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INTERACTION IN DIGITAL ECOLOGIES WITH CONNECTED AND NON-CONNECTED CARS

BY
MICHAEL KVIST SVANGREN

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AALBORG UNIVERSITY
DENMARK

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ENGLISH SUMMARY

Using technology in a car that supports driving, such as GPS and infotainment systems, is familiar to many people. However, a development in the characteristics of contemporary cars is that they can be used in combination with other interactive technologies that complement and extend car functionality beyond the driving experience. These combinations of interactive technology form what can be described as digital ecologies. However, unlike interaction with in-car technology, there is limited HCI research on people's interaction in digital ecologies with cars and how these support everyday mobility.

This thesis investigates interaction in digital ecologies with cars. Towards this end, the thesis investigates two research questions. The first research question works on how to characterise how people interact in digital ecologies with cars. The second research question works on understanding activities that can be supported by digital ecologies with cars. The investigation of the research questions presents two main contributions of this thesis.

Firstly, the thesis contributes with a framework that characterises interaction in digital ecologies with cars. It does this by describing HCI research on the central characteristics of interaction with digital ecologies and interaction with cars. The framework is constructed with this as a foundation. The framework consists of two dimensions: the first dimension describes interaction in digital ecologies as either being simultaneous or sequential, and the second dimension describes how cars can be a part of digital ecologies as either being connected or non-connected through the internet and its services.

Secondly, the thesis contributes with five papers presenting empirical findings on how digital ecologies with cars are used to support mobility in everyday life. The papers investigate the cases of electric vehicles and shared cars. The empirical findings show that digital ecologies are used in a number of activities to support mobility in everyday life and using the constructed framework as a lens, it is possible to characterise how people interact with them. For instance, for electric vehicles using a digital ecology consisting of several devices is important to support complementing car functionality in activities such as charging and planning. For shared cars, collaborative interaction between people through online services is important for planning a ride. The results of this thesis further discuss implications for design. Opportunities and challenges are suggested as inspiration for where designers should focus their attention when designing for activities where digital ecologies can be used to support mobility.

The PhD project that this thesis is based on is partly financed by the DiCyPS research centre funded by Innovation Fund Denmark. The aim of the research centre is to use software and data of complex cyber-physical systems to develop smarter and user-friendly solutions that benefit individuals and society.

DANSK RESUME

De fleste mennesker interagerer jævnligt med teknologi, for eksempel GPS og infotainmentsystemer i deres bil, for at understøtte kørslen. Imidlertid er en egenskab ved nutidige biler, at de kan interagere sammen andre teknologier, som supplerer og udvider bilens funktionalitet til interaktion uden for bilen og kørselssituationen. Sådanne kombinationer af interaktiv teknologi danner, hvad man kan beskrive som digitale økologier. I modsætning til interaktion med teknologi i kørselssituationen, er der inden for HCI-forskning begrænset viden om menneskers interaktion i digitale økologier med biler, og hvordan disse understøtter hverdagens mobilitet.

Denne afhandling undersøger interaktion i digitale økologier med biler. Til dette formål undersøger afhandlingen to forskningsspørgsmål. Det første forskningsspørgsmål arbejder på hvordan man kan karakterisere menneskers interaktion i digitale økologier med biler. Det andet forskningsspørgsmål arbejder på at forstå aktiviteter, der kan understøttes af digitale økologier med biler. Besvarelsen af forskningsspørgsmålene præsenterer to primære bidrag af denne afhandling.

Det første bidrag af afhandlingen med et framework, der definerer interaktion i digitale økologier med biler. Afhandlingen beskriver først HCI-forskning omhandlende centrale karakteristika ved interaktion med digitale økologier og interaktion med biler. Baseret på denne forskning konstrueres mit framework. Frameworket består af to dimensioner. Den første dimension beskriver interaktion i digitale økologier som enten at være samtidig eller sekventiel. Den anden dimension beskriver, at biler kan være en del af en digital økologi ved at være direkte tilsluttet eller ikke-tilsluttet internettet.

Det andet bidrag af afhandlingen er fem artikler, der præsenterer empiriske resultater om, hvordan digitale økologier med biler bruges til at understøtte mobilitet i hverdagen. I forhold til frameworket beskriver artiklerne brugen af elektriske biler som værende tilsluttede og delte biler som værende ikke-tilsluttede gennem internettet og dets services. De empiriske fund viser, at digitale økologier bruges i en række aktiviteter til at understøtte mobilitet i hverdagen. Ved at bruge det konstruerede framework som et analytisk værktøj er det muligt at karakterisere interaktion i artiklerne. For elektriske køretøjer er udvidelse af bilens funktionalitet gennem andre enheder vigtigt, for eksempel for at understøtte aktiviteter såsom opladning og planlægning. For delte biler er samarbejde mellem mennesker gennem onlinetjenester vigtigt for at planlægge en bildeling. Afhandlingen foreslår yderligere designmuligheder for specifikke aktiviteter, hvor digitale økologier kan bruges til at understøtte mobilitet. Desuden bidrager afhandlingen med designudfordringer, der kan tjene som inspiration for designere.

