Sistemi Interattivi a supporto dei Veicoli Autonomi. User Experience all'interno del concept di mobilità Pop.Up Next.

Summary of Doctoral Dissertation
Doctoral Program in (33th Cycle)

Interactive systems to support Autonomous vehicles

Understanding User Experience within Pop.Up Next mobility concept

Andrea Arcoraci
* * * * * *

Supervisors
Prof. P. Tamborrini
Prof. A. Di Salvo

Politecnico di Torino

Introduction

The scope for the first chapter is to introduce the context of investigation and explain the primary purposes of the thesis. The chapter starts to discuss and explore in a broader way the peculiarity of the future mobility system, dwelling on some crucial topic closely connected with the thesis. Then, after this high-level preliminary inquiry, the chapter will focus straight to the specific field of application; the autonomous vehicles (AVs). Finally, it will be discussed the primary purposes behind this doctoral research and the expected results, concretized within the research questions.

1.1 Context

Although metropolis played a central role in the significant advances of our society and most extraordinary achievements in the arts and sciences, they are continuing to struggle with an increasingly complex set of systemic issues that include the question of transporting citizen within the cities. Many of the largest cities in the world are striving to find mobility solutions that guarantee a concrete response to the growing need for mobility required by citizens. One of the major causes of this growing demand for mobility is the increase of population within urban areas [1] that cause the rise of numerous big cities in the world [2] consequently.
The interpolation of these significant challenges on a global level will have evident results that we can already perceive today in our urban centers; congestion is one of the most explicit symptoms, but it is not the only one. People living in urban areas are exposed to another equally important problem: air pollution which can be attributed mainly to vehicle emissions [3]. The most desirable direction, therefore, seems to be to focus primarily on optimizing the existing transport system by focusing on concepts such as system efficiency and effectiveness. In order to achieve this, alignment and cooperation of horizontal and vertical policies are needed [4]. Lam and Head [5] suggest a short definition to explain the core of sustainable urban mobility; *''the ease, convenience, affordability and accessibility of travelling to one's destination with minimal impact on the environment and others''*. One of the most common dilemmas when dealing with the issue of sustainable mobility is the question of automobility. Cars are widely considered an unsustainable vehicle mainly due to two extraordinarily evident and relevant factors: their substantial contribution to greenhouse gas emissions, and the excessive occupation of urban spaces, due to parking and more. Considering all the issues mentioned so far, we can, therefore, declare that the paradigm of private car ownership in the mobility system is unsustainable under the economic, ecological and social perspective [6]. To trigger a paradigm shift towards more sustainable mobility can be considered three main focus points [7]: efficiency shift, modal shift and the reduction of mobility needs. About efficiency, two central strategies are crucial to implementing the productivity of cars: car sharing and rides sharing. Both strategies can be now implemented with more success if combined with the autonomous vehicle's technology.

1.1 Autonomous vehicles

One of the most recent and established definitions for the description of autonomous vehicles is provided by the National Highway Traffic Safety Administration of the United States Department of Transportation, which defines them: *"self-driving vehicles are those in which operation of the vehicle occurs without direct driver input to control the steering, acceleration, and braking and are designed so that the driver is not expected to constantly monitor the roadway while operating in self-driving mode"* [8]."

Autonomous driving, described as a paradigm shift in daily transport, benefited by the prediction of possible positive impacts for humans and the entire mobility system. AVs could reduce pollutant emissions [9], improve the in-vehicle experience by offering to the passengers a free time for personal activities [10], and improve safety [11] [12]. AVs also represent a valid transport solution for those groups of users who are currently unable to use autonomously traditional vehicles, e.g. children, older people and people with physical problems. [13]. This opportunity means widening the mobility offer to a broader audience, resulting in both benefits for society and the risks of possible overloading of the system. Another potential benefit of AVs concerns the economic aspect, these vehicles integrated within a sharing system, could be more advantageous than the private vehicle, as users pay for the actual use of the vehicle, thus abandoning all the burdensome expenses produced by a proprietary vehicle [14]. Some of the concerns about the possible risks, on the other hand, concern the excessive reliance on the technological structure that supports self-driven systems; researchers warn about the possibly severe repercussions of hardware and software failures [15] [16]. If we then imagine that some scenarios presented within some studies [17] [18] show a possible increase in the number of vehicles on the roads, this consequently increases the possibility of accidents, and with greater severity. However, even if there are risks, as in the development of any other technology, autonomous vehicles still represent an evolutionary opportunity for the whole of society with potential improvements in many aspects. The reduction of risks and potential downsides will also depend significantly on how self-driven technology is developed and how the system makes decisions. Waldrop [19] in his research article, taking as an example, the AV developed by Google, offers us a synthetic and practical description of the basic functioning of these autonomous driving systems. The author explains that one of the most critical capabilities of AVs is to be able to perceive the surrounding environment through a continuous scanning process using a combination of radar, laser technology and cameras that collect a massive amount of data in a short time. Each of these technologies has specific functions. A central computer processes all the information collected by this equipment in real-time and generates decisions about the behaviour of the vehicle [19].

Another fundamental technology for the automation process is Internet connectivity [20], which allows the network of connections developed to support this technology.

Automation in AVs has been classified according to several taxonomies, one of the most widespread and accredited is that provided by the Society for Automotive Engineers [21]. The minimum level of automation in the SAE classification is defined as level 1, up to level 5, where the system achieves full control of the vehicle and takes responsibility for driving. Within this thesis, level 5 will be taken into consideration, conceived as a reference point useful to identify the application scenario instead of a rigid set of design guidelines.

High levels of automation, as in the case of levels 4 and 5, raise numerous perplexities and concerns also from an ethical point of view. The ethical implications of AVs could, therefore, represent a significant obstacle to the acceptance and adoption of this technology, significantly if the attribution of responsibility for possible accidents will be not clarified soon. The issue of user acceptance of AVs represents the biggest obstacle for the introduction of this technology [22]. According to recent studies [23] [24] [25], the public's intention to buy or use AVs is still generally too low. Some studies have attempted to apply theoretical models, such as the Technology Acceptance Model (TAM), to investigate some of the most influential factors in the intention to use AVs [26] [27] [28]. From the analysis of these extension models of the TAM, emerge a central hypothesis within the various researches; the ease of use and the perceived utility are two factors closely related to the intention to use AVs. Beyond these factors, trust [29] [28] and perceived risk perception [30] [31] have been highlighted as elements that play an essential role in the acceptance process. However, the inconsistent results between the various studies and the limited number of studies carried out do not yet provide a clear framework.

