robustness of the product (Physical pros)	
		Perceived safety (Physical pros)	
		Feeling of being in control or perceived control (Physical pros)	
		Cyber security (Digital cons)	

Physio-Pleasure	**Sensory experience**	**Haptic/tactile feedback(Physical pros)**	**Like/dislike (Attitude)**
		Crowdedness of interface (Physical cons)	
		Unorganized sections (Digital cons)	
		Visual complexity (Physical cons)	
	Aesthetics	Design and look (Digital pros)	
		Sensory pleasing interface (Digital pros)	
Socio-Pleasure	Aesthetics	Compliance with trends as minimalism, digitalization etc. (Digital pros)	Admiration/Contempt (Standards)
	Convenience	Connectivity to Internet (Digital pros)	
Ideo-Pleasure	Convenience	Customization of features or personalization (Digital pros)	Pleasant/ unpleasant surprise (Novelty)
		Environmental consideration or sustainability (Digital pros)	Admiration/Contempt (Standards)

However, in order to make these elements more meaningful, each theme/concern and the connection between categories need to be explained. In the following, each category and the relationship between the topics in each of the two models are explained. In the synthesis of findings, the connection between different aspects (i.e. categories, pleasures and emotions) is discussed.

3.4.6 Psycho-pleasure/ Goal/ Performance and trust

'Performance' and' trust', psycho-pleasure (derived from Jordan's product pleasure model) and the concept of goals (derived from Desmet's model) contribute to functionality and usability from the user's perspective. These aspects were related based on the results of this study.

The most repeated comment during the interviews concerned 'eyes-off-road' while using any type of interfaces: *"The top priority for me is to use the infotainment without looking at it"*. It is apparent that the required level of visual attention varies for different types of interfaces hence, the more an interface requires visual attention, the less pleasurable/ usable/ satisfactory its appraisal. This appraisal is only legitimate in a driving context. For non-driving contexts, almost all the interviewees agreed that visual attention is not an important factor: *"If you are not driving you don't need your eyes, so it doesn't matter how visually demanding the interface is"*.

There were several performance items, which users could relate to when it comes to physical and digital interfaces. Referring to the quantitative data, performance and usability were considered as the most critical aspects of an IVI. For instance, participants mentioned that they can quickly locate and recognize a function in a physical interface; *"… when you get used to it (physical interface), it can be very quick. Everything has its place, if you drive a car for more than 20000 km/y then you know where everything is."* The theme 'being able to quickly locate and recognize' was also related to sensory experience and muscle memory and played an important role in the perceived safety and performance of the system.

There was consensus among the participants that physical interfaces were 'safer'. This perceived safety was the result of being able to use the interface without looking at it which meant less distraction. However, the perceived safety could also be related to cyber security and other safety factors (e.g. a big red button perceived as a safety button). Furthermore, safety builds trust, which brings satisfaction. Besides, since different users have different definitions of safety and trust, perceived safety can be connected to ideo-pleasure. However, safety is the key in regards psycho-pleasure since it is the appraisal basis for all the other aspects. In fact, perceived safety could be considered the origin of trust in the system.

As did safety, familiarity played an important role for perceived reliability and for creating trust in the system. Trust explains the level to which users can rely on the stimulus. Therefore, there was a connection between trust and familiarity. Users perceived a higher level of trust with more familiar systems; however, familiarity for the users can be explained in two different ways based on the following examples from the interviews: "*I got used to physical interfaces, I've been using it for a long time, and I feel at home with it, it is literally more reliable to me*". and "*Digital screens look like my mobile phone; I feel I can trust it the same level as I trust my mobile phone*".

Physical interfaces can be trusted because they have been around for a long time, and this can be related to temporality of experience. On the other hand, digital interfaces can be trusted because they look like other daily used devices. Both statements seem reasonable, and this pattern was declared by most of the participants. Therefore, we can conclude that familiarity is an important factor in trust and

psycho-pleasure. Additionally, considering the different types of interfaces, users' trust depends on which interface they are more familiar with. Nevertheless, familiarity is not the only factor that builds trust and reliability.

Robustness or the durability of the screen is also a concern, which was mentioned by the participants several times: "*I can say that the digital interface looks more fragile. This means that they can easily break, what if they break while driving? Do they work in cold and hot climates? I prefer not to take the risk of using them… if they break, I suppose I have to change the whole rig, wouldn't it be expensive? …"*

The durability of an interface is closely related with the trust that it builds. In fact, a robust system creates trust, and it is appraised as a satisfying product. In this regard, digital interfaces were considered less durable. This can be related to users' association between glass (being a brittle material) and breaking. A few respondents said that they had experience with breaking a part of a physical interface, but they also mentioned that that it was easily replaceable.

Learnability and ease of use are two important factors in psycho-pleasure. They can be associated with familiarity since some users believed that they could learn to use a physical interface better and faster since the controls are dedicated to respective functions. On the other hand, some users believed that they could learn and use the digital interface in a more efficient way since they already know how to use their mobile phones. Either way, familiarity brings pleasure and satisfaction to users.

Assessments of learnability and ease of use might be related to the user's age. However, since age was not the focus of this study, we cannot with certainly declare a relationship between the age and learnability. One of the participants commented for example: *"I recently bought a Tesla, and I felt illiterate, as an old man, it took a while to learn it but still it is hard to use for me."* These items appear closely related to familiarity, in that the more familiar the interface is, the easier it can be learned and use. It is obvious that an easy-to-use system is both satisfying and enjoyable for the users.

Some respondents brought up the physical design of the UI elements: "*I think if I increase the music volume with a rotary knob, it is more accurate. Even I can do it without looking at it because I feel what is happening under my fingers…".* This example, which re-occurred several times during the interviews, emphasizes 'haptic feedback' as one of the benefits of physical interfaces. Also, the following statement indicates the importance of targeting accuracy which contributes to physio-pleasure: "*I think if the car is moving, I cannot press the right function in a digital interface*".

Dedication of controls is another challenging theme. Most users were more satisfied with one button per function but at the same time, a complex and crowded interface is not desirable. As an alternative, many users mentioned the benefits of 'multifunctional control knob' (as in Audi and BMW) in addition to the basic and most commonly used functions on their steering wheel.

Finally, experiencing being in control (or perceived control) conveys pleasure and satisfaction. This was claimed many times during the interviews, albeit respondents had many different approaches to the concept 'perceived control'. It was believed that being in control of a system depends on the task that is performed as well as the context of use as claimed by one respondent; *"I feel more in control with (a) physical (interface) when turning the volume down with a rotary knob, but I feel more in control when using the map on a digital interface… this also change when I am driving and not driving".* Also, perceived control can be related to physio-pleasure from a sensory perspective. For instance, a more 'grippy' button conveys better control.

There are some themes, which were not common concerns, but which some users had experienced, and which were mentioned also in the literature. One example involves reachability: *"Sometimes I feel that in the digital interface, you need to raise your hand a lot to reach the screen, but physical controls are usually installed low enough to reach…".* This statement contributes to the fact that digital interfaces need to be installed at a level high enough to be visible within the user's line of sight. Physical interfaces can be installed at lower levels in the dashboard and even in the middle consul. It is apparent from the interview data that users preferred the output device (screen) close to their eyes but the input device (controls) close to their hands.

There were also some concerns regarding accessibility in special circumstances. For example, in the following statement, the respondent claims that climate controls are better than physical since they are usually used with the gloves on: *"I often use my car in a cold climate, and I wear gloves, and the car is cold initially and I don't want to take off my gloves the first minutes I am in the car".* In addition, it was mentioned that the reflection of sunshine results in poor visibility of digital interfaces, a fact that is related to physio-pleasure.

Cleanability is another item that users claimed to be an important factor to consider. This quality can be easier and more satisfying to achieve with digital rather than physical interfaces, more specifically for users who must clean the interface frequently: *"Physical interfaces can be tricky to clean. It can be challenging when sometimes when you're cleaning you accidently press a button which may go wrong, but it is easier on digital… maybe the same way as our phones".* Users might not clean their interface all the time, so a self-cleaning interface is psychologically pleasurable.

Updating is yet another concern which contributes to psycho-pleasures of interfaces. Many users argued that they do not want to update their car interface since it can be troublesome. Some users had experienced this in cars equipped with new digital interfaces. However, referring to car manufacturers' guidelines, these updates usually do not take much time, but the existence of an updating option appears to bring a lot of dissatisfaction to the users.

A big screen is a pleasurable factor for most of the users as was claimed many times during the interviews: *"I often lack a big screen especially for navigation and in that way the bigger is better!"*. However, in some cases users complained about bigger screens: *"Well, the bigger screen is definitely an advantage, but it is somehow distracting and lots of things move around on it"*. This contributes to psycho-(dis)pleasure, but it can also be considered as a physio-pleasure element since it refers to the visual sense.

There are increasing concerns and dissatisfaction regarding the cyber security of digital interfaces since it can be connected to the internet. Although also physical interfaces can have internet connection, digital interfaces were perceived as more risky systems: "*My personal gut feel is that the physical is more reliable. What if the digital gets broken or get hacked? So, it is not good."*

The listed examples of concerns, identified in the Explorative Study, prove the fact that users' top priority is performance and usability and, more specifically, reaching their goals in a driving context. These items, which can be considered as the basis for other items, can affect other categories in different ways. For instance, users perceived a well-performed system as a more reliable system. As mentioned earlier, psycho-pleasure is related to functionality and usability aspects and can be positioned as the basis of user's appraisal. In addition, based on the quantitative analysis, physical interfaces contain most of the advantages that can be termed psycho-pleasures. Digital interfaces

perform well in a non-driving context when the IVI can be interacted with by the driver while not driving or by the passenger(s).

3.4.7 Physio-pleasure/ Attitude/ Sensory experience

The ways that the interface looks and feels are important factors for the users to appraise the interface's different aspects. These aspects are categorised as sensory experiences (i.e. visual and haptic aesthetics), physio-pleasure, and attitude (i.e. like/dislike) based on the models which were used in the study. Regarding the human senses, the focus of this study is on visual and haptics. Although there were comments about sound feedback and voice commands, but they will be considered as side results of the study.

Minimalism is a design trend in new products on the market and it is pleasant and surprising for users to see this trend also in their cars. Especially since the number of features on the screens are increasing, a minimalistic and simplicity approach contributes a lot to create more satisfaction with and attraction to the interface. Additionally, the aesthetic of the interface contributes to reducing distraction which can be considered as a psycho-pleasure aspect. It was claimed many times in the user interviews that: *"The digital interface looks really clean and minimal and gives a nice look to the car interior… when the interface looks clean, I feel I get less distracted…".*

The current design trend among automotive manufacturers is to offer a clean and neat interior look. The users apparently appraised this trend as a pleasant and pleasurable approach. This can be one of the most significant advantages of digital interfaces and, in contrast, one of the considerable disadvantages of physical interface. The aesthetic aspects of user experience regarding physical and digital interfaces can be evaluated in terms of pragmatics and hedonics. Considering both aspects, users can experience a more pleasurable and satisfying way of interaction with digital interfaces over physical interfaces. This can be seen in both the physical design of the interface and the graphical design of the user interface of the system. Considering the physical design from the user's point of view, a minimal look and clean surface are both practical and sensory appreciated. Considering the graphical design of the interface, some users appreciated the trendy and colourful graphical elements as more useful and sensory pleasing.

The participants in the user study mentioned haptic and tactile experiences at different occasions. Most important to them was that this experience contributes to haptic feedback and interacting with the interface without looking at it. However, most of the users preferred the 'haptic feel' of the touch screens (digital) since it is smoother and cleaner. This conclusion was drawn based on an experiment conducted during the interview. The participants were asked to close their eyes, touch the laptop keyboard with one hand and touch the laptop screen with the other hand, and change their hands while hovering over keyboard and screen. Most of the respondents commented that the screen gave them a more positive sensory experience: *"I feel that the touchscreen feels better… touch screens feel closer to my brain".*

The visual sensory experience was also considered in this study. Some participants argued in accordance with the following statement: *"Physical dashboards are so crowded, messy and confusing, sometimes looking at it makes you tired… I don't feel good about looking at all these buttons, small texts and indicators all the time".* A crowded interface, unorganized sections and visual complexity are themes that relate to physio-pleasure. These items can be found both in digital and physical interfaces, but users' attitudes towards the digital interfaces were more positive.

Sensory experience, as sensory aesthetics, can be associated with both pragmatic and hedonic user experiences. Positive haptic and visual sensory experiences, i.e. the focus of this study, contribute to higher user satisfaction and increase user performance. The effect of a pleasurable and attractive interface on user performance is also mentioned in several literature references. Based on the quantitative analysis, digital interfaces contain most of the advantages that can be associated with physio-pleasures tin the way that users relate to it.

3.4.8 Socio-pleasure and Ideo-pleasure/ Standards

In this study, socio-pleasure and ideo-pleasure (cf. Jordan's model) were considered as one category since they are closely connected. Moreover, standards (cf. Desmet's model) are related to users' personal and social norms.