Ph.d.-projektet, som denne afhandling er baseret på, er delvist finansieret af DiCyPS-forskningscenter støttet af Innovationsfonden Danmark.

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'Roads? Where we're going, we don't need roads'.

- Dr. Emmett Brown, Back to the Future

I many ways, writing this thesis was like going back in time and remembering the last three years of my PhD. This not only reminded me of my past work, but also all the amazing people I've come to know through the years. Thanks all!

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THESIS DETAILS

Thesis Name:	Interaction in Digital Ecologies with Connected and Non-Connected Cars
PhD Student:	Michael Kvist Svangren, Aalborg University
PhD supervisors:	Professor Mikael B. Skov, Aalborg University Professor Jesper Kjeldskov, Aalborg University

The following five accepted papers are incorporated into the thesis and can be found in the appendix:

1. **Michael K. Svangren,** Rikke Hagensby Jensen, Mikael B. Skov, and Jesper Kjeldskov; 2018. Driving on Sunshine: Aligning Electric Vehicle Charging and Household Electricity Production. In *Proceedings of the 10th Nordic Conference on Human-Computer Interaction.* (NordiCHI'18).
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2. Rikke Hagensby Jensen, **Michael K. Svangren**, Mikael B. Skov, and Jesper Kjeldskov. 2019. Investigating EV Driving as Meaningful Practice. Accepted for inclusion in *the 31st australian conference on human-computer-interaction* (OZCHI'19).

3. **Michael K. Svangren,** Mikael B. Skov, and Jesper Kjeldskov. 2017. The connected car. An Empirical Study of Cars as Connected Digital Devices. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services* (MobileHCI '17).
   DOI: http://dx.doi.org/10.1145/3098279.3098535

4. **Michael K. Svangren,** Mikael B. Skov, and Jesper Kjeldskov. 2018. Passenger Trip Planning using Ride-Sharing Services. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (CHI'18).
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5. **Michael K. Svangren,** Margot Brereton, Mikael B. Skov, and Jesper Kjeldskov. 2019. Investigating the Use of an Online Peer-to-Peer Car Sharing Service. In *proceedings of the 17th IFIP TC.13 International Conference on Human-Computer Interaction* (INTERACT'19),
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1 INTRODUCTION

It is estimated that between 2010 and 2015, the number of cars worldwide increased from 808 to 947 million. This increase shows no signs of slowing in the coming years [82]. In fact, cars represent 70 percent of all vehicle journeys in the European Union, taking the average European almost 13,000 kilometers a year [1]. Cars provide an individual flexible means of transportation. However, they also bring about societal and individual challenges, such as severe health impacts caused by the use of non-renewable fuel, air and noise pollution, and traffic congestion [56,75,94]. To address these challenges, different initiatives that optimise the use of cars are encouraged and supported by many governments across the world. Car optimisation initiatives include electric vehicles capable of using renewable electricity, and car sharing to reduce the number of cars on the road. Despite this, some research [40,53,98] indicates that this development challenges traditional driving and ownership, because it requires a change in how people think about and use cars.

Today, interactive technologies are designed to extend or complement existing car functionality that have the potential to address many of the challenges associated with moving away from the traditional use of cars. Many contemporary cars are equipped with connectivity, enabling people to interact with them through smartphone applications and online services. As examples, there are smartphone applications that allow people to get information about a car and control it, such as controlling car access and temperature settings (e.g. [81,100,101]). Furthermore, online services are available on a range of devices to facilitate initiatives such as car and ride-sharing (e.g. [18,37]). The use of such interactive technologies forms what can be described as *digital ecologies.* A digital ecology can be defined as *'a network of nodes of users and digital artifacts that is dynamically bound by interaction in users' activities'* [97]. Research in HCI (Human-Computer Interaction) has only started to investigate digital ecologies with cars and how people appropriate them to facilitate mobility. Towards this end, there are limited understandings of how people interact with digital ecologies and how they can be applied in everyday life to facilitate car mobility.

This thesis investigates interaction in digital ecologies with cars. The contributions of this thesis are twofold. Firstly, it presents a framework that provides a characterisation of interaction in digital ecologies with cars. Secondly, it presents empirical findings that describe how people interact with and appropriate digital ecologies with cars in their everyday lives. It does this through five paper contributions investigating electric and shared cars using the developed framework as an analytic lens.

In the following sections, I first provide context for the thesis describing the car in modern society, and the individual and social challenges related to it. Secondly, I introduce digital ecologies and cars and how my research fits into this context. Thirdly, I sum up the research questions that guide my work, and finally, I present an overview of the thesis and its chapters.