The introduction of AVs also offers the opportunity for new urban mobility services, such as the Autonomous Mobility on Demand (AMoD). AMoD is a mobility model that draws its foundations from car-sharing and uses AVs to transport customers to destinations they require, following their mobility needs [32]. AMoD, if coupled with the use of public transport, has the potential to become an economical and sustainable door-to-door transportation modality [32]. The benefits of AMoD services could be even more evident if AMoD is mixed to the practice of ridesharing [7]. Within the AMoD context, this practice is managed through dynamic ride sharing systems (DRS) . DRS is a system that allows to group travellers who start their journey from a similar origin and head to a similar destination, making them travel together in the same vehicle for part of their journey [33]. However, although AMoD, associated with DRS, is a valuable route to sustainability, some studies highlight potential risks from these services. Congestion and pollution, for example, could worsen if AMoD becomes too attractive to urban mobility users to the extent that it outweighs today's use of private vehicles [33].

1.1 Doctoral research

The research project discussed within this thesis is the result of a fruitful collaboration between the world of academia and the industrial sector. The main project's actors are Italdesign, a design company, and the Politecnico di Torino. The collaboration focuses on project Pop. Up Next (Fig. 1), a modular transport system that offers both modality transport: land and air travel. The system is fully autonomous and electric, launched by Italdesign company as a new mobility solution for the urban context.

Fig. 1 - Pop.Up Next Prototype presented in front of Italdesign headquarters

The Pop.Up Next project within this research represents a practical and "real case study", useful to stimulate the reflections on the introduction of AVs on the road, with a specific focus on automation level 5. Whit agreement between the two project's actors, the research has focused more specifically on the ground mode of transportation. The research will investigate the concept of sustainable mobility and, referring to the research areas of Human-Machine Interaction (HMI) and User Experience (UX) Design, while maintaining a broad vision that includes some aspects related to Interaction Design and Service Design. In conclusion, the concretization of the objectives of this thesis is expressed more explicitly through the following research questions:

- *What are the future needs and desiderata of users within fully AVs?*

This research question, following the Human-Centered Design (HCD) approach, poses a question regarding the new future needs and desires of humans inside AVs. The investigation implies broad-spectrum research and inevitably involves the evaluation of many aspects of the UX.

- *How can User Experience Design address sustainable experience in AVs, providing positive impacts for both the user and the whole system?*

The role of UX Design within the new mobility system has been discussed several times by several researchers. This research question is primarily aimed at understanding how this design approach can positively influence the UX, and more broadly, the whole system, thus achieving a sustainable experience for both.

- *What are the possible User Experiences within fully AVs in the context of shared mobility?*

The third and final research question aims to achieve a more practical-design research contribution starting mainly from the theoretical knowledge obtained in the two previous questions.

State of art

In this chapter, the main theories and issues concerning the research areas of User Experience (UX) and Human-Machine Interaction (HMI) associated with AVs will be addressed and discussed. The analysis of the literature within these two fields of research has been developed in two main phases: the first phase provides an overview of the main theories most recognized, while the second phase represents a more in-depth analysis of the issues related to the context of autonomous vehicles.

1.1 User Experience

The User Experience (UX) according to ISO is defined [34] as*: "person's perceptions and responses that result from the use and/or anticipated use of a product, system"*. Bødker [35] has defined the UX more broadly as "the third wave" of Interaction Design, in which the usability and ergonomics aspects related to Interaction Design are further expanded with other influential aspects in the daily use of products. According to [36] Hassenzahl and Tractinsky aspects such as beauty, fun, pleasure, and personal growth are necessary elements for the satisfaction of general human needs. The UX compared to Interaction Design adds the opportunity to consider individual interactions with the system within a more complete and broader experience in which various factors contribute in a systemic way to the final user response. This overall view of the experience also represents the most realistic and close view of the daily use of products and services. [36] Hassenzahl and Tactinsky argue that UX is heavily conditioned by the context of use and consider the UX as the result of three determining factors: the internal state of the user, the characteristics of the designed system and the environmental context in which the interaction takes place. Considering the complexity of the context in the design of artefacts is, therefore, one of the significant challenges of the UX; Buchenau and Suri [37] state that the experience related to artefacts is not an isolated event, but involves other objects, places and people. In order to optimize

this holistic and systemic view of the experience, the UX as an academic discipline uses a multidisciplinary approach that involves different perspectives that have the common goal of studying human experiences with products, systems and services. Many researchers have presented a consistent number of models to contribute to the understanding and design of the UX [38] [39] [40] [41] [42] [36] [43] [44]. For example, the holistic model of [44] Mahlke and Thüring's is one of the most recent and has been built based on the models and research contributions previously produced. The model identifies three types of components within the UX: the perception of instrumental qualities, the perception of non-instrumental qualities and finally, the perception of emotional reactions. The instrumental qualities refer to functional and pragmatic aspects of the system such as usability and usefulness, unlike the non-instrumental qualities that refer to more pleasure aspects such as appeal and attractiveness. Both aspects, according to studies conducted by [44] Mahlke and Thüring influence the third component that refers to emotional reactions and more generally, the evaluation of interactive systems.

1.1 User Experience in Autonomous Vehicles

Autonomous driving technology will irreversibly transform the in-vehicle experience. The ability of vehicles to self-managing without human interference in driving tasks will change the traditional habits of users, also substantially impacting their perception of user control and trust in the vehicle.

Passengers in vehicles with a high level of automation will all become regular passengers, with the possibility to gain some free time to dedicate to useful [45] [46] and leisure activities, also having the opportunity to explore new types of interaction with the vehicle and other passengers. This paradigm shift justifies recent increased attention of researchers in the field of human factors towards non-vehicle related activities, the so-called [47] "non-driving related activities" (NDRA). König and Neumayr [48] argue that the increased space for NDRAs in autonomous vehicles represents the second most important advantage derived from the introduction of this technology, anticipated only by the increased mobility possibilities for elderly and disabled people. Mokhtarian and Salomon [49] argue that NDRAs, such as relaxing, working, talking on the phone or reading a book, reduce the cost of travel and affect the positive, or at least less negative, travel experience. Bansal et al. [50] argue that users will also evaluate their willingness to spend money on these vehicles based on the actual use of their leisure time earned during the trip. However, the advantage of gaining time during the trip is not the only emerging issue in the UX in AVs. Moving the driving operations of the vehicle more and more in the hands of artificial systems requires the rethinking and redesigning of the relationship between human and machine, a factor that will heavily influence also the user response of the UX. For example, trust represents one of the most critical issues in the new HMI in autonomous vehicles [51], especially in high levels of automation where the autonomous system almost exclusively manages driving operations. The user does not evaluate the system based on his current skills but evaluates it based on how the system information is perceived and processed—the information provided by the system influence, therefore, the degree of user trust [52]. Autonomous systems need first to offer interfaces and interactions following the rules of usability [52], which not only allows the use of these systems efficiently and effectively but also helps to improve

user trust. The communication of the system must be "polite" [52] and consider including anthropomorphic elements. Some experiments show that the application of anthropomorphic elements in autonomous systems improves the acceptance of this technology [53] [54]. In conclusion, the new HMI in AVs will inevitably have to be focused on constant collaboration between the two actors, a need that could be emphasized in users with personal traits related to need for control.