Many users seek harmony in the design and appearance of the interfaces they use in their daily life. Harmony is a pleasurable experience for users. On the other hand, users want to follow trends and experience novelty which can be associated with their experience of buying a new car. To buy a new car is perceived as a 'new experience' for the users: "*The physical interface looks old and outdated… I want to see something new when I buy a new car".* Trends and novelty can be associated with social interactions and standards; harmony refers to personal ideals. Both harmony and trends can be categorised as ideo-pleasures and socio-pleasure, the same as standards.

A significant feature of new, digital interfaces is their similarity to smart phones and the possibility for users to use phone features in their car. This feature consists of access to phone apps, access to internet to connect and socialize, and customization and personalization of features. In addition, the digital interfaces were described as 'magnified mobile phones in car' by some respondents: *"The best thing the digital screens gives me, is the compatibility with my phone… I feel I have my phone magnified in my car!".*

Some other phone features are also recognizable in the digital interfaces and which the users could relate to, such as day/night modes, flexibility of items, certain interaction gestures, etc. In general, giving access to a personal device through the in-vehicle user interface was a pleasurable experience for the users. Phone access was mentioned as one of the most pleasurable features of digital interfaces as long as it does not endanger driving safety and performance.

Another item that gave users a feeling of pleasure while using an interface is environmental considerations. Considering environmental aspects and sustainability are a common trend and social belief nowadays. In fact, using a "green" product is pleasurable for most people. The users speculated that digital interfaces are more environmentally friendly than physical ones. However, most of the respondents claimed that it is not based on any prior knowledge but only a gut feeling, but still it is part of their experience. There is no proof that digital interfaces are more sustainable in comparison with physical interfaces, but this claim is worth to be further investigated.

Another aspect that contributed to socio-pleasure is the use of IVI by car passengers. Due to the increasing number of infotainment features and increased accessibility of interfaces in the cars, passenger(s) are involved in using the interface as well as is the driver. This fact has a significant socio-pleasure impact on the users/drivers. Hence, the access to the infotainment features by all the passengers in the car should be considered when designing the IVI. This factor can be a mean for co-experience (Forlizzi & Battarbee, 2004); however, the topic requires more studies and was not a focus in this study.

3.5 Synthesis of findings and conclusion

3.5.1 User experience of different interfaces

Since UX is a complex and multidimensional phenomenon, a user study into UX requires considering many different aspects of use. Therefore, the elaboration on each category described in the previous section is in this section followed by a description of the connections between and synthesis of these elements.

The analysis of psycho-pleasure, considering both the qualitative and quantitative data, showed that users' top priorities were performance and usability and, more specifically, reaching their goals in a driving context. Their attitudes were very different in a non-driving mode, in that, other aspects of the IVI became the source of appraisal for the users.

Psycho-pleasure in this study was considered as the basis of other pleasures and affected them in different ways. Users perceived a well-performed system as a more reliable system. Furthermore, as soon as the users trusted the system, they started appraising other factors. Perceived safety was identified as the origin of trust in the system.

Besides safety, there are some elements associated with psycho-pleasure that played an important role in satisfying user needs, (i.e. familiarity, robustness, learnability, ease of use and perceived control). Additionally, these user concerns/needs are associated with other aspects that create a pleasurable and satisfying experience. However, from a user experience perspective, all these aspects become so much personal since users' needs and concerns differ.

It is apparent that a reliable system can bring a high level of satisfaction. As mentioned, users can define trust in different ways based on their personal concerns and traits. It is therefore difficult to claim which types of interfaces create more satisfaction in terms of trust. However, based on the synthesis of subjective and objective data in this study, it is suggested that, in general, users perceive the physical interfaces as more trustworthy and reliable. Physical interfaces offer most of the psycho-pleasures in a driving context.; digital are more pleasurable considering non-driving contexts.

Physio-pleasure includes aesthetics and haptics in this study. It plays an important role in users' satisfaction with interfaces since interfaces are interactive to their nature. A smooth, flat and clean surface appear more pleasant for the users from a visual as well as haptic perspective. However, for some users, physical interfaces with different tactile surfaces/tactile experiences are perceived as more pleasing and satisfying.

Furthermore, users highly prefer a system with lower complexity and a less crowded look. Physical interfaces are perceived as constantly crowded with a complex appearance whereas digital interfaces are claimed to offer a more minimal, neat and clean look. However, several participants mentioned that the UI in a digital interface could be somehow complex and difficult to learn. In general, the digital interfaces were appraised as more satisfying in a non-driving context; physical interfaces were more satisfying in a driving context. This answers the second research question about the context of use.

Based on the results of this study, sensory experiences fulfil the need for physio-pleasure based on users' concerns. Some users perceived the physical interfaces to result in a more positive sensory

(haptic) experience since it contains different tactile and haptic experiences. Some other users perceived the digital interface to provide the more pleasurable experience.

There is a link between aesthetics, trust, performance and sensory experience, which prevents users to get satisfied only based on how the interface looks. Despite all the advantages of digital interfaces regarding aesthetics and sensory experience, the users did not appear to value physio-pleasure over psycho-pleasure. Moreover, the appearance of the interface can affect other product pleasures in different ways. Psycho-pleasure aspects can be affected by physio-pleasures: as claimed by the participants, a minimal and clean interface looks easier to learn and use. In addition, aesthetics has a close relationship with sensory experience and perceived control, reliability, and robustness can be perceived by the users based on their interpretation of the appearance.

In this study, socio-pleasure and ideo-pleasure were highly related. Socio-pleasure in digital interfaces represents current societal trends and norms. This aspect appraises the physical interfaces as out-dated and owned by middle-class citizens (even though many luxury cars still contain many physical controls). Based on the results of this study, physical interfaces could be argued to satisfy conservative users or laggards (cf. Rogers, 1962) whereas digital interfaces satisfy the trend seekers, i.e. innovators and early adopters (cf. Rogers, 1962). In addition, the use of IVI by all passengers in the car is a socio-pleasure aspect, and this type of use us increasing given the development of IVI systems.

An overview of all the findings regarding the way that users experience the different interfaces is presented in Table 8.

Table 8. Overview of the findings; advantages of the interfaces

Appraisal of	Physical interface	Digital interfaces
Psycho-pleasure	Trustful, safe, high performance in driving context	Pleasurable, convenient, satisfying in non-driving context
Physio-pleasure	Pleasurable when haptic and visual qualities of the interface contribute to usability	Pleasurable when haptic and visual qualities of the interface contribute to interface as an 'independent' product
Socio-Pleasure	Represents an older generation or middle-class customers	Pleasurable since it is trendy and fashionable. Also passengers can use the IVI
Ideo-pleasure	Pleasurable for conservative customers (laggards)	Pleasurable for trend seekers (innovators)

In summary, it can be concluded that all product pleasures affect each other in different ways. It is here argued that there is a complex interdependency between the different pleasures, depending on the user's concerns, behavioural type, and the context of use. Users refer to the pros and cons of interfaces in different ways, since user experience is highly related to their personal experiences and their ideals affected by social norms. Safety is the key factor in the emotional design of interfaces and is the

source of trust and reliability. Different pleasures are highly dependent of each other in the appraisal of physical and digital interfaces. Thus, there is no one preferred type of interface. There are different mindsets and tastes regarding different interfaces, which can be interpreted as different types of attitudes and behaviours in a particular context of use. These personal traits and behaviours are presented in the form of an impact map (Figure 22).

3.5.2 User types or behavioural groups

Product pleasure is not an inherent property of a product. It is a result of an interaction between a person (user) and a product. Users have different needs and different concerns, and both needs and concerns differ from person to person. Users have different attitudes and behaviours, and there is no single preference when different types of interfaces are considered.

This fact makes it necessary to create an illustration of different users' attitudes and behaviours towards IVIs. The results of the study presented here imply that there are mainly five types of users when it comes to automotive interfaces. Moreover, these users have different needs and wants which are unique. Considering these behavioural types and user wants gives a good insight into creating an effective design guideline.

The so-called impact map is one of the tools that could be useful. With the help of the impact map, one can describe the most significant user behaviours and attitudes in a structured manner. In addition, the 'needs and concerns' of the users are specified for each behavioural group. The input for the impact map in Figure 22 is based on the identified user categories and their respective behaviours and attitudes.

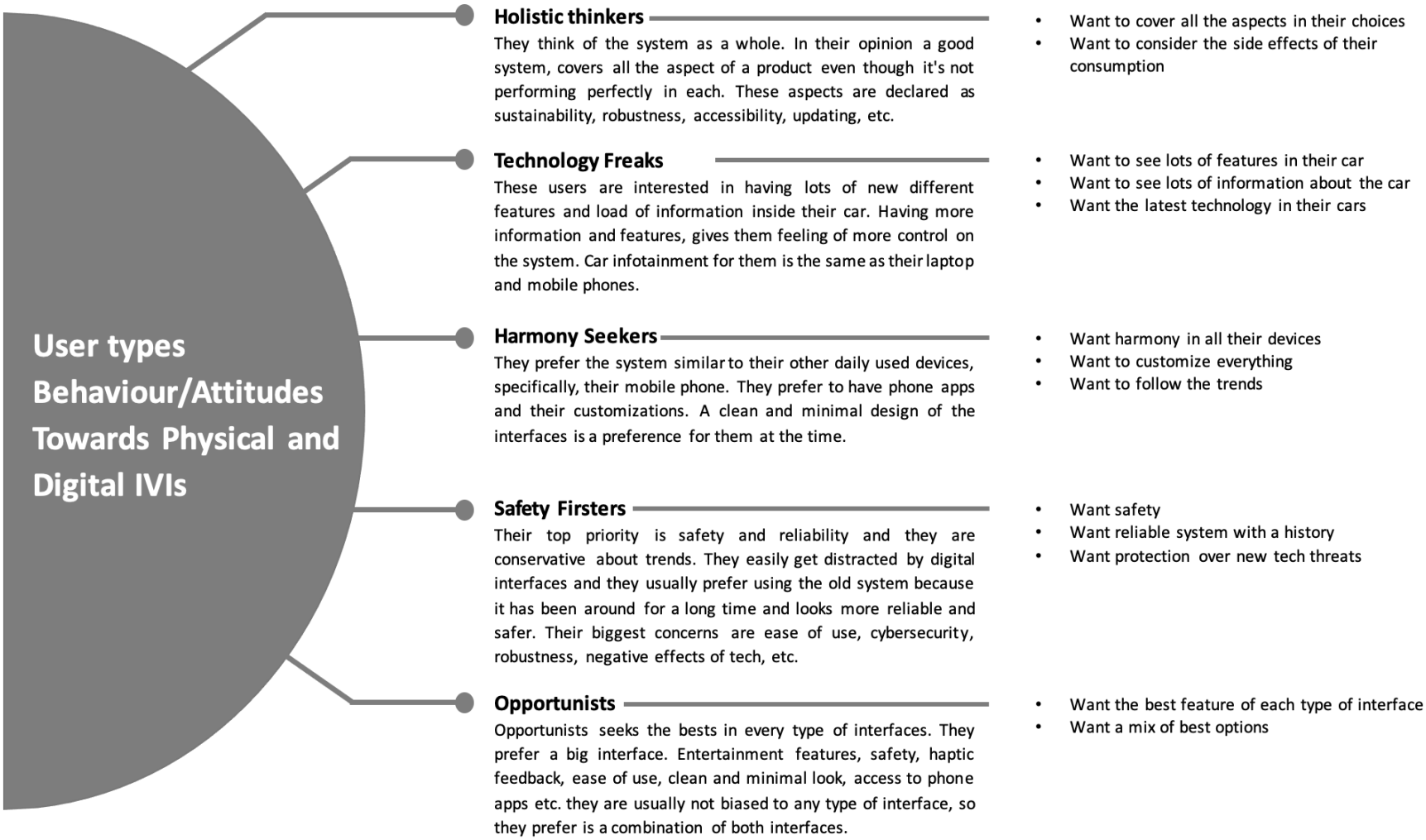

Figure 22. Impact map of user types (the text version is available in Appendix)

3.6 Discussion and future work

This study intended to answer the research questions by conducting an explorative user interview. The main research questions are; What do users identify as pros and what do they identify as cons for each type of interface (physical and digital)? and How does the context of use, affect the UX regarding IVIs?

Different aspects contribute to the experience of an IVI; pragmatic and hedonic dimensions (cf. Hassenzahl, 2005), sensory experience/physio-pleasure (cf. Desmet & Hekkert, 2007; Jordan, 2000), psycho-pleasures which are associated with usability and effectiveness of use (cf. Jordan, 2000; Norman, 2004) and temporality of user experience (cf. Pettersson, 2016). Considering these aspects, the focus of the study was not on the comparison of different types of interfaces but on specifying the significant pros and cons of each type of interface and the way that these pros and cons affect the user experience.