1.1 CARS IN MODERN SOCIETY

The car is important for how people transport themselves in modern society, and it is the most widely-adopted means of mobility in the world. The number of cars worldwide between 2010 to 2015 is estimated to have grown from 808 to 947 million, a trend that shows no signs of slowing in coming years [82]. In the European Union, more than 320 million cars account for 70 percent of all vehicle journeys [1].

The increased amount of cars provides an individual flexible means of transportation; however, despite such opportunities, there are both personal and societal costs. Firstly, in the European Union, most newly registered cars are still equipped with internal combustion engines that use non-renewable fuel as a mean of propulsion. Burning this fuel is associated with air pollution, especially in the local environment [53,65]. Air pollution is estimated to be the cause of up to 800,000 premature annual deaths in Europe [58]. Secondly, cars are a significant contributor to noise pollution that, according to the organisation WHO, has significant health impacts such as sleep disturbance, elevated blood pressure, and heart disease [83]. Finally, the increasing amounts of cars on the road is also a contributor to traffic congestion, which again has an impact on time spent, fuel consumption, and people's health [76,96].

In 2015, world leaders agreed to 17 goals for a better world in 2030 [79]. Changing how we use cars is important to accommodate some of these goals, such as clean and affordable energy, good health and well-being, and sustainable cities and communities. Several governments in Europe already have a plan for this transition, and as part of this, initiatives such as legislation and financial benefits are already being phased in. For example, car sharing initiatives are often cheaper than owning a car and have parking benefits in several countries [53,96]. Furthermore, in recent years, some European countries have also made plans to phase out the sale of fossil-fueled cars and replace them with hybrid and electric vehicles. For instance, Norway has planned to stop the sale of gasoline and diesel cars by 2025 [44] and Denmark by 2030 [90].

Even though there are several benefits to adopting initiatives such as car sharing and electric cars, research indicates that there are also challenges related to the feeling of status, freedom, and independence associated with driving and owning cars [98]. As examples, Kent and Rowling found planning overhead to be a challenge in car sharing [53] and Lundström highlights limited range in EV's, which induces the fear of battery depletion [62]. Such challenges have inspired HCI researchers to focus on the design of interactive technology to mitigate these. These efforts include digital services to enable people to share cars and rides more efficiently [36,85] and visualisations that reduce range anxiety driving electric cars [52,62,63].

In recent years, HCI research has begun to investigate how mobility using cars can be facilitated through connected interactive technology that forms what can be described as digital ecologies. These digital ecologies hold the potential to support mobility with cars in many ways, for example, by complementing and extending car functionality beyond the driving situation.

1.2 CARS AND DIGITAL ECOLOGIES

A characteristic of contemporary cars is the rapid technological development that they are undergoing. Interfaces in cars are becoming increasingly advanced, allowing drivers to access more functionality than before [16]. For example, computational units in cars monitor driver performance and interactive technology such as GPS and entertainment systems assist in driving. Furthermore, people can extend functionality by bringing devices with them into the car, e.g., using their smartphones for navigation, to stream music, or see notifications. These interactive technologies create new opportunities for both drivers and passengers. However, they also require an increased amount of attention from the driver, which is a significant contributor to car accidents [32]. As a consequence, most countries have tried to limit the use of interactive technology by prohibiting the use of handheld devices while driving [32].

Novel interactive technologies are continuously being introduced and used in cars in new ways [16]. Development in the use of interactive technology in the car has inspired HCI research to investigate and characterise interaction with these technologies, and the consequences they have on people's safety and driving experiences (e.g. [3,4,14,45,59]). For example, studies show that GPS systems improve people's wayfinding abilities and change the perception of their surroundings [4,14], but they also significantly increase driver distraction [3].

Recent advances has evolved cars into connected devices with the ability to access internet services [22]. Many examples of interactive technologies exist that can complement and extend car functionality though connectivity. Some applications allow users to remotely control basic functionality of the car like temperature settings (e.g. [81,101]), and other applications allow users to control and monitor advanced functionality, like starting and summoning the car (e.g. [100]). Several services also provide users with features to facilitate car mobility, like access parking, fuel, and charging stations (e.g. [29]). Other applications provide mobility as a service and offer easy access to car sharing for several people through online services (e.g. [8]).

Using several devices to complement and extend car functionality forms what can be described as a *digital ecology*. In HCI, a digital ecology can be defined as '*a network of nodes of users and digital artefacts that is dynamically bound by interaction in users' activities*' [97]. Similar to the natural use of the term 'ecology', the assumption of the HCI research investigating digital ecologies is that we cannot achieve a complete understanding of people's interaction by considering each device in isolation [51]. It is argued that such understandings are important for the design of interactive technology to fit into peoples digital ecologies more intuitively [7,15].