1.1 User Experience in the context of shared Autonomous Vehicles

According to the objectives of this thesis, oriented towards sustainable mobility, the context of shared mobility on demand, better recognized as Autonomous Mobility on Demand (AMoD) [32] [55], will be considered. However, sum the peculiarities of sharing services to the peculiarities of AVs leads to the emergence of further important issues for the UX, in addition to those already addressed in the previous paragraphs. For example, considering AMoD as an evolution of traditional taxi, one of the revolutionary elements compared to the latter is the disappearance of the human driver inside the vehicles. This revolutionary event changes customer expectations and triggers a possible change of user's behavior inside the vehicle; the user will feel free to act more freely, perceiving the space inside the vehicle as a more private and less public. The interaction with the vehicle also benefits, as the user will feel able to manage his experience autonomously and calibrate the available settings according to his preferences, without having to worry about asking for the driver's intermediation. [56].

On the other hand, in order to be accepted, autonomous shared vehicles must be able to break down the barrier represented by users' attachment to the vehicle they own. This user resistance scenario can be mitigated by the role of the UX, which, as evidenced by many other technologies [33], could represent the appropriate strategy to make AMoD services more attractive. Users may be willing to overcome worries about automation and their attachment to the private car only in exchange for new tangible benefits [33] and extraordinary experiences within AMoD services [33]. Other critical aspects concern the issues of shared rides in AMoD services. The DRS represents a fundamental element for the sustainability of the system [7], but it must face also the real willingness of the users to spend some time in the cabin with foreign passengers [57]. The DRS may conflict, for example, with the emphasized privacy needs of some users. Other users, on the other hand, could focus on needs such as comfort, speed of travel and cost of service [33]. These needs may also vary depending on the user's mood, travel motivations and other contextual factors. Jacques et al. [58] state that individuals may deliberately choose modes of transport based on attributes related to utility and pleasure, thus being able to balance these attributes within the UX in AMoD means obtaining more possibilities of attractiveness for these services. About HMI, many of the issues that emerged in the analysis previously addressed for AVs remain valid within AMoD services.

Methodology

In this chapter, the methodologies and research approaches adopted within this thesis will be presented and discussed.

In the first part of the chapter, in a general way, the role of Human-Centered Design and its centrality in the context of autonomous vehicles will be discussed. Subsequently, one of the most crucial research methods for this work, Research Trought Design (RTD), will be discussed in depth. Finally, the details of the methodological structure and the process of implementation of the method will be shown and explained in a more specific way, accompanied at the end by an overall schematic representation of the methodology used.

1.2 Approach

Uno One of the critical aspects of this research approach is the focus on Human-Centered Design (HCD). The centrality of human in design for Gill [59] is defined as "a new technological tradition which places human need, skill, creativity and potentiality at the center of the activities of technological systems". Placing humans at the center of the project acquires even more critical, especially in complex technological contexts such as that of AVs. A correctly functioning autonomous driving technology is useless if users are not willing to accept and adopt it.

Through this vision, the research intends to tackle design experiments capable of producing reflections and contributions in the field of design.

Design experimentation conducted for research purposes is a widespread practice in science and is better recognized under the name of Research through Design " (RTD). Research through Design (RTD) is a research methodology that exploits the value design as a tool for building new knowledge in science [60]. Researchers, through RTD, design and prototype artefacts with the primary purpose of investigating new design issues and analyze phenomena related to the interaction with systems, products and services. The achievement of prototypes within this practice plays a fundamental role, as they represent the crucial element from which new knowledge and reflections arise [61]. The research methodology is based on the approaches discussed so far. It is possible to identify two main types of activities that have made it possible to achieve the objectives of this thesis; a comprehensive and constant analysis of the scientific literature combined with the planning of design experiments resulting from reflections induced by contributions in the literature and previous experiments. The scheme proposed in FIG.2 offers a greater understanding of applied research methodology.

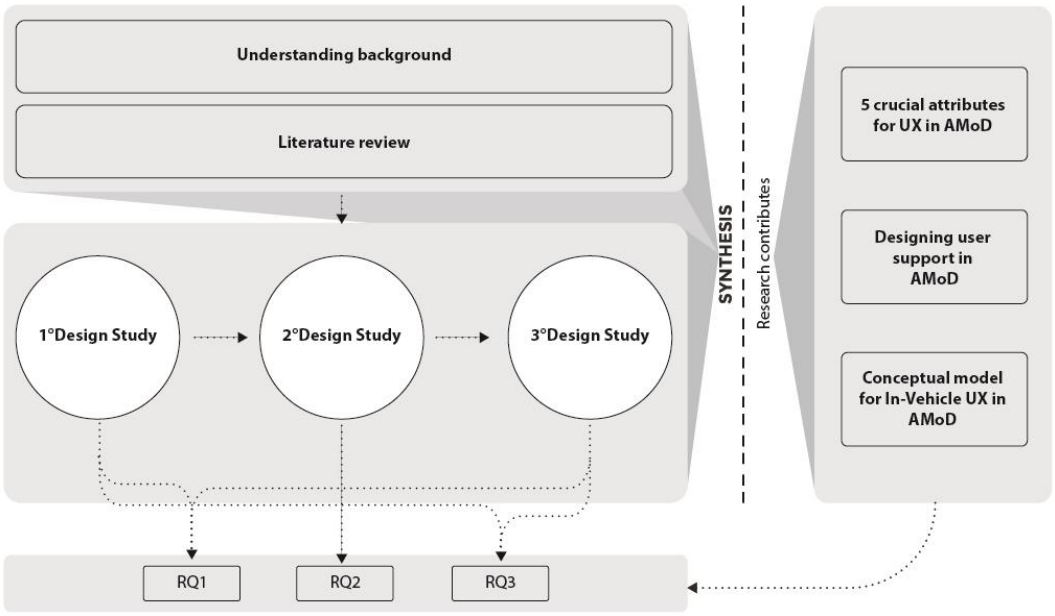

Fig. 2 – The scheme of research methodology applied.

Research results

In this chapter will be shown in the first instance, the research results of the three main design experiments conducted within the PhD research. The experiments discussed are intended to contribute to answer to the research questions and provide useful knowledge for the definition of the final contributions of this thesis. In conclusion, the final contributions to the research will be presented.

4.1 **1° Design study:** Exploratory study for the User Experience in autonomous vehicles

However, AVs to be accepted need to be perceived as useful, safe and competent; in this scenario, designers have the responsibility to explore approaches and methods to achieve a positive UX adapted to the new emerging context.