According to Wellings et al. (2010), concepts such as user experience, perceived quality and aesthetics, are not separated from the customer's mindset of usability and should be considered as part of the whole. In this study, psycho-pleasure has priority in a driving context and is the basis of other pleasures. Psycho-pleasure correlates with usability (Jordan, 2000). Much earlier research emphasized that the time spent on secondary and tertiary tasks means time for 'eyes-off-the-road' (Kern & Schmidt, 2009; Tsimhoni & Green, 2001;). This fact was admitted by almost all of the participants; all *interfaces are distracting to some extent and the less distracting they are, the more usable and pleasurable they are*.

Familiarity is another topic which has been addressed in different research (e.g. Budiu 2019; Karlsson et al. 2019). This aspect, which correlated with both physio-pleasure and psycho-pleasure in this study, was admitted by the users in two different ways. For some users, a traditional interface (physical) is more familiar since it has been around for a long time, for other users an interface that looks like their daily used devices (digital) is more familiar. Furthermore, the users appraised a more familiar system as easier to learn and use. Moreover, one of the findings of this study is that a familiar system is perceived as more reliable and therefore more likely to be trusted.

Sensory aspects were addressed in the literature as the pros and cons of different interfaces. Meixner (2017) and Ng et al. (2017) emphasized for example the direct relation between the complexity of the interface and driver's distraction. Based on the results of this study, the complexity of interface affects both psycho-pleasure and physio-pleasure. A visually complex system is less visually pleasing for the users, and they prefer a clean and minimal look. From this perspective, digital interfaces are more pleasing.

There are several literature references that emphasize the importance of "haptics" as an enjoyable hedonic experience (Burnett & Porter, 2001; Rydström et al. 2017). It was also acknowledged by the participants that digital interfaces lack haptic feedback. In fact, digital interfaces do not provide clear feedback of task completion, and the absence of haptic feedback has a negative effect on user's appraisal. Several articles addressed this subject as one of the disadvantages of touchscreens (Pitts et al., 2009; Serafin et al., 2007).

Regarding haptic sensation, more specifically touch, users appraised smooth and flat surfaces as more satisfying and pleasurable (physio-pleasure). However, many users agreed with being more in control

while using physical interfaces, as mentioned by Rydström et al. (2017), and this perceived control comes from the touching and grasping of physical controls.

The findings regarding ideo-pleasure and socio-pleasure (here considered as one type of pleasure) are among the most important outcomes of this study. There appears to be limited research on the personal and social aspects of car interfaces, but the findings of this study show that the preferences for the type of interfaces are highly dependent on the users' concerns and attitudes (cf. Desmet and Hekkert 2007). Moreover, conservative (i.e. laggards in Rogers' terminology) users prefer physical interfaces and the trend seekers (i.e. early adopters or innovators in Rogers' terminology) prefer digital interfaces. However, five different user behaviour/attitudes have been identified as to their preferred type of interface. In fact, there is not one preferred type of interface; it depends on the user's attitude, concerns, behaviour and the context of use.

The social aspect of IVIs is highly related to personal aspects, however, the contribution of passengers in using the IVI can have a considerable impact on the design of interfaces and the concept of co-experience (Forlizzi & Battarbee, 2004).

From what could be understood by analysing the results of the study, existing IVIs as technical products are, per se, not meaningful to users. This claim is based on the users' input that even though car interfaces are getting more and more important, they are important as a component in a car, but they are meaningful primarily as a tool for communication (the same argumentation applies to mobile phones). This argumentation can be taken further. Although some technical functions, such as speaking assistants, already exist in cars, it is not evident that users find a meaningful relation between, in the specific case the IVI and the voice over - it is merely another mode for interaction (input-output). Thinking in terms of meaningful design, and what features or characteristics (e.g. personalisation) that could increase how meaningful users find the IVI and the way to interact with it, could have considerable impact on the user's satisfaction. This aspect seems under-researched and requires more investigations and further studies.

During the Explorative Study, the intention was to explore the aspects that users identify as pros and cons of the respective types of interfaces. Several aspects were identified and interpreted in terms of user experience. However, this study focused on the 'bigger' picture of this experience. For a deeper understanding of this topic, it is necessary to study, more in-depth, all the aspects that contribute to this topic. These aspects are illustrated in Figure 23 in the form of pleasures. The recommendation is to conduct this study in the form of a user study with physical setups. Different aspects, as is described in Figure 23, contribute to exploring the user experience of physical and digital automotive interfaces. All these aspects need to be thoroughly investigated in order to explore the actual experience of users. Moreover, since user experience is time dependent, future studies are recommended to investigate the users' behaviours in relation to anticipated, momentary and episodic experiences.

Several socio-pleasure and ideo-pleasure aspects were identified and seemed to influence the users' appraisal of the interfaces. To address these pleasures in future designs require a deep understanding of future trends and cultural aspects. In addition, as mentioned before, the concept of co-experience – which in this study is associated with the use of IVI by the passengers – contributes to socio-pleasure and requires further investigations. Environmental considerations of different interfaces, as an important ideo-pleasure aspect in this study, also need to be studied and the level of sustainability considerations in different types of interfaces requires further investigations.

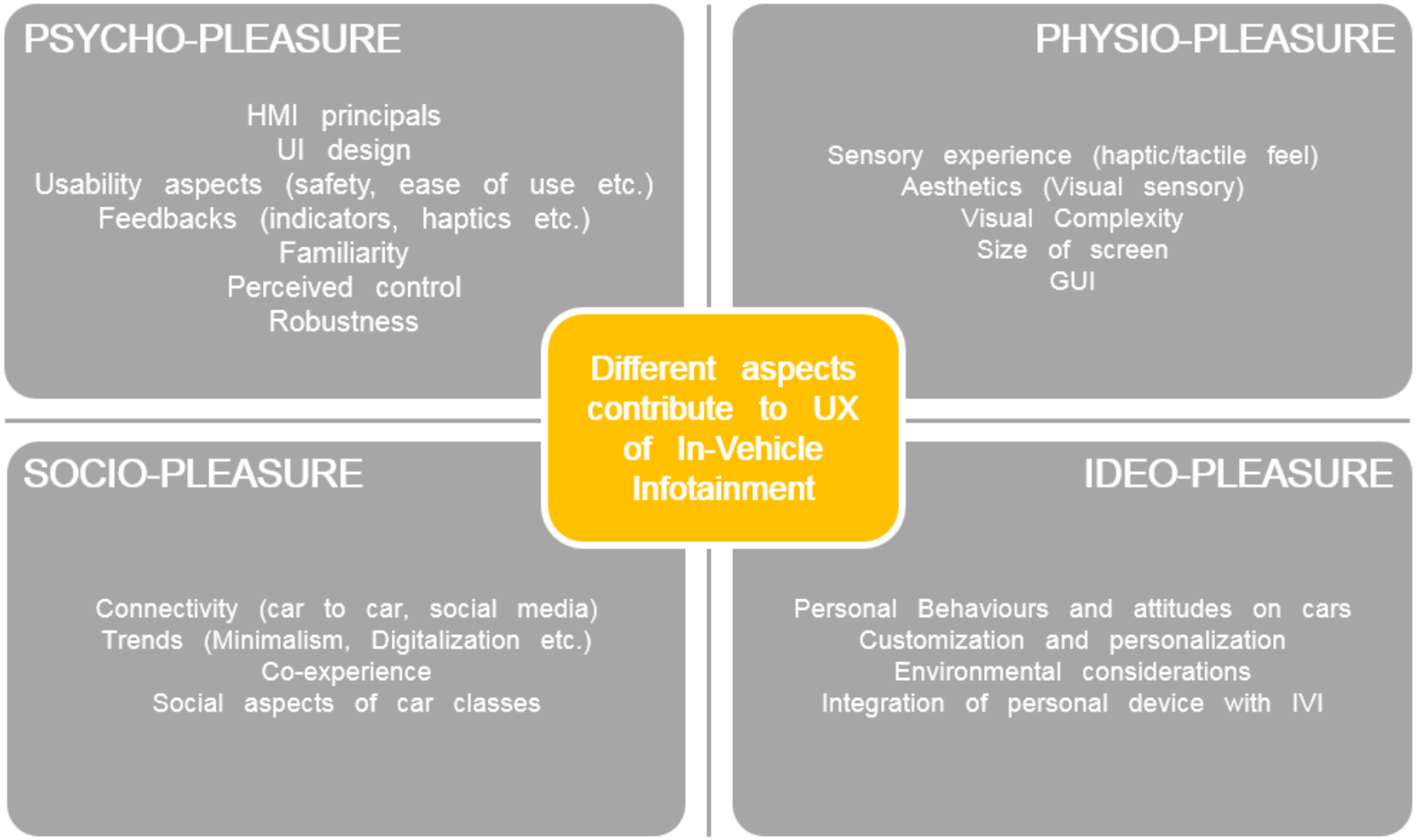

Figure 23. Overview of different aspects that contribute to UX of IVIs

4 Implications for the Design of a New type of IVI

4.1 Design considerations

In this work, the pros and cons of different types of interfaces have been investigated and described, with the intention to develop a new concept that considers the results of the investigations. However, it was not possible to cover all the identified aspects since some of the pros and cons contradicted each other. In addition, there were technical and strategic considerations that needed to be acknowledged in order to create an integrated product.

According to Jordan (2000), the design of a product should not result in solving one problem only to introduce another, but it should consider and prevent all possible problems that the new product might produce. For a new design solution, a deep understanding of the users' needs and behaviours tied with the recommendations from research and design literature are required. Moreover, the new concept should not be 'too' innovative since there is the risk of rejection by the users (cf. Rogers 2005).

The increased number of IVI functions in modern cars, such as high-end audio, video, phone pairing, etc. is inevitable and had to be considered in the new design. However, the increased number of functions and applications are directly related to the complexity of HMI (Meixner, 2017). This encouraged a minimalistic and clean UI, something that was mentioned many times by the participants in the Explorative Study. Such a minimalistic design requires specifying the necessary functions of the system and prioritizing the most commonly used applications.

User experience, perceived quality and aesthetics are not separated from the customers' mindset of usability, and the new design should be considered as concept that covers a holistic set of requirements (cf. Wellings et al., 2010). The first question to decide regarding the design was what type of interface is preferred, digital or physical? According to the reasoning in the former chapter, there was no one fully preferred option. Therefore; a combination of both interfaces was to be sought. This answer results in many additional considerations, e.g. to what extent this integration (combination) should happen? This question is addressed in the design process.

The work presented here, and other, related studies tell us that different aspects should be considered in order to create a pleasurable product for users. The aspects are sensory experience, familiarity, natural interaction, perceived safety and trust, ease of use and learnability, robustness, novelty and consideration to environmental aspects. They bring pleasure and satisfaction to users and cover the emotional dimensions of the product.

In addition, aspects such as customization, adherence to trends, connectivity (both re device connection and socialization) and other ideo-pleasure and socio-pleasure aspects should be considered. These aspects can be easily implemented in a digital interface since it is more flexible and compatible with other devices.

Regarding modalities[5] users might, as argued by Karlsson et al. (2019), be reluctant to switch between different modalities. Therefore, the different modalities should be limited to some specific modalities, which are necessary for users' interactions. However, according to Rydström et al. (2012), there is no one perfect input device that covers an entire task, and which is always the best choice. Therefore, the choice of modalities should be based on the task and the context of use.

Regarding the effectiveness of multimodal interaction, 'skipping steps' and getting directly to the desired function is advantageous for the users. Several studies emphasise the right choice of modalities and input/output devices based on the context of use and the task (Karlsson et al., 2019; NG et al., 2017; Rydström et al., 2012). For instance, the referred to studies recommended touch for increase/decrease (e.g. music volume and fan speed), speech for search, gesture for navigation etc. A large touchscreen was therefore considered for tasks such as search and navigation. Most of the users considered having a big screen as one of the main advantages of digital interface.

Mobile phone connection and using smart phone applications in the car were mentioned several times by the participants in the Explorative Study. It is more or less a fact that nowadays, users are dependent on their mobile phones. Even though there are risks associated with using the phone while driving, it is possible to limit the phone functions depending on the driving situation (e.g. speed, dangerous zones, driver cautiousness etc.) and use phone applications and the phone for interaction in both driving and non-driving contexts. Moreover, connecting the phone to the IVI can bring the user's personal setting and preferences to the IVI, which is of great value for users. As an example, it was mentioned by some participants that they usually use their phones as an input device for entering destination and receiving information on navigation.

Using a phone as an input device for IVI can also contribute to accessibility. According to Wittmann et al. (2006), car interfaces (digital) are usually placed high enough to provide a short eye travelling distance between the road and the screen. However, this placement means that the users have to lift their arms to reach the screen. Phones are usually easier to reach and access. In addition, it was also mentioned by the participants that sometimes they use gloves while seated in the car. The first function that they need to activate on the IVI is the climate control. Touchscreens do not provide this option to interact with a non-conductive device (Barry, 2019) so that having the climate control cluster as tangible, physical controls, is of value to users.