This thesis investigates interaction in digital ecologies with cars. It does this by looking at digital ecologies with the interaction between multiple interactive technologies and people as opposed to considering technology in isolation. In HCI, a body of research has worked with investigating the interaction with technology to support the driving situation. As a result, there are understandings of the effects and purposes of such technologies to support drivers and passenger driving activities. However, HCI research investigating multitudes of interactive technology used to support activities beyond that of the driving situation is limited. For example, many contemporary cars today are connected, and it is possible through applications on other devices to interact with the car's functionalities while not driving it or even being near it. These opportunities for interaction might support entirely different activities than the driving situation allows for. Despite this, there are still limited investigations of how people interact with, and appropriate digital ecologies to support activities related to mobility with cars.

1.3 RESEARCH QUESTIONS

The work presented in this thesis is motivated by the questions regarding how people interact with digital ecologies with cars and how these support mobility in everyday life. The thesis is structured in two research questions:

RQ 1: *What characterises interaction in digital ecologies with cars?*

The first research question addresses how to characterise interaction in digital ecologies with cars. The thesis approaches this through a review of the HCI literature on interaction with cars and on interaction in digital ecologies. This provides a context and theoretical foundation for developing a framework that characterises interaction in digital ecologies with cars.

RQ 2: *Which activities can be supported by digital ecologies with cars?*

The second research question deals with which activities can be supported by digital ecologies with cars. The thesis approaches this by using the developed framework as an analytic lens. Interaciton is illustrated through five paper contributions. The papers investigate the cases of electric and shared cars. The contributions provide empirical understandings of how digital ecologies with cars are already being used in everyday life, and based on this, implications for future designs are provided.

1.4 THESIS STRUCTURE

This thesis consists of six chapters. The first chapter presented the introduction to the two areas of digital ecologies and cars and the research questions. Chapter 2 provides the conceptual background and key concepts for both interaction with cars and interaction with digital ecologies. I merge these concepts into a framework for understanding interaction in digital ecologies with cars. Chapter 3 describes applications of interaction in digital ecologies with cars through five paper contributions where the framework was used as an analytic lens. Chapter 4 presents a discussion of the contributions of Chapters 2 and 3. Finally, Chapter 5 concludes the thesis and answers the research questions.

2 INTERACTION IN DIGITAL ECOLOGIES WITH CARS

This thesis works on the question of how to characterise interaction in digital ecologies with cars. To investigate this, I will describe HCI research on interaction in digital ecologies and research that describes interaction with cars. Concepts from these two research areas research leads to the construction of a framework that can be used to characterise interaction in digital ecologies with cars.

In the first two sections of this chapter I first provide background on HCI research concerning interaction and digital ecologies (Section 2.1). Secondly, I provide a description of HCI research on interaction with cars (Section 2.2). The purpose of these two sections is to provide a context for the last section (Section 2.3) where I describe my framework for understanding interaction with cars in digital ecologies.

2.1 INTERACTION IN DIGITAL ECOLOGIES

In this section, I will describe the central concepts of interaction in digital ecologies. In the next section (see Section 2.2.1), I will elaborate on the term 'digital ecology', its origins, and central themes of HCI research. The second section (see Section 2.2.2) will elaborate on HCI research that provides different perspectives of how to understand digital ecologies.

2.1.1 DIGITAL ECOLOGIES

Digital ecologies have their origin in the more traditional term *ecology* (also referred to as *eco-system*) which emerged in various disciplines in the 1920s [17]. However, the term *oekologie* (meaning ecology) originates from biology and was coined much earlier in 1866, by German zoologist Ernst Haeckel, from the Greek *oikos* meaning *home, place to live* [72]. The term covers a way of thinking where we shift focus from individual relationships to relationships between parts and the essential idea is that '*an ecology is the properties of a whole that none of the parts alone has'* [17].

The term 'digital ecology' leans towards the natural use of the ecology metaphor, where the rationale is that we cannot possibly understand a single species fully without considering its interactions with its environment [17]. Similarly to the natural use of the term 'ecology', the assumption is that we cannot achieve a complete understanding of interaction with interactive technologies in a digital ecology by considering each device in isolation [51]. Both Rogers and Bagnara describe this way of thinking as a shift from understanding the interaction between one person and one computer to investigating multitudes of technologies as interconnected with multiple technologies and people [5,91]. According to Raptis et al. [88], the term 'ecology' has been adopted in HCI. However, since the field deals with digital artefacts rather than living organisms, as in the original use of the term, the more specific term *digital ecology* was adopted.

I see two themes in the existing HCI literature on digital ecologies; design and understanding. Research in these two themes are focused on interaction between many devices and many users.