This study stems from the awareness of this need, intending to lay the foundations for a broader compression of possible future scenarios for the use of Level 5 AVs (SAE) [21]. The experimentation had grounded and developed in collaboration with the students of the Virtual Design course within the master's degree in Systemic Design of the Politecnico di Torino, and the company Italdesign that made available the physical prototype of the project Pop.Up Next. The more specific objectives of this research project are: To understand the future needs and desires of the actors within the new mobility system, to explore possible UXs within autonomous vehicles and to investigate design opportunities regarding the application of new technologies, interaction methods and types of Human-Machine

Interfaces within autonomous vehicles. The design methodology applied to the whole of this research project draws its foundations from the intersection of the disciplines of Interaction Design and UX. These disciplines are flanked by the speculative approach of Design Fiction [62], a practice that has provided the design tools for the construction of speculative stories useful for the exploration of future scenarios within autonomous vehicles. Design Fiction has also fostered the shift of the functionalist focus of HCD towards a more speculative and narrative focus, thus meeting the objectives of the research. The design process starts from a holistic analysis of user needs within urban mobility, the analysis conducted through the study of reports provided by institutional and public bodies, and the development of ethnographic research conducted within the Turin urban mobility system. The holistic analysis dedicated to the study of the UX in the various mobility services stems from the desire for a broader understanding of the needs of citizens in the various experiences of the use of multiple mobility services. Understanding the factors that impact positively and negatively on the urban transport experience represents an opportunity to improve the UX in the mobility of the future. The project outputs are concentrated in 8 high-level concepts. The concepts have been developed in collaboration with eight working groups for a total of 37 undergraduate students of Politecnico di Torino. The projects focus on the ability of interfaces and intelligent systems to support and understand the needs and characteristics of individual users and on the exploration of the various possible activities and interactions that users may wish to carry out during the journey, proposing scenarios of unusual use compared to traditional vehicles.

Below are some of the design peculiarities that emerged from the eight concepts:

- Il concept “The extended personal” sfrutta la tecnologia olografica applicata direttamente al dispositivo personale dell’utente come interfaccia per l’interazione con il sistema a bordo. Il progetto si basa sull’idea di un uso intelligente ed essenziale dei dispositivi tecnologici, riducendo al minimo l’integrazione di dispositivi non strettamente necessaria a bordo.
- Il concept “Relaxed Monitoring” concepisce la UX a bordo attraverso un’ottica di monitoraggio continuo dell’esperienza. L’esperienza in Relaxed Monitoring muta a seconda dell’esigenza dell’utente che ha la possibilità di trasformare la cabina del veicolo in un ambiente immersivo dedicato ad esempio al rilassamento, attraverso suoni, luci e proiezioni collegate al suo stato emotivo.
- L’esperienza all’interno del concept “Pick up needs” si basa su una visione fortemente innovativa e futuristica in termini di applicazioni tecnologiche e modalità d’interazione con il sistema. All’interno del concept è stata sviluppata un’interfaccia olografica tridimensionale in grado di fornire dei feedback tattili. L’utente interagisce con l’interfaccia direttamente attraverso la manipolazione manuale di un cubo 3D.
- “360°x360°” è un concept che mantiene un carattere fortemente digitale come quello descritto in precedenza, ma invece di sfruttare lo spazio aereo

interno per la proiezione delle interfacce, vengono sfruttate tutte le superfici vetrate della cabina. Questa scelta è dettata dalla necessità di sviluppare un'interazione anche con il contesto esterno attraverso la realtà aumentata e di creare delle esperienze immersive a 360° all'interno del veicolo.

- L'esperienza nel concept "Continuos Communication" si basa sul mantenere un costante dialogo tra il sistema e l'utente lungo tutto il viaggio. Il contesto progettuale tiene in considerazione la fruizione del servizio anche da parte di un utente con disabilità visiva. L'interfaccia, quindi, esplora questo caso d'uso prestando particolarmente attenzione ai bisogni specifici di questi utenti, ma allo stesso tempo restando scalabile per tutti gli altri utenti normodotati.
- "Playful grammar" indaga la possibilità di sperimentare una personalizzazione della grammatica gestuale per l'interazione con il sistema. Per lo studio di questo concept sono stati ripresi i concetti di personalità umana con lo scopo di identificare relazioni tra diversi tipi di gestualità e i diversi tratti di personalità.
- "Body touchless" è un concept che si sofferma sul due elementi cruciali; la dematerializzazione guidata dal bisogno di spazio a bordo e igiene dei dispositivi nei veicoli condivisi, e la privacy come bisogno dell'utente di svolgere attività in maniera privata e confortevole. L'interazione in questo concept avviene in assenza di dispositivi fisici e si modella sul corpo dell'utente rimanendo invisibile agli altri.
- "My favourite instrument" esplora la possibilità di assecondare le passioni e gli interessi personali dei singoli utenti concentrandosi su alcune delle possibili esperienze professionali gestibili a bordo del veicolo. I progettisti si focalizzano in particolare sulla fotografia, sulla musica e sulla professione del reporter.

The eight high-level design concepts are characterized by a futuristic vision of the UX in Level 5 AVs (SAE) [21]. The projects aim to propose design solutions of various kinds that respond to the possible future desires and needs of users within this new generation of vehicles. The research, exploiting a speculative approach, could identify different possible contexts of use for these services and has contributed to highlighting the importance of the UX in the design and planning of these shared mobility systems. The next step of this research is to reflect on the numerous contributions that have emerged intending to apply the specifics design opportunities in more practical contexts of experimentation in which it is possible to evaluate in a more pragmatic way the actual application value.

4.2 **2° Design study:** Sustainable interactions for User Experience within Autonomous Vehicles

Probably one of the most revolutionary factors derived from the introduction of AVs remains the lack of control of driving operations by the human; this revolutionary element also offers space for the integration of various forms of in-

vehicle entertainment, such as games and multimedia content. According to the author, it is crucial to address this issue in order to understand what kind of desirable future scenarios can be pursued in order to address the integration of these contents responsibly and sustainably for users. This research experimentation started as an investigative exploration aimed at understanding more practically the various design spaces for the development of valuable entertainment content for in-vehicle UX. The intention is to exploit the entertainment content to convey values and to promote sustainable UX, and more widely sustainable of the system. The study, therefore, addresses the issue of sustainability by first understanding the characteristics of this concept and then evaluating the different educational approaches proposed in the scientific literature. One of these approaches considered for this study is the voluntary approach; although the attitudes and behaviors of individuals are guided by deep structures, for example, economic structures, these structures are in part the result of the choices we make in our daily lives. Dobson [63] suggests that the possibility of achieving sustainable development also depends on individual behavioral change. According to the voluntary approach, the research project intends to test an alternative strategy aimed at triggering a behavior change related to sustainability issues. The educational strategy exploits the elements of the game, such as fun, and the use of ironic language to involve the user and increase their motivation towards a more responsible attitude. The project experimentation, therefore, foresees the development of an interactive augmented reality game that adopts the proposed educational strategy. The effectiveness of the games in the educational role has been empirically confirmed in several studies [64]. The game intends to integrate itself into the transport experience and changes its configuration continuously based on multiple factors, such as the context of use and the specific characteristics of the individual users. During the playful experience, the user is immersed in a hybrid world composed of fictional elements and constant references to the real world. The main objective of the player is to manage this world by responding to a series of requests provided by other characters, the consequences of these choices are mixed with other factors producing outputs derived from the interaction between the player, the vehicle and the surrounding environment. As a result of the choices decided by the player, the conditions of the world in the game vary continuously, in many ways. The most important signal that the player must keep under control to understand the real state of the world is represented by three bars that indicate the level of sustainability of the system in its three dimensions; economic, social and environmental. If one of these bars exceeds the expected limits, maximum and minimum, the world reaches the peak of instability and unsustainability, so the game is over.