Another important matter for accessibility that also contributes to visual comfort is to have the input control and the feedback device in the same place. One of the disadvantages of physical interfaces is that the input device and visual feedback indicators are usually not found in the same position. However, this can be achieved by having a dynamic interface. As a solution, having the physical controls built-in in the touchscreen is considered to be pleasurable for the users but this assumption must be evaluated with users (see the final chapter).

Environmental aspects and sustainability considerations are aspects that were important for the participants. Users want to feel better regarding environmental impacts of their consumption and IVIs as a product brings the same concern. The participants appraised digital interfaces as more sustainable. Assuming that this appraisal originates from the material used in each type of interface,

[5] In this study, only haptic and visual are considered as the focused human senses. The other modalities such as voice, gesture etc. are not considered.

less plastic and more environmentally friendly material (e.g., crystal, metal as recyclables materials) can bring value to the users. So, in the design of the IVI, materials should be considered not only from a physio-pleasure perspective, but as an important factor for sustainability (and hence ideo-pleasure).

Users seek meaning in the product that they are interacting with. As mentioned earlier, it was found that the interfaces lacked unique characteristics. The conceptual design was a good opportunity to look into the meaning of this component and tie it with emotional aspects of a product. This could be done by adding character to the design through personalization. Creating attachment between the user and the interface is not easily achieved since the IVI must provide the necessary in-vehicle functions. However, since there is already a connection between the users and their mobile phones, it is a good opportunity to integrate these devices in a safe way and let the users feel more attached to the IVIs. This approach can help create 'trust' between the user and the interface.

4.2 Design guidelines

As a result of the work presented here, it is important to formulate clear and actionable design guidelines that can be used by practitioners who want to consider the users' emotional reactions to and relationships with different types of IVIs. However, the work has so far not covered all aspects, but it is hoped to open some doors for future studies on this topic.

Some design considerations were mentioned in previous section. In this section, the focus is on actionable guidelines with the help of the pleasure categories proposed by Jordan (2000). As mentioned earlier the approach to the design is user-centred, which means that the guidelines must be used together with a deep understanding of user needs, user concerns as well as thorough understanding of the context of use.

The design guidelines build on the most significant user preferences towards different types of IVIs. Some other aspects identified in the Explorative Study were not included here since they either contradict other aspects or they were too extreme or too context dependant. To cope with this challenge, flexibility and customization are recommended which will ensure that users from different behavioural groups will have a positive experience using the final concept.

Furthermore, it is apparent that all the items in the guidelines cannot be included in one design, but it is expected that the most relevant items be used in order to make a meaningful design.

Synthesising guidelines available in literature, considering relevant standards (NHTSA, 2016), and the results of the initial Explorative Study, the proposed design guidelines are presented in Table 9.

Table 9.Proposed design guidelines

Item	Design consideration	Actionable suggestion/explanation	Contributes to type of pleasure
1	The most frequently used functions should be the easiest to access	Could be in the form of dedicated physical controls in the lower part of CSD	Psycho-pleasure
2	The IVI should be a combination of physical and digital interface elements	A big touchscreen in combination with necessary functions as physical controls	Psycho-pleasure/Physio-Pleasure
3	A big, visible and reachable screen is desired	Big enough for map navigation and if possible, for watching movies (the possibility of transferring to horizontal mode is desired)	Psycho-pleasure/Physio-Pleasure
4	Haptic feedback and different tactile characteristics (i.e. combination of bumpy and smooth surfaces) should be considered	Regarding tactile features, at least the interface panel should have a different tactile surface than the functional parts	Psycho-pleasure/Physio-Pleasure
5	The interface should be connected and compatible with smart phones	Enable access to phone applications and internet browsing in a safe mode.	Psycho-pleasure/Ideo-pleasure/Socio-pleasure
6	The interface should look clean and minimalistic	Besides avoiding complex shapes in the physical design, this can be achieved by eye gazing devices. (When user is not looking; the interface can be off or dimmed.)	Psycho-pleasure/Ideo-pleasure/Socio-pleasure
7	The most used function clusters should be static and have its specific section	E.g. audio control and climate control can be physically separated. This can help access to/use of muscle/spatial memory	Psycho-pleasure/Physio-Pleasure

8	Easy cleaning should be considered	Flat and even surfaces are easier to clean	Psycho-pleasure
9	The design and look should consider environmental aspects	Use of environmentally friendly material can have a big impact on users' appraisal (e.g. crystal, metal etc.)	Ideo-pleasure/Socio-pleasure
10	All passengers should be able to use the infotainment and convenience functions	Giving access to rear seat passengers for audio and climate control, easy to use by left hand for front seat passenger and/or giving the possibility of controlling these functions with a phone app	Socio-pleasure/Psycho-pleasure
11	Natural interaction should be considered	Familiarity and redundant modalities such as gesture or speech have a big impact on experiencing more natural interaction	Psycho-pleasure/Physio-Pleasure
12	Learnability, ease of use and user friendliness should be considered as the principal requirements	A tutorial/help function can always be available as a button	Psycho-pleasure
13	The GUI should be flexible	E.g. the text size, colour palette and landing page items should be possible to change/modify	Psycho-pleasure/Physio-Pleasure
14	Cyber-security should be considered	Since connection to the Internet raises concerns regarding security, users should be reminded that the system and their personal data are protected	Psycho-pleasure/Ideo-pleasure
15	Day/night mode and different brightness while used and not used should be considered	Automatic mode is desirable	Psycho-pleasure/Physio-Pleasure

16	The number of colours (both in physical design and GUI) should be as few as possible in order to keep the screen minimalistic and less distracting (considering standards)	Using the functional/ standard colours as the main colours (e.g. red, blue, green) and the rest of the GUI can be achromatic	Psycho-pleasure/Physio-Pleasure
17	The interface should be designed to create user attachment	Personalization and customization of the interface	Ideo-pleasure/Socio-pleasure
18	A meaningful design and interaction are desired	Can be achieved by introducing a virtual character that the user is/becomes familiar with (e.g. Siri, Cortana)	Ideo-pleasure/Socio-pleasure/psycho-pleasure
19	Neomorphism forms as the most congruent forms to human perception can be considered for the GUI	These types of form are trendy and look natural, however, the design of GUI should be in harmony with the physical design	Physio-Pleasure
20	The interface should be perceived as robust	Use robust materials and avoid fragile forms and shapes	Psycho-pleasure
21	The updating process should not be distracting	Can be short and preferably during off times	Psycho-pleasure
22	The look of the interface should follow trends	Minimalism and neomorphism are both functional and new trends. However, the update can help with bringing more trends	Ideo-pleasure/Socio-pleasure
23	Some levels of novelty are necessary for a positive user experience	Updating can be a mean for novelty	Ideo-pleasure/psycho-pleasure
24	The features should be customizable and personalized	Personalized placement of some functions can result in attachment. This can be done in case of non-primary-tasks-related functions	Ideo-pleasure/psycho-pleasure

4.3 Applying the guidelines

As one of the results of this project, the guidelines (Table 9) have been used as the basis for a conceptual IVI design. This concept considers the emotional aspects that were identified in the explorative user study and the Literature Review. The guidelines have been applied as follow (see also Appendix):

1) **The most frequently used and safety functions** are considered to be: (a) multimedia control, (b) climate control, (c) additional safety and necessary functions (see NHTSA, 2016) and (d) home button - on/off. All these items are designed in the form of physical controls (Figure 24).

Figure 24. The commonly used functions as physical controls

2) **The design is a combination of physical and digital designs** (Figure 25). The combination was decided based on the notion of the most frequent used functions and safety buttons (i.e. hazard) as physical elements and other functions included in the multifunctional touchscreen.
3) **The screen is considered as big and visible.** The size of the screen is 9.7", i.e. the size of an iPad Gen 4. This makes the implementation of operational systems (OS) easier for the practitioners.

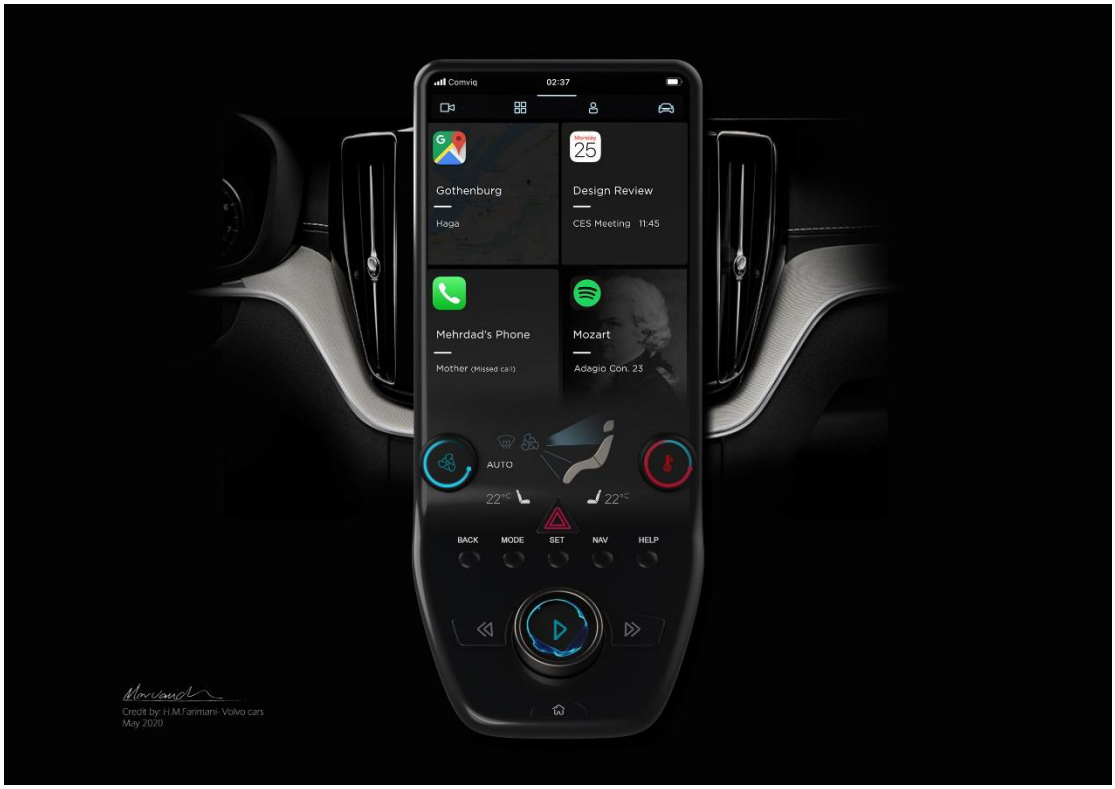

Figure 25. The combination of both physical and digital elements

4) **The physical controls (push buttons and knobs) offer haptic feedback,** and the button material/tactility differs from the cluster surface (Figure 26).

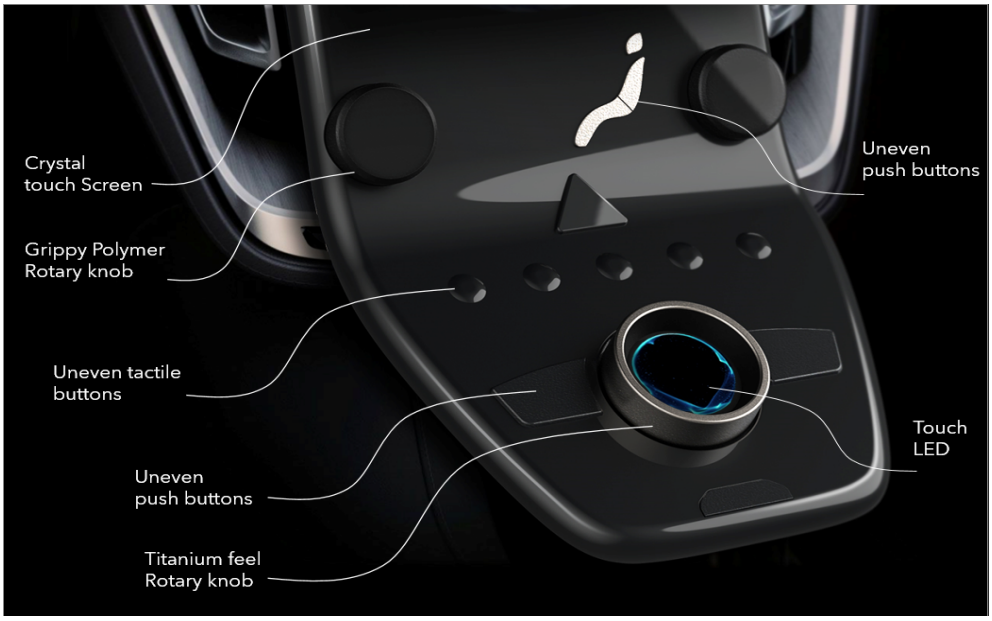

Figure 26. Different material and tactile in the lower part of the IVI

5) **The interface GUI is considered similar to smart phones** and therefore has high compatibility with smart phone OS (Figure 27).