The first theme is *design* for digital ecologies. Contributions have focused on guidelines, frameworks, and design suggestions that concern *form* and less on accounts of understanding use, practise, and activities in the real world [55,91]. Examples of these are suggestions of systems capable of cross-device interaction such as a number of devices complementing each other by distributing an image over several screens (e.g. [61,80]) and frameworks, and design guidelines for various settings (e.g. [49,69]). According to Brudy et al., a central challenge in this type of research is that there is limited knowledge about the environments that are representative of people's interaction with technology in their everyday lives and outside the lab [15].

The second theme is *understanding* digital ecologies. According to Rogers [91], this is a far less common theme in HCI. The work under this theme investigates the environments in which interactive technologies are used in terms of activities and interactions in people's daily lives. Contributions have focused on conceptualisation, frameworks, definitions, and accounts on why and how digital ecologies are being used. An example of research under this theme is Forlizzi [33] investigating the digital ecology surrounding robot vacuum cleaners. She found that they interact with people in the household and shape their cleaning practices and how they use other cleaning technologies.

In this thesis, I focus on understanding interaction in digital ecologies. The argument is that there are limited accounts of digital ecologies being used in everyday lives that can inform design. Further, when referring to the term digital ecology in this thesis I refer to systems of multiple interactive technologies and people as a complementary perspective to using technology in isolation. To elaborate further on the research on understanding digital ecologies, I will outline HCI literature on understanding digital ecologies in the next section where I describe the different definitions and challenges related to it.

2.1.2 UNDERSTANDING DIGITAL ECOLOGIES

Understanding a digital ecology means understanding the relationships between its components (e.g., people, devices, and activities). This builds on the assumption that we cannot achieve a complete understanding of people's interactions with various interactive technologies in a digital ecology by considering its components in isolation [51]. In the HCI literature, different terms refer to digital ecologies and understanding their components. For instance, *ecology, artefact ecology, product ecology,* and *information ecology* are all used here to describe the same phenomenon of a digital ecology. In the following, I will describe these terms and their contributions to understanding and analysing digital ecologies in the remainder of this section. In the following sections, I will address three perspectives that I have identified in the literature; the *person*, the *product*, and the *interaction* perspective.

One perspective is focusing on the *person* as central to a digital ecology. Jung et al. describe what they refer to as *personal ecologies* as '*a set of all physical artefacts with some level of interactivity enabled by digital technology that a person owns, has access to, and uses*' [51]. Their notion of an ecology centres the person as the user of the artefacts, and thus, ecologies are centred around people. They show how to study personal ecologies by mapping out the set of artefacts used in a particular environment [92]. Along the lines of personal ecologies, Bødker and Klokmose [9,10] describe what they call *artefact ecologies* and draw on Activity Theory to describe all devices used in people's daily activities. Bødker and Klokmose acknowledge the definition of ecologies in [10] however, note that it does not capture how people appropriate technology and describe an ecology as one where artefacts can be part of multiple activities and are substituted for each other, and as such, they are *dynamic* [10]. The person perspective is useful for mapping out ecologies and why technology is used. Using a sketching approach, Jung et al. [51] showed specific devices might have different meanings depending on the activities that they are a part of, e.g. based on context, a mobile phone might be used for both communicating with the family or scheduling events. Bødker and Klokmose studied the case of introducing new artefacts into an existing ecology using interviews and found that ecologies go through an *unsatisfactory*, an *exited* and a *stable* state [10].

Another perspective is focusing on the *product* and which context it is being used. Forlizzi defines what she calls a *product ecology* that describes that an ecology consist of *a product, other surrounding products, people, activities, place, and social* and *cultural context of use* [35]. Similarly, Nardi and O'days definition on *information ecologies* defines an ecology as *'a system of people, practices, values, and technologies in a particular local environment'* [77]. The focus in these definitions highlights the importance of the envoronment of use and in particular people's practices. These perspectives on digital ecologies are useful for understanding how technologies are incorporated into people's everyday activities and shape their practices. For instance, Forlizzi and Disalvo [34] studied how robot vacuum cleaners changed people's practices in their home. For example, the activity of cleaning at home often requires a traditional vacuum cleaner. However, it could also be complemented by a robot vacuum cleaner that interacts with the residents and shapes their cleaning practices, i.e. when and where they clean.