A virtual prototype was developed to test this strategy with users. The test involved interaction with the game and a questionnaire with questions about the experience. The purpose of this test was to measure the degree of user involvement during the playful experience and the educational capacity of the game; the latter was evaluated thanks to the specific skills of expert users.

According to the users, the game appeared relatively easy to use, while the objectives were vague and difficult to understand for the first time. Most of the

users stated that they felt quite involved during the game experience. Regarding the communicative style associated with sustainable education, it was defined by most users as an innovative approach, although many of them were not able to assess whether this method is supportive in sustainability education or even counterproductive. However, despite the considerable margins for improvement emerged about the proposed strategy and the prototype realized, the research experimentation has overall achieved one of its initially set objectives; the development and identification of a possible entertainment content within the UX of fully AVs aimed at providing value for the user and the whole system.

4.3 **3° Design study:** Understanding Human-Machine interactions within autonomous vehicles through the design of several interactions style grounded from human personality.

The experiment aimed to investigate the HMI through the integration of the human personality construct within the interactions and interfaces of AVs' system. The first part of the research analysis was dedicated to the understanding of personality models proposed in the literature, then the Big Five model [65] was identified as one of the most accredited and supported by most scholars. This model has been related to studies about the theme of "Product Personality" PP [66], PP has contributed to research to bring the construct of human personality into the dimension of artefacts.

As a result of the primary research, three types of personalities were finally identified to be associated with the system of AV: one neutral and rational (model 1), another sociable and creative (model 2), and the last one characterized by instability and uncertainty (model 3). The three models of interaction voluntarily mark some specific personality traits to stimulate reactions from users; those reactions were useful to investigate issues in HMI emerging. The three models of interaction were then tested in a virtual setup with users within two online workshops that involved a mix of research methods; questionnaires, focus group and nominal group technique. One of the fundamental objectives of this experimentation has been achieved; the exposition of the three interaction models based on different traits of human personality has triggered a fruitful debate about the multiple issues involved in the Human-Machine relationship. Also, all participants in both tests were able to recognize and perceive substantial differences in the three videos exposed; this means that the manipulation of variables in the design of the interactions has obtained good feedback during the experimentation phase. The feedback of the participants also shows a strong connection with the variables used to build the three personalities of the system. The model 1, for example, has been defined more times like a detached personality, formal, neutral and aseptic, many of these elements turn out analogous to the base concepts used for the designing of this model. Model 2 was the most cited and debated in both workshops and received overall positive

comments about its ability to engage the user and put him/her at ease. Also, this model was overall the most appreciated in both tests, although there are several critical sides highlighted. Many people exposed the need to manage empathy of the system in model 2; they said the managing could be according to the context and special needs. Finally, model 3 is one of the models that received the most criticism, especially in the first workshop. Participants complained about the system's style of interaction, especially the way information was transmitted. Overall, the participants, in the hypothesis of imagining a possible personality of the system in fully AVs, stated the need to consider numerous aspects related to the context and the specific characteristics of each user. The participants, therefore, want a dynamic system capable of continuously adapting to emerging situations. Despite the need for flexibility, there are some stable points, most of the participants expect from the system the ability to empathize with the passenger, putting him/her in a comfortable environment by communicating reliability and safety during the experience.

4.4 Final contributions of research

In this paragraph will be exposed the final contributions of this thesis as the result of the reflections and considerations arising from the three design studies conducted during the PhD period (presented in the previous paragraphs), and the reflections derived from the analysis of the scientific literature.
The first contribution concerns the identification of 5 essential factors that aim to guide the design of the service and UX in AMoD services. The key factors are the following:

- **Flexibility**
  The attribute of flexibility is intended here in a broad sense; AMoD services need flexibility in many ways. A multitude of users will most likely use AMoD services; thus, flexible design solutions are needed, to satisfy the multiple necessities of users. Flexibility and adaptation should be implemented in AMoD service within both the service structure and the whole UX. Flexibility is also necessary especially in light of some forecasts highlighted in the research [13] that foresee the use of these services by users with very distant age groups such as children and elderly, and users with specific needs related to disability.
- **Responsibility**
  Responsibility has a fundamental value in AMoD services. Responsibility intended towards the user and the whole system. Although autonomous vehicles, and AMoD services have the potential to bring numerous benefits [28] [9] [10] [11] [12] [13] it is equally important to remember that several risks and critical aspects related to this technology have also been highlighted in the literature [15] [16] [17] [18] [33]. The design decisions within AMoD services will, therefore, play an essential role to address this technology towards the most preferable and sustainable direction. The

design of these services should take into account several critical issues and try to mitigate them through targeted strategies and solutions. One of the most critical concerns of the experts is represented by a possible misuse of these services [33], with important consequences in terms of system congestion and increased environmental impacts mainly due to vehicle emissions. ¬To address this risk; it will not only be necessary to intervene in terms of policies and restrictions; it is also essential to act through bottom-up tools that directly act within the everyday life of users.

- **Extraordinary UX**
  The design of a correct UX within AMoD services is one of the key factors for the success and adoption of this transportation mode. Many obstacles could hinder users in the use of these services; it is, therefore, essential to offer an extraordinary UX aimed at increasing the attractiveness of AMoD services in many aspects, in order to mitigate the resistance to acceptance and adoption of these services by users. First, one of the critical aspects that could certainly create a more significant attraction for these services concerns the satisfaction of human needs. Focusing the design of AMoD services on a Human-Centered Design approach [59] means evaluating design decisions based on the real needs of the user, without running the risk of building an offer that follow only the needs of the company or is based on approximate evaluations.
- **All-inclusive, simple and useful**
  If in the previous attribute the design considerations focused more on the importance of non-instrumental qualities [44] in the UX in AMoD services, within this attribute more instrumental qualities [44] are instead addressed, elements that are equally crucial for the acceptance and adoption of AMoD services. One of the practical and tangible benefits that these services can bring in the daily life of users is to free them from multiple concerns; responsibilities and commitments that they currently face for the management of the private vehicle. "All-inclusive" is therefore intended as offering a complete “mobility box” that satisfies the user in his or her urban movements without the burdensome impact of a private vehicle.
- **Reliability**
  The last attribute, but perhaps also the most important, is that of reliability. Reliability attribute is crucial because AMoD services are based on the use of fully AVs, a technology that according to several studies [23] [24] [25] still causes much doubts on users that could turn into a lack of trust and a lack of willingness to use AVs. The issue of reliability for AMoD services is, therefore, a big problem, perhaps the biggest of all, is one of the most decisive factors in the process of acceptance and adoption of AMoD services. Customers of these services could also link the reliability in autonomous vehicles to the reliability of the service [33], it is therefore necessary that both, the vehicle system and the service system maintain a high level of perceived reliability to reduce the risk of rejection or disuse.