Figure 27. Similarity of GUI to smart phones' OS

6) **The minimal and clean look** of the interface characterizes both the physical design and the GUI. In order to enhance minimalism, the interface indicators are dimmed when the car is switched off.
7) The most used functions are static and have their specific position (Figure 28)
8) **Easy cleaning** is considered in the design. Also, the interface is waterproofed. A smooth and even surface enhance easy cleaning.
9) **The material of the main body** is crystal (or at least a crystal look) and the knobs are made from metal.
10) **All passengers can access the infotainment** and convenience functions from a smart phone app.
11) **The GUI is expected to look familiar** to most individuals in the target group. Natural interaction is considered.
12) **The GUI is as easy** as that of mobile phones so it can be perceived as easy to learn and use. Moreover, there is a physical help/tutorial button in the lower panel of the IVI.
13) **Both GUI and the indicators on physical controls are adjustable**. e.g. the font size of the indicators, the colours, and some other functions can be modified by the user.
14) **Cyber security** is considered in the OS.
15) **Daytime/night-time modes** and different brightness while using or not using are considered. There are different brightness modes for the screen. When the IVI is not used; all the lights dim.
16) **The number of colours** (in physical design and GUI) is as few as possible in order to keep the screen minimalistic and less distracting. The main colour of the panel is black while cyan is chosen as the indicator colour since it is considered calm and less distracting (Figure 28).

Figure 28. IVI's overall look and design

17) **Personalization and customization** of the items and setting are considered in the design of the GUI.
18) A **virtual assistant** is included in both the functionality and the design of the GUI (Figure 29). When the assistant is talking, its eyes and mouth are indicated on the physical buttons (only for non-driving mode).

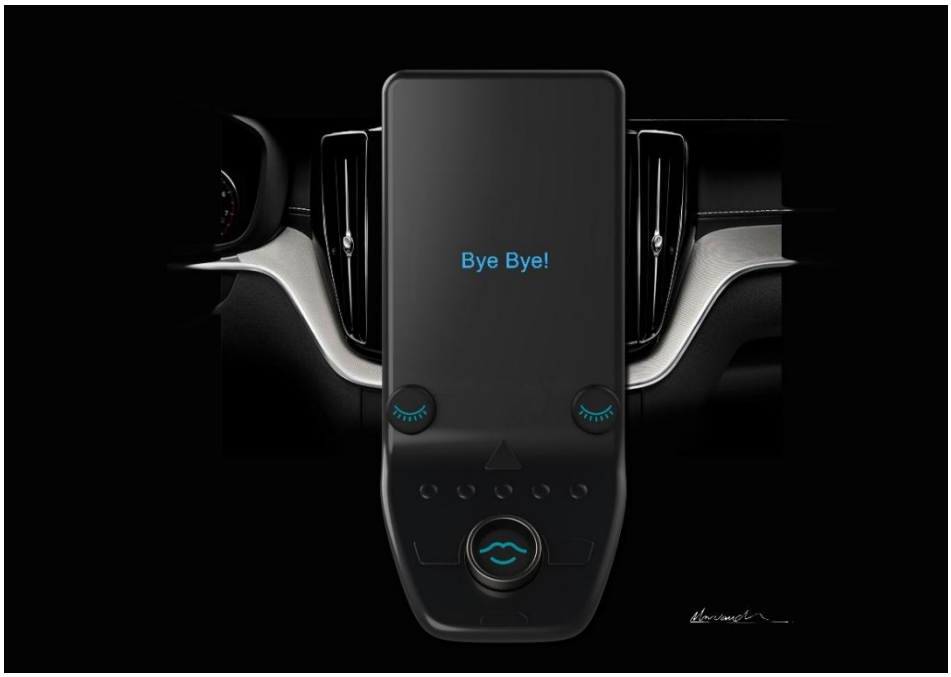

Figure 29. Virtual assistant functionality and interaction

19) The GUI design is considered to harmonise with the physical design (Figure 30).
20) The physical design is intended to convey robustness.

Figure 30. The harmony of physical design and GUI

21) **Updating** can be scheduled by the user. By default, it will happen in the background while the car is off.
22) **The design of the physical design and the GUI** (e.g. choice of colours and icons) considers present trends.
23) Although there are similar designs in the market, the whole concepts designed to be new and fresh for the users (Figure 31).

Figure 31. Novel design and compatible with current trends.

5 Evaluation of the Design Concept

Since the user-centred UX design approach is an iterative process, the developed concept had to be evaluated by users with the help of UX evaluation tools. Two approaches were chosen for the evaluation:

1) Interviewing the same twelve participants who were involved in the Explorative Study - this is here referred to as the *Interviews*.
2) Sending out a questionnaire/survey, including representative visuals of the concept, to a larger population of users - this is here referred to as the *Survey*.

5.1 Aim

The Interviews were conducted to get in-depth feedback regarding the interpretation and implementation of the design guidelines in the design concept. Moreover, the Interviews were intended to validate the users' input to the Explorative Study by them being exposed to a visual representation of their design preferences.

The purposes of the Survey were to: 1) evaluate the final concept with a broader audience and 2) validate the user types (referring to Impact map). The first aimed to reduce the effect of the bias that might occur as a result of interviewing the same users in both the Explorative Study and the Interviews. The second aimed to compare the answers of a specific survey participant with those of his/her user type in order to evaluate the users' inputs on designs which comply with user preferences. The assumption was that users belonging to a certain user type would rank the features higher which address that specific behaviour and associated preferences.

5.2 Method

5.2.1 Participants

The participants who were chosen for the Interviews were the same participants as in the Explorative Study. Therefore, the same demographics. The participants were also categorized in different user types (see Impact map).

The Survey was sent out to a random group of users via social media platforms. The respondents' demographics were asked for in a screening process so that only users with the same demographics as those participants in the Explorative Study were included in the analysis.

5.2.2 Data collection

Both evaluations were conducted online. As in the Explorative Study, the subjective data collected in the Interviews was both qualitative and quantitative. In order to obtain comparable data, the Interviews and the Survey included a Likert scale which consisted of a number of items. Participants rated their agreement with each item (or statement) on a scale ranging from "Do not agree at all" (1)

to "Totally agree" (5) (Table 10). Furthermore, explanations and reasons behind the ratings were collected after each section using complementary questions.

Table 10. Example 1: "By using this interface, I feel I have control over the functions."

Do not agree at all (1)	2	3	4	Totally agree (5)

The results from the Interviews and the Survey were summarized into a radar chart and compared with the data from the Explorative Study. Almost all the steps which were taken were the same ones as those taken in the Explorative Study.

5.2.3 Interviews

The questions in the interviews were based on the literature, the Explorative Study results, and the design guidelines as they appeared in the form of the conceptual design. The questions were organised in sections according to Jordan's (2000) product pleasures:

- Section 1). Aimed at physio-pleasure, i.e. sensory experience.
- Section 2). Aimed at psycho-pleasure, i.e. usability, learnability etc.
- Section 3). Aimed at socio-pleasure and ideo-pleasure, i.e. personalization and customization aspects.

For each section, a related animation was presented to the participants, and they were asked to focus on the specific topic. For example, the animation for section 1) was presenting the way the interface looks and feels, the material texture, etc. (Figure 32) and the focus was consequently on sensory experiences. At the same time the Likert scale items were shown on the screen. The items had the same format as in the Explorative Study. However, since some additional functions were added to the concept, the interviews in this study contained some additional questions.

Figure 32. A screenshot of interview format which the respondents were exposed to while answering the questions.

After each animation, a set of questions were asked to explore the users' understanding of the concept. A number of statements concerned the advantages of the concept, and the participants were free to agree or disagree with each of them. After each section, the participants could elaborate on their reasoning and talk about their anticipated experience with the interface. At the end, there were several general questions probing the overall experience of the users. An overview of the interview questions is presented in Table 11.

Table 11. Overview of Likert scale and evaluative interview questions

Section	Likert Scale Items	Complementary Question/ Probing	Visual product representation	UX aspect
Section 1	- The interface looks familiar to me.	- What are your thoughts on this interface considering how it looks and how it may feel to interact with it?	Image of overall appearance + Animation (1) containing visual appearance and textures, materials etc.	Physio-pleasure (Familiarity in appearance, Sensory Experience, Visual appearance, touch)
	- I think that interacting with this interface will be sensory pleasing.			
	-The visual appearance of the interface is pleasant to me.			
Section 2	-I think that I will quickly learn how to use this interface	- How do you evaluate this interface regarding aspects such as learning how to use and using it? (freely discuss it)	Image of sections + Animation (2), containing how to use, learn, combination of physical and digital interfaces, controls etc.	Psycho-pleasure (Usability, learn, ease of use, combination, Perceived control)
	-I think that I will be able to use this interface without difficulty.			
	- I feel that I can use the common controls (climate, multimedia ...) without looking at the interface.			
	- I think that this interface is a good combination of physical and digital elements in interface design.			
Section 3	-The design of the interface is innovative.	- How do you evaluate connectivity, customization, and personalization of this interface? (freely discuss it)	Image of smart phone connection + Animation (3) containing voice over, connection and accessibility to phone and customization of functions.	Ideo-Pleasure/ Socio-pleasure (Novelty, customization, Personalization, attachment, Trend)
	- This design of the interface looks novel and trendy.			
	- I think I can be socially connected to other people by using this interface.			

	- I feel that I can customize this interface according to my preferences.			
	- I can become attached to this interface the same way as to my mobile phone.			
General Questions	- What do you see as the advantages of this interface?	-How does these pros and cons can affect your experience? -Does this concept fulfil your expectations as you elaborated on in the previous study?	In the case of comparison; Images of existing interfaces (what was presented during the Explorative Study) + Image of the participant's car interface	Overall Experience
	- What do you see as the disadvantages of this interface?			
	- Do you think if this interface results in a more positive user experience, in comparison with the existing solutions (your own car's interface)?			
	- Do you have any other comment about this interview that might be useful for us?			

5.2.4 Survey

The survey was organised in two different sections. In the first section, the users were exposed to visual representations of the final design and in the second section, the users were required to specify their preferences and attitudes towards car interfaces. The first section was almost identical with the Interviews regarding questions and statements but targeted a broader range of users' inputs on the design concept. The second section was designed to understand the users' preferences why each statement in section 2 corresponded to one or several questions in section 1.

The questions in the Survey were in the form of statements and ratings considering the features of the concept. For instance, 'Harmony seekers' (as a user type) want to see consistency between the products that they own. Therefore, it was expected that they agreed more with the following statement than with the other statements: "It is positive that the design of the interface has similarities with the interfaces in my other devices."

This evaluation targeted five user types which were specified with the help of the Impact map. The respondent's type was recognized by a screener form where, for example, a statement corresponding to the above question read "I want the car interface to be similar to my other devices."

The remaining items are presented in Table 12.

Table 12. Questionnaire and Screener items

Behavioural type	Questionnaire (to what degree do you agree or disagree with the following items?)	Screener (How important are the following items for you?)
1. Holistic thinker	1. This concept covers lots of aspects of an interface (usability, sustainability, etc.).	1. I want to consider all the aspects of a product.
2. Tech-freaks	2. This interface offers a lot of features.	2. I want to see a lot of features in my car interface.
	3. This interface will be able to provide lots of information.	3. I want to be exposed to a lot of information in the car interface.
	4. This interface design makes use of the latest technologies.	4. I want to have the latest technologies in my car.
3. Harmony seekers	5. The design of this interface is similar to the interface design in my other devices.	5. I want the car interface to be similar to the interfaces in my other devices.
	6. I can customize this interface like I do my smartphone.	6. I want to be able to customize the interface in the car.
	7. The design of this interface follows today's design trends (minimalistic look, clean surface etc.)	7. I want to follow the design trends.
4. Safety firsters	8. The interface design takes safe interaction into consideration.	8. I want a reliable car interface that does not have a negative impact on traffic safety
	9. This interface design physical controls as a traditional way of interaction.	9. I prefer a traditional way of interacting
5. Opportunists	10. This interface design contains a positive mix of both physical and digital interface elements.	10. I want the best possible features in my car.

5.2.5 Design representation

The developed concept was at an early stage of development; hence, a proper tangible prototype could not be presented to the participants. Therefore, the design representation was a set of animations and images of the concept (for images and videos, see Appendix). The animations presented different aspects of interaction with the concept and were demonstrated in the form of a movie which in some cases contained context, descriptions, and sounds.

Since some of the participants were already familiar with the topic, they were expected to understand the different UX aspects which were addressed in the design representation, e.g. familiarity, perceived control, sensory experience, etc. On the other hand, other participants were not familiar to the topic and the visual representations were therefore designed to be as descriptive and explanatory as possible.

5.3 Analysis

The analysis included a joint analysis of the qualitative and the quantitative data from the Interviews and the Survey and a comparison with the Explorative Study results. This section describes the analysis of both studies.

5.3.1 Quantitative data analysis

The quantitative data consisted of the participants' Likert scale ratings in the Interviews as well as in the Survey.