A third perspective is focusing on *interaction* which provides specific concepts to understand the relationship between components of a digital ecology. Sørensen et al. [97] argue that unlike the above definitions, the interaction perspective is useful for *"informing specific understandings and design on the level of user interfaces and interaction techniques'*. Johansen [49] characterise interaction as occurring both in *time* and *place* and that interaction can be either *synchronous* or *asynchronous*. Johansen use office work as an example. As such, face-to-face and remote meetings are examples of synchronous interaction that happens the same time, but in different places i.e. collocated and remote. On the other hand, public displays and email are examples of asynchronous interaction in the same but different places. Drawing inspiration on Johansen's concepts, Sørensen et al. [97] contribute with their *4C framework* and define a digital ecology as '*a network of nodes of users and digital artefacts, that is dynamically bound by users' activities*' [97]. They do not give an explicit definition of an activity but provide examples such as '*working at the office or watching Netflix at home*' which can both involve several users and artefacts [97]. Similar to Johansen they characterise interaction as either *sequential* or *simultaneous*. In Sørensen et al. terminology simultaneous interaction is when '*users do something using several digital artefacts at the same time*' [97]. In sequential interaction, the users '*start doing something with one digital artefact and then continue on another*' [97]. They further elaborate on the two, by providing specific concepts to explain interaction. Sequential interaction consists of two types of interaction; *commonality* and *continuity*. As an example, if a person edits a text on a laptop and then continue to edit it on the smartphone this is continuity. Simultaneous interaction consists of *collaboration* and *complementarity*. As an example, several people writing a paper together in an online editor can be classified as collaborative interaction.

The above literature on understanding digital ecologies provides three different perspectives on understanding digital ecologies. Each has their valuable perspectives and contributions. However, the use of these perspectives to explore areas of systems of interactive technologies are limited, i.e. the office [49], home [34,51], and healthcare [31]. New interactive technology is being designed and used in people's everyday lives and becomes part of someone's digital ecologies [51]. This means that there are emerging digital ecologies that HCI researchers only have a limited understanding of how to characterise and design for them [15]. One example of an interactive technology that has become part of a digital ecology is the car.

2.2 INTERACTION WITH CARS

In this section, I will describe two areas of HCI research on cars. First, I describe central research themes on interacting with technology in the car, exploring its impact on safety and experiences. Second, I elaborate on recent themes of research in HCI on cars. These themes go beyond the traditional car use and into areas enabled through emerging interactive technology and capabilities of modern cars.

2.2.1 HCI RESEARCH ON INTERACTION WITH CARS

In this section, I will elaborate further on HCI research exploring interaction with cars. This area has investigated the opportunities and challenges of the increasing amount of interactive technology that is built into the car (e.g., infotainment and GPS systems) and that people bring with them (e.g., smart devices meant to extend the car's capabilities). This research can be divided into two themes; safety and experiences.

A central theme in HCI research concerning the car is *safety*. Towards this end, two important areas of concern have been to investigate driver distraction and cognitive load. HCI research has focused on interacting with technologies inside the car such as existing interfaces (e.g. [3,45,59,78], novel interfaces (e.g. [30,54,60,68,70,78]), and interaction techniques (e.g. [2,4,50]). Jensen et al. [45] studied how drivers' glance at a GPS during driving and Leshed et al. [59] studied how drivers engaged and disengaged with the environment using GPS navigation systems. Nass et al. [78] suggest improving automotive safety by paring driver emotion and car voice emotions. Löcken et al. [70] demonstrate a prototype that uses ambient light as an alternative to graphical navigation and Ecker et al. [30] challenge the use of deeply-nested menu structures found in many car displays. Studying in-vehicle systems, Bach et al. [3,4] compare the use of tactile, touch, and gesture-based interaction techniques.

Another theme in HCI research on the car is driving *experiences*. A number of studies investigate social interaction in the car (e.g. [23,39,43,85,104]) and drivers' and passengers' experience using different technology in the car (e.g. [14,84]). For example, Perterer et al. [86] studied how passengers and drivers interact in the car to inform the future design of in-car technologies, and Wilfinger et al. [104] explored designs on how back and front seat passengers can share experiences in the car. Brown et al. [14] also investigate drivers' perceptions of their surroundings when using GPS and found that people experience their surroundings differently when driving with a navigation device.

More recently, interaction has moved out of the car, facilitated by connectivity to other interactive technologies. HCI research investigated the capabilities of the connected car and investigated both safety and experiences. Coppola et al. define the term 'connected car' as '*equipped with modern applications, capable of interacting with other smart devices, and capable of accessing the Internet and its services at any time*' [22]. HCI research already started to explore designs for cars that extend beyond interaction in the car. HCI research includes the concepts of communication between cars when driving to improve traffic safety [102,103], or to provide people with experiences, such as changing the experience of parking through collaboration [20] or sharing music between cars when driving [84]. However, although research has provided suggestions for designs on the connected car, they are limited in their understanding of actual interaction and appropriate in everyday life.

2.2.2 RECENT THEMES IN HCI RESEARCH ON CARS

In this section, I describe HCI research on emerging areas with cars. The research is fueled by a desire to investigate new ways of using the car. In the following, I will elaborate on three recent themes in HCI research; autonomous, shared, and electric driving.