The author, aware of the difficulties, and the limits of the application of indications and theoretical considerations in the design field, has developed further contributions related to more specific aspects. Further contributions have the intent to explore and identify possible operational solutions for AMoD services, following the five attributes mentioned above. The development of the design considerations proposed here is based on the idea suggested by Fagnant et al. [67], according to which the design of AMoD services should be based on a combination of elements taken from conventional car-sharing and taxi services, subsequently adapted to the needs of the context of AVs.

The first aspect identified concerns the theme of user support during the whole experience. According to the knowledge gathered during the literature review, acceptance and adoption in AVs is a complex process influenced by many factors [26] [27] [28]. For example, trust is one of the main factors involved in acceptance and adoption processes, and to mitigate this issue is needed a constant support to the users. Following the concept of continuum acceptability-acceptance-appropriation [68] users should receive support before, during and after the ride. AMoD services should, therefore, offer support through different channels and different tools made available to the user throughout the experience.

Within the thesis are presented, some of the possible support tools for AMoD services. The identified tools respond to the necessities of the incredible variety of potential users in AMoD services and the many different needs of individuals. First, an overall view of the possible touchpoints involved in the AMoD service along the main phases of the UX has been elaborated and provided. The analysis of touchpoints has provided a distinction between physical touchpoints and digital touchpoints; this division is useful as it allows the enhancement of both way of interaction with the service. Although information and digital technologies have the potential to improve or even allow, the use of these services, it is essential to keep in mind that AV technology offers mobility also to potential users of AMoD services characterized by a lower ability to access these technologies (for example elderly or disabled users [13]). Therefore, it is essential to diversify the touchpoints to increase the possibilities of access to the service by more groups of users less expert with these technologies. Subsequently, based on the journey map elaborated thanks to the analysis carried out in the 1° study of this thesis, and on the touchpoints identified in the previous paragraph, a Blueprint model of the service has been developed with the aim of identifying a possible structural organization in AMoD services. The Blueprint of the service can be defined as a map or a flowchart that aims to show all the operations of the service delivery process [69]. The Blueprint proposed aimed to explore and identify the possible interactions between the user and the various components of the service within the three main phases of the UX; before ride, during ride and after ride.

The last contribution of this thesis focuses finally on the in-vehicles experience, following the five attributes, the design exploration focused to address a particular issue, namely the need for AMoD services to provide extremely flexible in-vehicle experiences. One of the key challenges that this study has addressed is the ability

of the vehicle's system to provide a customized UX based on various factors. The concept will therefore focus on understanding and managing the dilemma of personalization within in-vehicle experience, mainly assessing contextual factors and user preferences that have emerged from the analysis of the scientific literature and research previously conducted throughout this thesis. The design solution aims not to adopt radical approaches. The type of approach adopted, therefore, remains flexible. The author of this study assumes that the technology is not yet able to understand and manage autonomously the type of content and the type of customizations to be provided to the user, but at the same time, the author considers too cumbersome and impractical the idea that the user must manually set any customization of the in-vehicle experience. The proposed solution, therefore, intends to exploit the great potential of technology in processing information and create a well-defined user profiling, but at the same time offers the user the possibility to have direct control of his experience. The project analysis starts with the identification of "non-driving related activities" (NDRA) [47] that users would like to carry out inside the fully AVs. This information has been extrapolated from other scientific research, and subsequently selected with the contribute of reflections elaborated within this thesis. From the analysis of the collected information, some important patterns emerged. The patterns identified in previous analysis allowed the classification of users' needs into three "travel moods": a more relaxing, comfortable and everyday mood, a more evasive mood linked to extraordinary situations and events outside of everyday life, and finally a more productive context linked to work and concentration. This type of classification is, however, characterized by a certain degree of flexibility and is not intended to create vertical clusters, on the contrary, the information present in the three moods are deeply connected. The subdivision of the activities in the three "travel moods" therefore remains a possible strategy for more efficient and more practical management of in-vehicle UX, allowing the user to enjoy the contents he needs in a faster, easier and more pleasant way.

Within the thesis, there is also a more detailed description of the operational processes for the management of the model, also supported by: an investigative analysis about equipment necessary to support the activities within the three travel moods, analysis of environmental characteristics that the three moods influence and analysis of the multiple HMI style within each mood. However, it is essential to underline that all design considerations regarding the three moods have been developed with the awareness that the preferences and needs of each user remain the critical element of customization. The system must be able to capture all this information and improve the complexity over time. What the system intends to offer in the first instance is therefore relatively important, these are default settings that do not always meet the real needs of users. In conclusion, it can be said that the model aims to increase user satisfaction by exploiting some transversal elements related to most users, such as concentration at work, stimulation of the senses in extraordinary experiences and the association of home spaces with comfort, privacy and relaxation.

Conclusions

The research project has addressed many issues within the context of autonomous vehicles, taking care to investigate the UX in different aspects through a holistic and widespread approach, following the objectives of the thesis. This approach was also supported by reflections based on the scientific literature; a deep disconnection between the several issues emerging within the field of UX in AVs has been noticed. This thesis, to respond to the lack of global vision of UX in AVs focused on a broader approach. The very nature of the UX presupposes the use of a broader approach since experiences are composed of a considerable number of events and influenced by multiple interconnected and interdependent factors related to the user, the system and the context [37].

The results of the thesis have responded to the research questions in different ways and have contributed to generate a useful perspective, mainly for those dealing with more practical-design aspects in the field of AVs.

Expressly, the answer to the first research question, inherent to the future needs and desires of users within autonomous vehicles, was exhaustively provided by the preliminary analysis necessary for the development of the three travel moods developed within the final contributions of the thesis. The analysis included the collection of information related to the preferences and desires of users within AVs, collected from several studies in the literature that conducted a vertical research on this topic, using mostly user research methods such as questionnaires and interviews.

Concerning the second research question, intent on understanding the potential of the UX to produce positive impacts for the user and the system, the answer was provided in a widespread way. First, through the 2° design study that contributed to making more practical the possibility to integrate contents within the UX in AVs that produce positive impacts for the user and the whole system. Secondly, within the design indications provided in the final contributions of the thesis, where has been offered some indications on how the UX in AVs can guide users towards a more conscious and responsible use of these services, producing positive impacts for itself and the whole system.