The average value of each rating was calculated. The data in Table 13 was extracted from ten[6] interviews with the same participants as in the Explorative Study. As each Likert scale item referred to a specific product pleasure, the average rating for items referring to each of the product pleasures were also calculated. The calculated value for each pleasure category is presented in form of a radar chart for comparison.

For the survey, forty-nine answers were received. In order to analyse data from the survey's section 1, the first step was to calculate the average rating of each statement. As the second step, each respondent’s individual answers to the questions in section 1 were compared with the answers to the screener form. The comparison was meant to see how the respondent related to different UX aspects of the concept and to what extent that aspect was important for that specific respondent. By taking this approach, the user types (i.e. behavioural groups) were validated.

[6] The number of participants in Explorative Study was 12 but due to accessibility limitations, only 10 of these 12 were interviewed.

5.3.2 Qualitative data analysis

The qualitative data were analysed by applying a 'thematic content analysis method'. Moreover, the data collection process considered a hierarchical user needs model (Jordan, 2000) and the basic model of product emotions (Desmet & Hekkert, 2002).

Similar to the Explorative Study, different themes were extracted from the interview transcriptions and comments. Each theme covered one or several concerns which were expressed by the participants and is explained in the analysis section. The number of themes is fewer than the themes which were extracted in Explorative Study since some of the items with lower priorities were filtered out and excluded from the design guidelines. All themes, as they are presented in Table 14, show the topics which the users could relate to regarding the validation of the concept. It is important to mention that these themes were extracted from the users' free discussions and comments and were not extracted from comments in relation to the ratings.

5.4 Findings

5.4.1 Quantitative data

In the Explorative Study, the qualitative data was prioritised. In the evaluation, the quantitative data is presented first since this allows comparison between the evaluation of existing IVI solutions and the evaluation of the new design concept.

Table 13. Average ratings per item (n=10)

Pleasure categories	Likert scale Item	Average rating	Average rating of each category
Physio-pleasure	- The interface looks familiar to me.	4	4.5
	- I think that interacting with this interface will be sensory pleasing.	4.5	
	-The visual appearance of the interface is pleasant to me.	5	
Psycho-pleasure	-I think that I will quickly learn how to use this interface	3.5	4.25
	-I think that I will be able to use this interface without difficulty.	4.75	
	- I feel that I can use the common controls (climate, multimedia ...) without looking at the interface.	4.5	
	- I think that this interface is a good combination of physical and digital elements in interface design.	4.25	
Ideo-pleasure	-The design of the interface is innovative.	4.75	4.25
	- I feel that I can customise this interface according to my preferences.	4.5	
	- I can become attached to this interface the same way as to my mobile phone.	3.5	
Socio-pleasure	This design of the interface looks novel and trendy.	4.75	4
	I think I can be socially connected to other people by using this interface.	3.25	

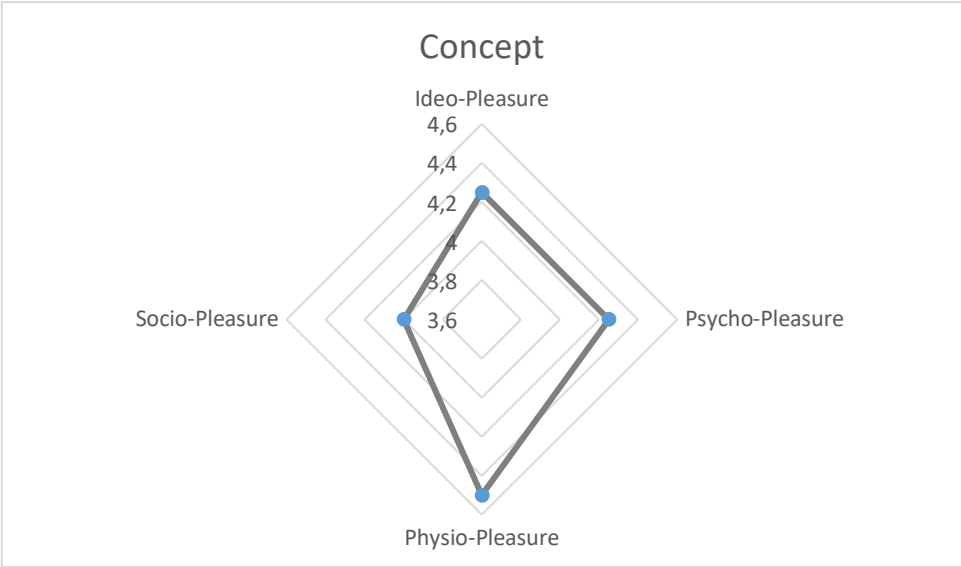

Figure 33. Radar chart showing average of ratings of the new concept

5.4.2 Qualitative data

The concerns that users addressed during the interview study (Table 14) were almost the same as those that were considered in analysis of Explorative Study (Table 7) and in the design guidelines (Table 9). Hence, it is suggested that they describe an integrated picture of user needs and concerns.

Table 14. Themes extracted from the Interview Study and the Survey. Examples of participants' statements.

Category	Theme	Pro statement	Con statement
Psycho-pleasure	Combination	Good combination of physical and digital interfaces	
	Perceived controls	Optimum number of physical controls for necessary functions… I feel safe with them	
	Screen size	The screen is big sufficient	The big screen can be distracting
	Ease of use	Simple and easy to understand and use functions	
	Haptic feedback	"I can feel what happens when pressing a button"	
	Phone connection	Access to all my phone apps is a very positive thing	Accessing to phone apps is distracting
	Cleanability	Looks easy to clean	
	Information distribution	Graphics look simple and minimalistic	"I think I cannot get enough information from a very simple screen" (UI)
	Aesthetics	Aesthetically pleasant	

Physio-pleasure	Familiarity	Similar to my phone	
	Aesthetics	Simple and minimal look	
Ideo-pleasure	Attachments	"I want it in my car since I can feel closeness"	
	Customization	"I like the customization settings"	I have slight concern about my personal data security
Socio-pleasure	Trend and novelty	Looks trendy and can be a future thing	"Might not be so attractive for my grandmother!"

The number of negative (i.e. cons) responses were significantly less in evaluation of the design concept when compared with the Explorative Study. However, this result can be due to the users' incomplete perception of the represented concept as it was mentioned many times during the interview study that*: "I would like to have a tangible prototype of the concept to assess it more thoroughly".*

In addition, by comparing the qualitative results from both studies, the design concept, as a visual representation of the pros and cons, included most of the advantages of the existing solutions with few disadvantages regarding each pleasure aspect (Figure 34).

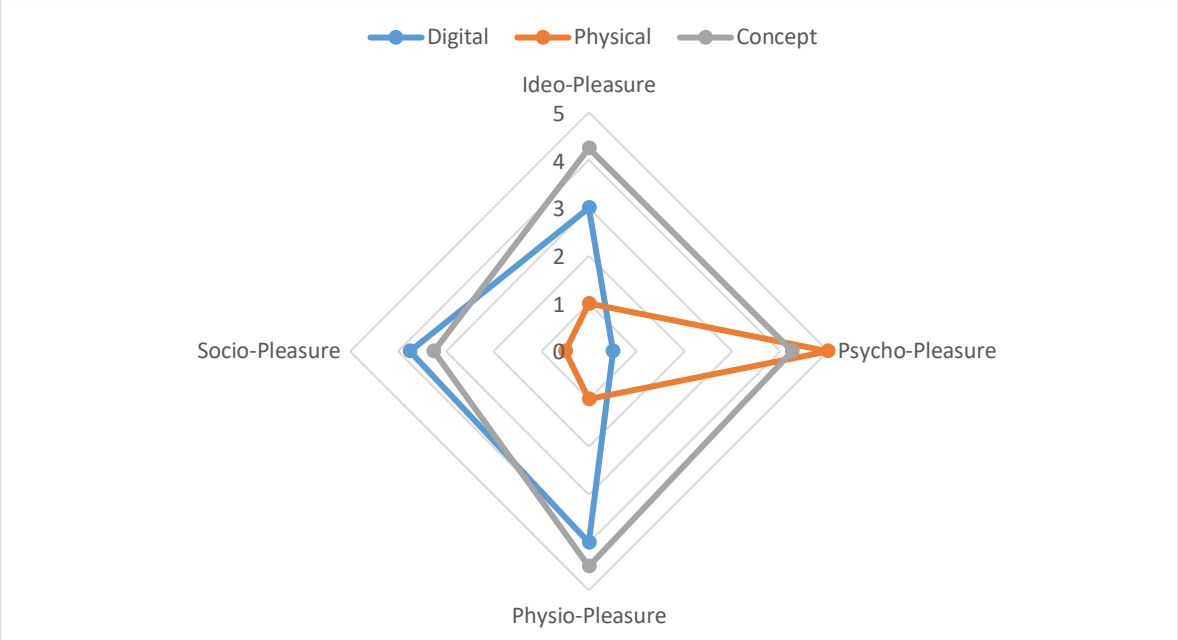

Figure 34.Comparison of the different types of interfaces based on a quantitative data analysis

However, the concept which incorporates the pros and excludes the cons of digital and physical interfaces, is not perfect considering all types of user pleasures. For instance, users still believed that physical interfaces are more usable (i.e. psycho-pleasure) than other interfaces and that digital interfaces are more novel and trendier (i.e. ideo-/socio-pleasure). However, considering the context of use, and the fact that the evaluated concept is a combination of physical and digital interface elements, the final concept was appraised as a successful and pleasurable IVI by the users.

From the participants'/respondents' perspective, the most significant advantages of the new concept were:

1) a good combination of digital and physical interface elements,
2) novel and trendy look,
3) minimal and clean design,
4) aesthetically pleasant,
5) offers customization and personalization,
6) offers familiarity and similarity to mobile phones,
7) phone connection features,
8) big screen.

Moreover, the disadvantages were as follows;

1) a big screen can be distracting,
2) too much novelty might be confusing for older users,
3) personal data security issues.

The survey results show that there were different user types when it comes to evaluation of the interfaces. Furthermore, the user types suggested earlier were proven to be a reasonable categorization of the users. However, some adjustments were needed. The adjustments concerned 'Harmony seekers' and 'Safety-firsters'. The evaluation results show that 48 (out of 49) respondents ranked safety as the most important feature. So, there were very few users who did not consider safety as their first priority and who ranked other factors as more important in a driving context[7]. This means that "Safety firsts" are probably not a specific user type but a general attitude of the users in a driving context. Furthermore, regarding 'Harmony seekers', 45 (out of 49) users declared that they seek similarity and harmony in their devices, and they expect the car interfaces to be the same in terms of the UI. This implies that there are many users who consider harmony (i.e. similarity, consistency, familiarity) as a positive experience, why this item–too– is a general attitude rather than a specific user type. However, it should also be acknowledged that there are users who do not prefer similarity and consistency in their product, but they were in minority in the present study.

In summary, the data collected in interviews were analysed using both quantitative and qualitative methods and considering the different UX models. The data was compared with data from the Explorative Study in order to evaluate the final concept. The results of the analysis showed that addressing the pros and cons of different types of interfaces resulted in a design that covered most user needs. The evaluation of the new design concept– as a representation of these pros and cons– shows that a combination of both types of interfaces can offer a more pleasurable and usable solution. Regarding the user types, it can be concluded that there appears to be two main (i.e. general) user types which most of the users share (e.g. Safety Firsts and Harmony seeker) and the remaining user types can be categorised as sub-categories.

[7] This item might be changed in non-driving context.

6 Summary and Conclusions

There were different stages in this master thesis project and each stage produced several results. The results of these stages can be summarised as follows.

The study started with a Literature review consisting of literature covering UX, HMI and IVIs. These topics were very important in the project since the input for the empirical studies and conceptual design originated from this work. Moreover, different UX models, which were the basis of this study, were extracted from the Literature Review. The Literature Review showed that there are different pros and cons of IVIs which have been investigated in earlier research. However, a majority of these studies focused on usability aspects and very few considered the context of driving and non-driving, and almost none considered passengers as users of IVI.

The results of the initial Explorative Study showed the responses of users towards physical and digital interfaces. The study indicated that there is no fully preferred type of interface (i.e. physical and digital) but a combination of both could be pleasurable. This finding was later validated in the evaluation phase. Moreover, concepts such as familiarity, trust, haptics, novelty, ease of use, learnability and trends were items that explained user needs and concerns. One of the key findings is that these items had a different meaning in a driving versus a non-driving context.

In addition, it was found that the preferred type of interface was related to different user types. In fact, in order to investigate the pros and cons of each type of interface, context of use and user behaviour should be considered. Therefore, the users in this study were categorised into five different behavioural groups and for each group, different needs and concerns were specified. These factors are addressed in Desmet's product emotion model as 'concern'. 'Concern' can be a combination of user behaviour and context of use. However, evaluating the final concept showed two main user types or attitudes of users and that other user types can be sub-categorized under these two main categories.