A recent theme in research is *autonomous driving*. Autonomous driving has the potential to solve societal challenges assiciated with cars such as roadside accidents and reduced congestion [19]. Many cars today are capable of some level of autonomous driving capabilities, e.g., lane-keeping capabilities and semi-autonomous driving, however, several modes of autonomy exists. Casner et al. [19] describe five modes of autonomy ranging from Level 0 – manual car driving, to Level 4 – fully autonomous. Within these modes, specifically the design of assistance systems for autonomous driving [12,57,66,73] and studies of driver behaviour and opinions towards specific autonomous driving features [26,89] have been explored in HCI. As examples, Borojeni et al. [12] show that drivers respond to take-over requests differently depending on the movement of the car and argue that awareness of context should be taken into account in design. Studying driver behaviour during autonomous driving, Reimer et al. [89] found that drivers were more likely to engage in a secondary activity when driving fully autonomously than semi-autonomously.

A second theme involves *shared* cars. Sharing is associated with benefits such as increasing the number of people in a car, thus reducing the number of vehicles on the road [95]. Sharing cars is a phenomenon that started in local communities, however, it has gained public interest lately, as the internet has enabled sharing platforms to reach a wider group of people more efficiently [13,38,42]. There is typically a distinction between sharing the car itself, *car sharing* [6,28,53,94–96], or sharing a car as a resource such as a ride, *ride-sharing* [21,24,25,74–76]. HCI research identified individual motivational aspects for participation in sharing such as belief in the common good [25] and environmental awareness [95], but also reasons for non-participation like overhead when planning trips, lack of trust, and discrimination [24,75]. A body of HCI literature also investigates the implications that the use of sharing platforms have on different communities. As examples, Dillahunt et al. [24] studied how people with low incomes could benefit from using ride-sharing. They found that these populations benefit from rich social interaction with drivers and other passengers. Meurer et al. [75] explored ride-sharing for the elderly and found that independence and decisional autonomy were particularly important.

A third theme of recent HCI research focuses on *electric vehicles* (EVs), which are currently being phased in by many European countries, e.g., Norway aims to stop the sale of fossil fueled vehicles in 2025 [44]. EVs have the potential to reduce local emissions and are capable of being fueled by renewable electricity [65]. However, research indicates challenges of user acceptance towards adopting EVs as they present a different driving experience than traditional cars, such as limited range and the lack of driving feedback [52,63,65]. Toward this end, a number of applications already exist to support EV use (e.g., car control and range prediction [81,101], charging planning [29,87]). In HCI, the research on EVs predominantly concerns how range and driving experiences affect driving and how design can support it. Many studies investigate fluctuating range prediction and with it, the feeling of range anxiety, i.e. the fear of depleting the battery [52]. As examples, Lundstrøm et al. explored how range prediction affects drivers in electric cars [62–65] and in relation to this, Jung et al. explored how range uncertainty can be displayed to reduce range anxiety [52].

The above themes of recent research on cars in HCI provide valuable insight into people's use of specific interfaces for purposes such as take-over requests, sharing cars, and reducing range anxiety. Although specific interfaces have been investigated as a means to mitigate many of the challenges associated with challenging traditional use of the car, they provide limited insight on the role of digital ecologies.

2.3 FRAMEWORK: INTERACTION IN DIGITAL ECOLOGIES WITH CARS

The context of digital ecologies and cars described in the previous sections of this chapter provide the theoretical foundation for the framework for characterising interaction in digital ecologies with cars. The framework is depicted below (see Figure 1). The framework describes two dimensions of interaction with digital ecologies with cars; *interaction* and the *car.* The interaction dimension describes types of interaction in digital ecologies. It is based on Sørensen et al.'s [97] understanding of interaction. The car dimension describes ways that a car can be part of a digital ecology. It is based on connectivity following Coppola et al.'s [22] definition. The dimensions of the framework are further elaborated on below.

Digital Ecology		**Interaction**	
		Simultaneous	**Sequential**
Car	**Connected**		
	Non-Connected		

Figure 1: Framework for describing a digital ecology of interaction with the car.

The first dimension defines interaction in digital ecologies. I adopt the terminology and concepts on interaction from Sørensen et al. [97]) as either being *simultaneous* or *sequential*. Sørensen et al. describe simultaneous interaction as when *'users do something using several digital artefacts at the same time'* [97]. In sequential interaction, the user '*starts doing something with one digital artefact and then continues on another*' [97]. As such, in my framework, when I refer to simultaneous interaction, I refer to users interacting with several digital artefacts at the same time, and 'sequential' as when users start interaction on one digital artefact and then continue on another. Both simultaneous and sequential interaction have their own set of concepts to describe interaction. In the following, I will give illustrative examples of complementarity as simultaneous interaction and continuity as sequential interaction. In simultaneous interaction, the driver will use the navigation on his smartphone to complement the activity of driving. Following the definition above, this is simultaneous interaction as users are interacting with several artefacts at the same time. In sequential interaction, a user will start listening to music on his smartphone and then continue that activity on the car's entertainment system. Following the definition above, this is sequential interaction, as several users are interacting with several artefacts, but not at the same time.