Finally, the answer to the third research question, referring to possible UXs within a shared autonomous vehicle, was provided by the model developed within the final research contributions. The model of the three travel moods, theorized as an operational strategy, offers a practical solution to the need for flexibility and customization that AMoD services should offer users.

In light of the results obtained from this thesis, and the limitations about the holistic approach adopted, one of the considerations regarding the possible future developments of this work focuses on the need for to deepen the multiple issues raised by this research. The author, at the end of this work, considers it necessary to start a series of verticalization focused mainly on the issues addressed in the five

fundamental attributes identified for AMoD services. It is also urgent to improve the model developed for the in-vehicle UX through research processes that consider the creation of prototypes and the planning of experiments to test the feasibility and efficacy of proposed strategy.

References

[1] United Nations, Department of Economic and Social Affairs, Population Division, World Urbanization Prospects: The 2014 Revision (2014).

[2] United Nations, The World's Cities in 2016: Data Booklet, accessed August 4, 2017.

[3] Karagulian, F., Belis, C. A., Dora, C. F. C., Prüss-Ustün, A. M., Bonjour, S., Adair-Rohani, H., & Amann, M. (2015). Contributions to cities' ambient particulate matter (PM): A systematic review of local source contributions at global level. Atmospheric environment, 120, 475-483.

[4] Janasz, T. (2017). Paradigm shift in urban mobility: towards factor 10 of automobility. Springer.

[5] Lam D., Head P. (2012) Sustainable Urban Mobility. In: Inderwildi O., King S. (eds) Energy, Transport, & the Environment. Springer, London

[6] Marletto, G. (2010). Structure, agency and change in the car regime: A review of the literature.

[7] Berger, G., Feindt, P. H., Holden, E., & Rubik, F. (2014). Sustainable mobility—challenges for a complex transition.

[8] NHTSA. (2019). Automated Vehicles for Safety. Retrieved from https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety.

[9] Brenner, W., & Herrmann, A. (2018). An overview of technology, benefits and impact of automated and autonomous driving on the automotive industry. In *Digital marketplaces unleashed* (pp. 427-442). Springer, Berlin, Heidelberg.

[10] Mertens, P. (2018). Automotive Autonomy. *ATZ worldwide*, *120*(1), 86-86.

[11] Davila, A., & Nombela, M. (2012). *Platooning-safe and eco-friendly mobility* (No. 2012-01-0488). SAE Technical Paper.

[12] Rupp, J. D., & King, A. G. (2010). *Autonomous driving-A practical roadmap* (No. 2010-01-2335). SAE Technical Paper.

[13] Fagnant, D. J., & Kockelman, K. (2015). Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice*, *77*, 167-181.

[14] Alessandrini, S., Delle Monache, L., Sperati, S., & Cervone, G. (2015). An analog ensemble for short-term probabilistic solar power forecast. *Applied energy*, *157*, 95-110.

[15] Fagnant, D. J., & Kockelman, K. M. (2018). Dynamic ride-sharing and fleet sizing for a system of shared autonomous vehicles in Austin, Texas. *Transportation*, *45*(1), 143-158.

[16] Koopman, P., & Wagner, M. (2017). Autonomous vehicle safety: An interdisciplinary challenge. *IEEE Intelligent Transportation Systems Magazine*, *9*(1), 90-96.

[17] Kröger, L., Kuhnimhof, T., & Trommer, S. (2016). Modelling the Impact of Automated Driving. In *Private AV Scenarios for Germany and the US. Presented to the European Transport Conference. German Aerospace Center, Berlin*.

[18] Trommer, S., Kolarova, V., Fraedrich, E., Kröger, L., Kickhöfer, B., Kuhnimhof, T., ... & Phleps, P. (2016). Autonomous driving-the impact of vehicle automation on mobility behaviour.

[19] Waldrop, M. M. (2015). No drivers required. *Nature*, *518*(7537), 20.

[20] Lu, N., Cheng, N., Zhang, N., Shen, X., & Mark, J. W. (2014). Connected vehicles: Solutions and challenges. *IEEE internet of things journal*, *1*(4), 289-299.

[21] SAE On-Road Automated Vehicle Standards Committee. (2018). Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles. *SAE International: Warrendale, PA, USA*.

[22] Zhang, T., Tao, D., Qu, X., Zhang, X., Zeng, J., Zhu, H., & Zhu, H. (2020). Automated vehicle acceptance in China: Social influence and initial trust are key determinants. *Transportation research part C: emerging technologies*, *112*, 220-233.

[23] Abraham, H., Lee, C., Brady, S., Fitzgerald, C., Mehler, B., Reimer, B., & Coughlin, J. F. (2016). Autonomous vehicles, trust, and driving alternatives: A survey of consumer preferences. *Massachusetts Inst. Technol, AgeLab, Cambridge*, *1*, 16.

[24] Menon, N., Pinjari, A., Zhang, Y., & Zou, L. (2016). *Consumer perception and intended adoption of autonomous-vehicle technology: Findings from a university population survey* (No. 16-5998).

[25] Schoettle, B., & Sivak, M. (2014). *A survey of public opinion about autonomous and self-driving vehicles in the US, the UK, and Australia*. University of Michigan, Ann Arbor, Transportation Research Institute.

[26] Buckley, L., Kaye, S. A., & Pradhan, A. K. (2018). Psychosocial factors associated with intended use of automated vehicles: A simulated driving study. *Accident Analysis & Prevention*, *115*, 202-208.ù

[27] Madigan, R., Louw, T., Wilbrink, M., Schieben, A., & Merat, N. (2017). What influences the decision to use automated public transport? Using UTAUT to understand public acceptance of automated road transport systems. *Transportation research part F: traffic psychology and behaviour*, *50*, 55-64.

[28] Zhang, T., Tao, D., Qu, X., Zhang, X., Lin, R., & Zhang, W. (2019). The roles of initial trust and perceived risk in public's acceptance of automated vehicles. *Transportation research part C: emerging technologies*, *98*, 207-220.

[29] Choi, J. K., & Ji, Y. G. (2015). Investigating the importance of trust on adopting an autonomous vehicle. *International Journal of Human-Computer Interaction*, *31*(10), 692-702.

[30] May, K. R., Noah, B. E., & Walker, B. N. (2017, September). Driving acceptance: Applying structural equation modeling to in-vehicle automation acceptance. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct* (pp. 190-194).

[31] Xu, Z., Zhang, K., Min, H., Wang, Z., Zhao, X., & Liu, P. (2018). What drives people to accept automated vehicles? Findings from a field

experiment. *Transportation research part C: emerging technologies*, *95*, 320-334.