In order to validate the results, the intention was to represent all findings in the form of a design concept and evaluate this concept with users. Having a design concept and evaluating it with users could help to have a better understanding of the specified pros and cons. However, before creating the design concepts, design guidelines had to be formulated: What do the results imply for the design of an IVI? To create the design guidelines based on the empirical study results, the user needs and concerns had to be filtered and converted into an actionable guideline. The challenge was that some of these users' needs/concerns contradict each other. Two approaches to cope with this challenge were to: 1) exclude extreme items from the list of concerns (e.g. *I only prefer a physical interface since it is more reliable*) and 2) consider flexibility in the design as much as possible. These approaches resulted in categorising user concerns in terms of Jordan's 'Hierarchical model of user needs' and shaping a design guideline.

Moreover, one of the key findings of this study indicates that the IVI as a product, lacks meaning in itself. The IVI has always been recognized as a dependent component of a vehicle. Furthermore, it is a fact that the functions of IVI should not be prioritised to the primary task of driving, However, with the developments of autonomy level of cars, the importance of IVI as a significant part of the car interior becomes clearer. Therefore, adding a character and user's personalization to the IVI in order to create an attachment between the IVI and the users were considered as a possible option.

In order to validate and evaluate the design guidelines, they should have been applied to a concept. Therefore, a concept was created to represent the guidelines and used to be evaluated by the users. The concept is a combination of both physical and digital interfaces including some added features.

There were two main approaches for evaluation of the concept, one was to evaluate the final concept by interviewing the same users as in the Explorative Study. The other was to send out a survey to a larger group of potential users. The results of the evaluations showed that the same concerns were identified as specified in Explorative Study. Moreover, from the users' point of view, most of the pros and cons of different types of interfaces were considered in the concept; it is a better solution than the existing IVIs. However, some adjustments must be applied to concept.

In summary, this study considers a bigger picture of the physical and digital elements of an interface. The research questions were answered by conducting an Explorative Study and an evaluation. The results indicated that there are different pros and cons in IVIs which required to be reviewed towards the UX aspects. In this study, it was tried to create guidelines that covers the user experience of physical and digital interfaces. However, there are still many different IVI related aspects and areas that need to be investigated in order to create a positive and pleasurable experience for the users.

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Appendices

Appendix A. Visuals of primary empirical study

This study was cancelled due to COVID-19

Custom made physical and digital HMI for user testing

Volvo cars driving simulator rig

Appendix B. Screener form

Background Questionnaire (Screener form)
"Exploring the user experience of digital and physical automotive interfaces"

Please, select your age group.

- ☐ > 25 years
- ☐ 25-35 years
- ☐ 36-45 years
- ☐ 46-65 years
- ☐ > 65 years

Please, specify your gender.

- ☐ Female
- ☐ Male
- ☐ Prefer to not describe

Do you hold a valid driving licence?

- ☐ Yes
- ☐ No

Which year did you receive your drivers' license?

Year _____

Please, specify your driving experience.

- ☐ < 5.000 km/year
- ☐ 5.000 – 10.000 km/year
- ☐ 10.001 – 15.000 km/year
- ☐ 15.001 – 20.000 km/year
- ☐ 15.001 – 20.000 km/year

Do you mainly drive for private reasons, or do you drive professionally?

- ☐ Primarily non-professional
- ☐ Primarily professional

Please, specify your car model and year of production (example: BMW-2011)

The test instructions and the interview will be held in English. Are you comfortable in answering simple questions around the use of the car interface and your experience during the test in English?

- ☐ Yes.
- ☐ No.

Please send this form to:
Hossein.farimani@volvocars.com

Thanks, and I will contact you soon.
Hossein

Appendix C. Invitation and GDPR

Invitation for Participation in Research Study

“Investigating the user experience of physical and digital automotive interfaces”

Dear colleagues and friends,

My name is Hossein Farimani, and I am doing my Master in the program Industrial Design Engineering at the Chalmers University of Technology. Currently I am working on my master thesis “User insights on physical and digital interfaces in the automotive context” at the User Experience Center at Volvo Cars.

You may have wondered about current trends in vehicles to go all digital. Years ago you had lots of push buttons and knobs on your dashboard, to control different functions, but nowadays these are mostly gone, and you usually have a big touch screen and very few physical controls.

What do you think about this transition? Do you that it is a good approach or do you long for the ‘old school’ interfaces with physical controls? Besides safety and usability, with which type of interface do you truly enjoy the interaction?

Study Structure

To gain more insights about the user experience when interacting with digital and physical infotainment systems, we are conducting a study during week 10 and 11 to investigate how drivers’ experience the interaction with different infotainment systems. During the test, you will be driving in a simulator and perform a number of tasks with two different conceptual interfaces. The test will take around one hour, and you will receive an incentive for your time and efforts.

Signing Up for the Study

If you are interested in participating, please fill in the attached questionnaire **and send it back to us in a reply to this email**. If you meet the criteria for participation, we will get back to you to book a suitable time for participation.

In the case that the participation criteria are not met, we will not get back to you with an answer and we will delete your questionnaire in accordance with GDPR.

For more information, please contact:

Study Leader

Hossein M. Farimani <hossein.farimani@volvocars.com>

Supervisor

Fjolle Novakazi <fjolle.novakazi@volvocars.com

Thank you for your interest!

Anonymity & the Right to Terminate Participation

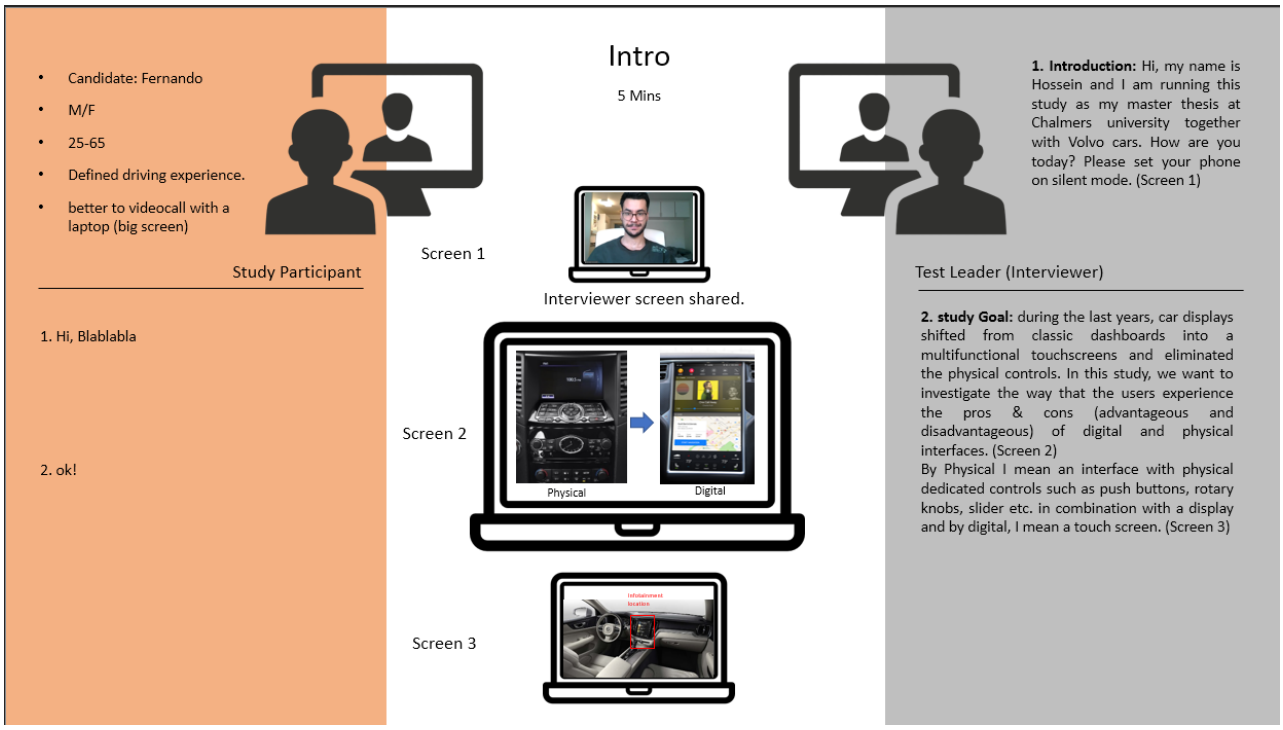
For processing of all information that can be attributed to you as a person, the rules of the General Data Protection Regulation (GDPR) are followed. Volvo Car Corporation is responsible for the personal data collected in the study and the contact person is Data Protection Officer Jan Wellergård. When the study has been completed, it will therefore not be possible to trace the information to any individual. The study should not be seen as a personal test, i.e. no one will be judged in any way. We analyse how a whole group varies, not how a particular individual behaves. Therefore, there is no best/worst answer or best/worst performance.

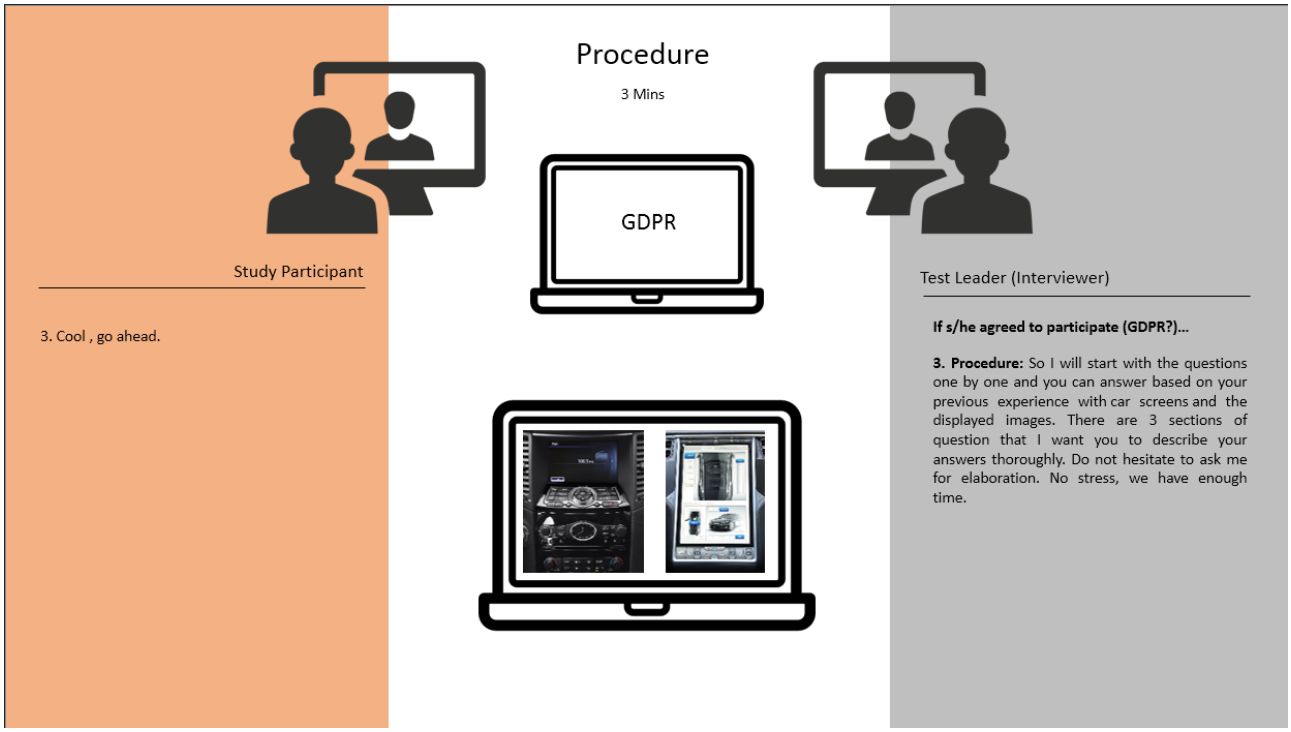
You have the right to terminate the test at any time, for example if something feels uncomfortable or stressful. You do not need to motivate the interruption in any way, just say that you want to end the test, and we will.

Confidentiality

The purpose of the study, as well as the measuring equipment and test methods are strictly confidential. We therefore ask you to respect this and not tell any other person about the information you have received so far, or possibly will be receiving in the future.

Appendix D. Explorative study interview material





Appendix E. Interview transcriptions and themes

There are 22 interview transcriptions for both Explorative and evaluative studies. Due to the limitation of space, only one transcription is presented as below. Each transcription was followed by a table of themes the same as Table 3.

Pros n Cons

Digital: I guess I have to talk about my own experience. So my own car is a combination. You can use both touch screen or knobs and dial gauges.

I found it easier to use the traditional because my eyes will stay on the road. My hands using the turning knobs is much easier for instance if I want to change radio station or songs the touch screen require that you look at that. You will definitely be distracted so it's good that I have both options.

So the main problem with digital is that you have to look at it. The second problem is that you have to be accurate and concentrate then you will miss a function. I Think it takes longer to perform an option on touch screen also the fonts are usually small. And I think this is the main problem. There is also usually a delay in this touch screens and is not as sensitive as iPhone screens maybe its technology so sometimes you have to push it twice, it can be a short coming.

I feel that here you eliminate one of your senses and it is not good.

The pros are that there are more options. Because you can do everything as simple as your iPhone screen. Imagine you have 10 million buttons but here you can do all the things with only one touch. It brings more data to your interface, and it is good.

I do not have a voice control on my car, but I think that will work well. So I'd prefer voice activation.

Physical: I am more familiar with this; the good point is that there's a lot of buttons. First it looks confusing but after a while you learn it and quickly you can locate it and push it which is so clear what to do. The same thing about knobs which are very handy when changing the channels and volume.

As an example, if I want to turn on the volume. In the digital you know where to push your finger then you gonna keep it or scroll up or down and distract you. But physical is so clear. Also. You anyway need a screen anyway for navigation.

I actually find out that we are not really using the screens that much usually they are far behind the today's technology in comparison with iPhone, so we use our phones for instance for our navigation. It looks like waste of money. I barely use the screen for navigation, and I prefer to use my iPhone because it shows the traffic and my favs etc. I would rather to have a place to put my iPhone instead of the screen :)

Cons: The bad thing about physical is that sometimes like radio, you have a lot of channels, and it would be confusing to have buttons for each so this can be a good thing about touch screens btw. you have the option to search in screen.

driving context: If you are not driving you don't need your eyes so digital is better but since you are driving it's not and its all about safety. So let's say, if I only use my iPhone and my phone connect properly to the interface and since I can activate it with voice, then it will get much easier.

Imagine I am going to use a car for 5 years but using and iPhone for maybe 2 years and you keep updating the apps anyway, so if you connect the iPhone to the screen since it's a better visibility then that would be great cut you always use your smart phones since you are more familiar with.

Transition:

I see more functionality in the new versions. Before there was no GPS, even not CD. But the new ones you have even access to internet but some basic functions such as AC it does not matter to be physical or digital. I think for multimedia it is better to be digital but for other basic functions like AC or flasher and signals it is better to be physical. My personal gut feel is that the physical is more reliable . What if the digital get broken or get hacked so it is not good.

It is not easy to use knob to use with GPS, so touch screen is easier for map.

So to wrap up, for navigation, digital is better, for audio it depends since you have a better visualization on digital but better control with manual and the same with phone, I don't care to be digital it can be all manual. So it depends on the function.

Physical always put some restriction of space so digital is better for most of the function.

Anything else: if it was voice activated it added more value. I actually prefer to have the basics on my steering wheel, and I use it more. Also Tuby (eye gaze detection) which you can also makes control easier.

Appendix F. Implication of multi-layered model of product emotions

Stimulus	Concern (anticipated experience)	Appraisal (situated use)	Emotion (Episodic experience)
Digital Pros	Goal (I want similarity to my other devices)	Motive compliance (the GUI looks like my phone)	Satisfaction
	Goal (I want a big screen)	Motive compliance (digital gives a bigger screen)	Satisfaction
	Goal (I want lots of information and functions)	Motive compliance (digital gives lots of info…)	Satisfaction
	Goal (I want access to internet)	Motive compliance (I can have access to internet on digital)	Satisfaction
	Goal (I would like to have different brightness of screen)	Motive compliance (Digital has day/night mode)	Satisfaction
	Goal (I wish I could customize my car screen)	Novelty (Oh, I heard digital can be customizable)	Pleasant surprise
	Goal (I usually use my phone a lot, having access to my phone app is a priority for me)	Novelty (I found out I can play my fav music list with my Spotify app on the infotainment)	Pleasant surprise
	Goal (I always keep my car interior clean)	Motive Compliance (it is too easy to clean digital screens, just like my laptop)	Desire
	Attitude (I love minimal and clean looks)	Pleasantness (I think digital interfaces are so pleasant since they look minimal and clean)	Attract
	Attitude (I like smooth, flat surfaces)	Pleasantness (digital feels a positive sensory experience, touch)	Desire
	Attitude	Novelty (Digital interface is just so new and modern; I love tech stuff)	Amazement
	Standard (using a green product is a value for me)	Legitimacy (Digital feels more sustainable)	Admiration
	Standards (minimalism is a trend)	Legitimacy (digital is minimal and trendy)	Admiration

	Standard (having connection to people is a value for me)	Legitimacy (I can see my incoming messages on the screen)	Admiration
Digital Cons	Goal (my priority is using the interface without looking at it)	Motive compliance (Digital always demands looking at it)	Dissatisfaction
	Goal (I am annoyed by the light reflection on the screen)	Motive compliance (Digital screens reflect the sun light and that is annoying)	Dissatisfaction
	Goal (robustness of the screen is a priority for me)	Motive compliance (I feel digital interface is not robust enough)	Dissatisfaction
	Goal (I usually use the interface with my glove)	Motive Compliance (it is not possible to use the touchscreen with gloves)	Dissatisfaction
	Goal (I want the interface to be easy to use)	Motive Compliance (Digital interface is somehow confusing and hard to use)	Dissatisfaction
	Goal (I usually memorize the place of each function and use it without looking at it)	Motive compliance (in digital interfaces, everything is moving around and dynamic, I can't remember the places)	Dissatisfaction
	Goal (I would NEVER update my car interface)	Novelty (the other day, I had to wait for my Tesla to update itself, it was annoying)	Unpleasant surprise
	Attitude (I would like to feel the feedback of function under my fingers)	Pleasantness (Digital looks like nothing is happening when you press a function)	Dislike
	Standard (interfaces should be easy to use for the old and people with disabilities)	Legitimacy (Digital interface is not easy for old people and somehow, impossible to use for people with Parkinson)	Contempt
	Standard (I care about my information protection)	Legitimacy (What if digital interface gets hacked? That is awful)	Indignant
Physical Pros	Goal (I need to learn the interface quickly)	Motive compliance (physical is easier to learn since everything has its place)	Satisfaction

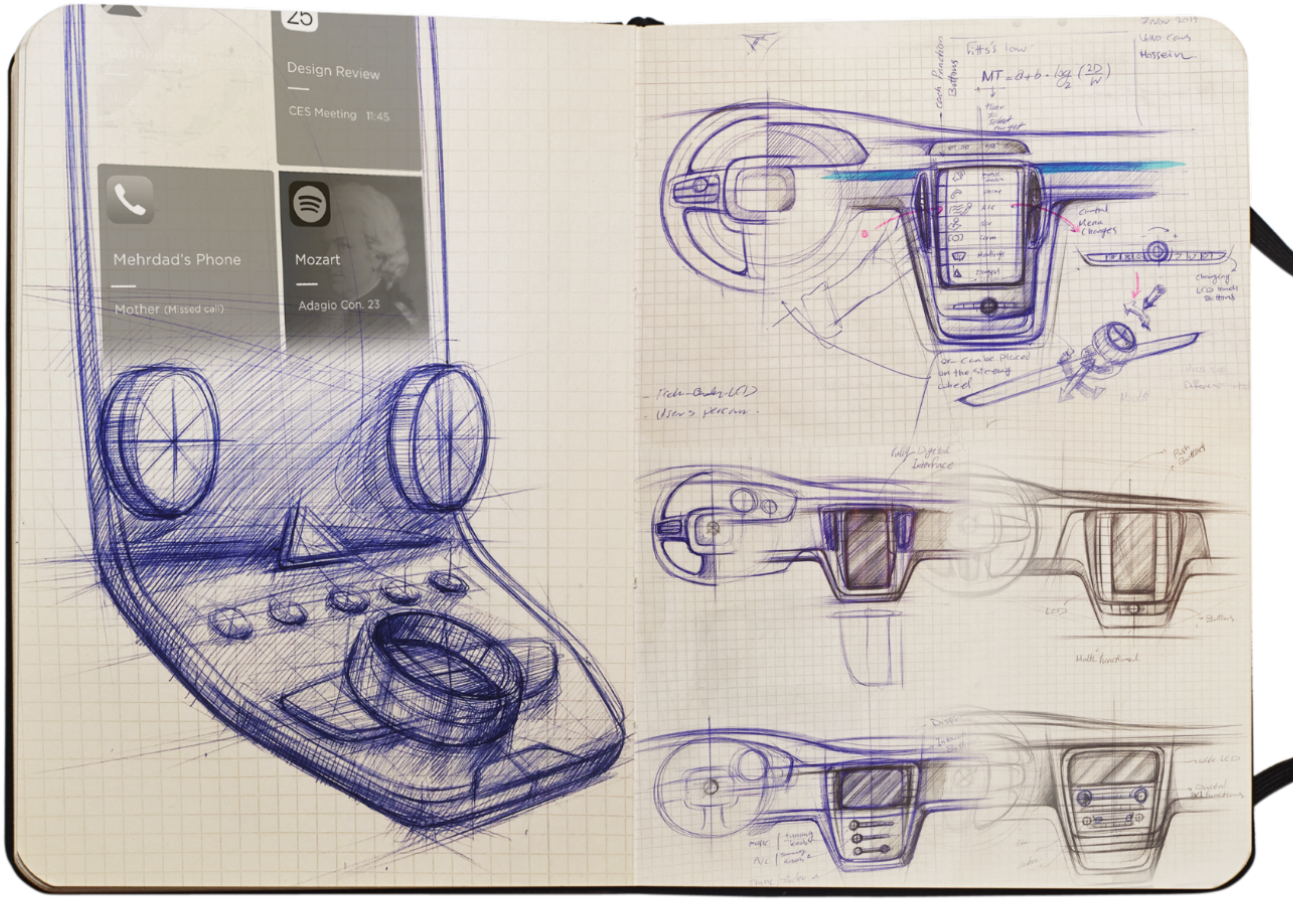
	Goal (I want to use the interface without looking at it)	Motive compliance (I can feel the functions with my fingers on physical interface (haptic feedback) I think it's valuable)	Admire
	Goal (I NEED one button per function)	Motive compliance (I have one per function (dedicated) controls on physical)	Satisfaction
	Goal (I want to find and do the functions quickly)	Motive compliance (if you get used to physical, it's so quick to find and perform a task)	Admire
	Goal (I don't want the interface break easily)	Motive compliance (physical interfaces are more robust)	Satisfaction
	Goal (I want to have control over the system)	Motive compliance (I feel in control with physical)	Satisfaction
	Attitude (I love physical buttons; I think I am an old school button-guy!)	Pleasantness (Physical interfaces are my fav in the case of buttons)	Like
	Attitude (I like familiar devices)	Pleasantness (I feel more at home with buttons)	Desire
	Standards (Interfaces should be reliable and safe)	Legitimacy (Physical looks more reliable and safer to use)	Admiration
Physical cons	Goal (I am obsessed with cleaning the car interior)	Motive compliance (physical has holes and it's hard to clean)	Dissatisfaction
	Attitude (I feel bad when the interface is so crowded and messy)	Pleasantness (physical is always messy and crowded with unorganized sections)	Disgust
	Standard (we should consider sustainability in products)	Legitimacy (physical interface with all these plastic parts are not sustainable, actually, it is just a gut feel)	Indignant

Appendix G. Evaluation B data collection

There were 49 responses to the survey and here only 11 answers are showed as sample data.

Questionnaire											Screener										Background Questions			
Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q9	Q10	Q11		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	A	G	DL	DY
4	4	5	5	4	4	4	4	4	5		4	2	2	4	4	2	2	5	3	4	25-35 years	Female	Yes	2011
4	4	3	4	2	3	5	4	2	5		3	3	3	4	5	5	3	5	1	5	25-35 years	Female	Yes	2011
3	4	4	3	4	5	4	2	3	2		3	4	2	5	4	3	5	5	2	3	25-35 years	Female	Yes	2009
4	5	5	5	5	4	5	5	4	5		4	5	3	2	4	5	2	5	5	4	25-35 years	Male	Yes	2010
5	5	5	3	4	5	5	4	4	5		4	4	3	5	5	5	5	5	3	4	25-35 years	Male	Yes	2015
4	4	4	3	4	2	4	4	5	5		3	2	2	4	4	1	3	5	4	4	25-35 years	Female	Yes	2011
4	5	5	2	3	4	5	4	4	4		2	2	2	2	3	2	3	4	3	3	> 25 years	Male	Yes	2018
3	4	4	4	4	3	2	3	5	5		5	3	3	5	4	2	2	5	4	5	46-55 years	Male	Yes	1992
4	5	5	3	4	3	5	3	3	4		4	4	2	3	4	2	2	5	3	4	36-45 years	Male	Yes	1998
5	4	5	3	4	4	4	4	3	5		4	2	1	4	4	5	4	5	2	5	36-45 years	Male	Yes	2003

Appendix I. Sketches of final concept



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Appendix H. Links to the videos of concept

https://www.youtube.com/watch?v=KgxktBdPo78&t=136s

https://www.youtube.com/watch?v=CEgioomBr38&t=17s

https://www.youtube.com/watch?v=EYACWk--kVE

https://www.youtube.com/watch?v=0fyS_zuW2Lk&t=14s

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