[32] Spieser, K., Treleaven, K., Zhang, R., Frazzoli, E., Morton, D., & Pavone, M. (2014). Toward a systematic approach to the design and evaluation of automated mobility-on-demand systems: A case study in Singapore. In *Road vehicle automation* (pp. 229-245). Springer, Cham.

[33] Larsson, P. (2018). User Experience of On-demand Autonomous Vehicles - Part 1: Background and User Experience framework. DOI: 10.13140/RG.2.2.11665.07523.

[34] ISO (2010) Ergonomics of human-system interaction. Part 210: human-centred design for interactive systems (ISO 9241-210: 2010). International Organization for Standardization, Switzerland

[35] Bødker, S. (2006, October). When second wave HCI meets third wave challenges. In *Proceedings of the 4th Nordic conference on Human-computer interaction: changing roles* (pp. 1-8).

[36] Hassenzahl, M., & Tractinsky, N. (2006). User experience-a research agenda. *Behaviour & information technology*, *25*(2), 91-97.

[37] Buchenau, M., & Suri, J. F. (2000, August). Experience prototyping. In *Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques* (pp. 424-433).

[38] Desmet, P., & Hekkert, P. (2007). Framework of product experience. *International journal of design*, *1*(1), 57-66.

[39] Forlizzi, J., & Battarbee, K. (2004, August). Understanding experience in interactive systems. In *Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques* (pp. 261-268).

[40] Forlizzi, J., & Ford, S. (2000, August). The building blocks of experience: an early framework for interaction designers. In *Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques* (pp. 419-423).

[41] Hartmann, J., Sutcliffe, A., & Angeli, A. D. (2008). Towards a theory of user judgment of aesthetics and user interface quality. *ACM Transactions on Computer-Human Interaction (TOCHI)*, *15*(4), 1-30.

[42] Hassenzahl, M. (2004). The interplay of beauty, goodness, and usability in interactive products. *Human–Computer Interaction*, *19*(4), 319-349.

[43] Jordan, P. W. (2002). *Designing pleasurable products: An introduction to the new human factors*. CRC press.

[44] Mahlke, S., & Thüring, M. (2007, April). Studying antecedents of emotional experiences in interactive contexts. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 915-918).

[45] Wadud, Z., MacKenzie, D., & Leiby, P. (2016). Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles. *Transportation Research Part A: Policy and Practice*, *86*, 1-18.

[46] Wardman, M., & Lyons, G. (2016). The digital revolution and worthwhile use of travel time: implications for appraisal and forecasting. *Transportation*, *43*(3), 507-530.

[47] Hecht, T., Kratzert, S., & Bengler, K. (2020). The Effects of a Predictive HMI and Different Transition Frequencies on Acceptance, Workload, Usability, and Gaze Behavior During Urban Automated Driving. *Information*, *11*(2), 73.

[48] König, M., & Neumayr, L. (2017). Users' resistance towards radical innovations: The case of the self-driving car. *Transportation research part F: traffic psychology and behaviour*, *44*, 42-52.

[49] Mokhtarian, P. L., & Salomon, I. (2001). How derived is the demand for travel? Some conceptual and measurement considerations. *Transportation research part A: Policy and practice*, *35*(8), 695-719.

[50] Bansal, P., Kockelman, K. M., & Singh, A. (2016). Assessing public opinions of and interest in new vehicle technologies: An Austin perspective. *Transportation Research Part C: Emerging Technologies*, *67*, 1-14.

[51] Lee, J. D., & See, K. A. (2004). Trust in automation: Designing for appropriate reliance. *Human factors*, *46*(1), 50-80.

[52] Hoff, K. A., & Bashir, M. (2015). Trust in automation: Integrating empirical evidence on factors that influence trust. *Human factors*, *57*(3), 407-434.

[53] Lee, J. G., Kim, K. J., Lee, S., & Shin, D. H. (2015). Can autonomous vehicles be safe and trustworthy? Effects of appearance and autonomy of unmanned driving systems. *International Journal of Human-Computer Interaction*, *31*(10), 682-691.

[54] Waytz, A., Heafner, J., & Epley, N. (2014). The mind in the machine: Anthropomorphism increases trust in an autonomous vehicle. *Journal of Experimental Social Psychology*, *52*, 113-117.

[55] Basu, R., Araldo, A., Akkinepally, A. P., Nahmias Biran, B. H., Basak, K., Seshadri, R., ... & Ben-Akiva, M. (2018). Automated mobility-on-demand vs. mass transit: a multi-modal activity-driven agent-based simulation approach. *Transportation Research Record*, *2672*(8), 608-618.

[56] Kim, S., Chang, J. J. E., Park, H. H., Song, S. U., Cha, C. B., Kim, J. W., & Kang, N. (2020). Autonomous taxi service design and user experience. *International Journal of Human–Computer Interaction*, *36*(5), 429-448.

[57] Krueger, R., Rashidi, T. H., & Rose, J. M. (2016). Preferences for shared autonomous vehicles. *Transportation research part C: emerging technologies*, *69*, 343-355.

[58] Jacques, C., Manaugh, K., & El-Geneidy, A. M. (2013). Rescuing the captive [mode] user: an alternative approach to transport market segmentation. *Transportation*, *40*(3), 625-645.

[59] Gill, K. S. (1990). *Summary of human-centered systems research in Europe*. University of Brighton, SEAKE Centre.

[60] Zimmerman, J., & Forlizzi, J. (2014). Research through design in HCI. In *Ways of Knowing in HCI* (pp. 167-189). Springer, New York, NY.

[61] Keyson, D. V., & Bruns, M. (2009, October). Empirical research through design. In *Proceedings of the 3rd IASDR Conference on Design Research* (pp. 4548-4557).

[62] Blythe, M. (2014), "Research through design fiction: narrative in real and imaginary abstracts", In *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 703-712).

[63] Dobson, A. (2007). Environmental citizenship: towards sustainable development. *Sustainable development*, *15*(5), 276-285.

[64] Fabricatore, C., & López, X. (2012). Sustainability Learning through Gaming: An Exploratory Study. *Electronic Journal of e-learning*, *10*(2), 209-222.

[65] McCrae, R. R., & John, O. P. (1992). An introduction to the five-factor model and its applications. *Journal of personality*, *60*(2), 175-215.

[66] Mugge, R., Govers, P. C., & Schoormans, J. P. (2009). The development and testing of a product personality scale. *Design Studies*, *30*(3), 287-302.

[67] Fagnant, D. J., Kockelman, K. M., & Bansal, P. (2015). Operations of shared autonomous vehicle fleet for Austin, Texas, market. *Transportation Research Record*, *2563*(1), 98-106.

[68] Distler, V., Lallemand, C., & Bellet, T. (2018, April). Acceptability and acceptance of autonomous mobility on demand: The impact of an immersive experience. In *Proceedings of the 2018 CHI conference on human factors in computing systems* (pp. 1-10).

[69] Shostack, G. L. (1982). How to design a service. *European journal of Marketing*.