The second dimension defines two ways in which the car can be part of a digital ecology. Following recent developments with cars concerning connectivity, I find it useful to divide how the car is part of a digital ecology into *connected* and *non-connected*. To describe the two, I use the definition by Coppola et al., who define the connected car as '*equipped with modern applications, capable of interacting with other smart devices, and capable of accessing the Internet and its services at any time*' [22]. The first part, connected, covers cars in digital ecologies where the car itself is connected and capable of interacting with other devices, and capable of accessing the Internet and its services at any time. Examples of interaction with connected cars are remote-controlling central functions such as heating or displaying car-specific information through smartphone applications. The second part, non-connected, covers cars in digital ecologies that are not connected and therefore not capable of interacting with other devices. An example of non-connected cars in digital ecologies is where people complement and extend functionality by bringing interactive technology with them into the car such as their smartphone to access real-time traffic information and guidance. A different example is the use of online services to gain access to cars that are not connected, such as online taxi or ride-sharing services.

3 PAPER CONTRIBUTIONS

This thesis investigates the question of which activities can be supported by digital ecologies with cars. To investigate this, I will present the empirical research contributions in five papers that describe activities where digital ecologies with cars are interacted with to facilitate mobility. Each paper has been placed in the framework (see Figure 2) according to their primary contribution to activities supported by interaction in digital ecologies with cars. The papers investigates the two themes of electric cars that are connected and shared cars that are non-connected. Each quadrant of the framework is exemplified by a paper and additionally, a paper bridges Quadrants 1 and 2.

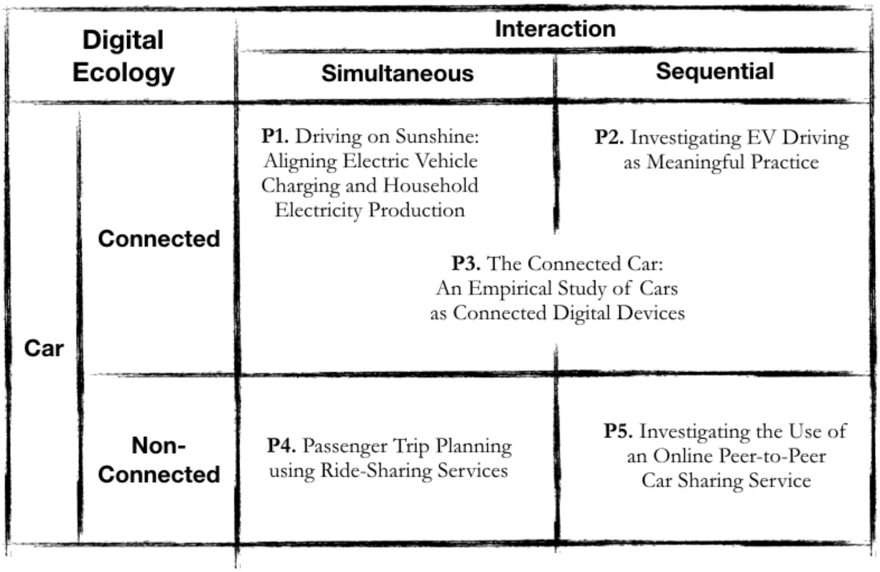

Figure 2: The five papers placed into my research framework

As a prerequisite for using the framework, I use Sørensens et al.'s definition of a digital ecology as a guide. The definition describes a digital ecology as consisting of *'a network of nodes of users and digital artefacts, that is dynamically bound by interaction in users´ activities'* [97]. As such, each of the papers investigates concepts using a number of methods to map the interplay between users, digital artefacts, and user's activities.

The remainder of this chapter gives a detailed summary of each of the paper contributions. The structure of the summaries is divided into four sections as follows: Firstly, the research question is described along with how the it relates to the framework of this thesis. Secondly, the methodology is described. Thirdly, central findings from the papers are summarised. Finally, the specific findings relating to the framework of this thesis are described where I have extracted examples of concepts in simultaneous and sequential interaction.

3.1 PAPER 1

Michael K. Svangren, Rikke H. Jensen, Mikael B. Skov, and Jesper Kjeldskov; 2018. Driving on Sunshine: Aligning Electric Vehicle Charging and Household Electricity Production. In *Proceedings of the 10th Nordic Conference on Human-Computer Interaction* (2018).

The study described in the first paper explores electric vehicles and how households use interactive technology to integrate and align charging their car with electricity production. The paper contributes to the understanding of simultaneous interaction with connected cars by illustrating the use of multiple devices to be able to control and get information about the EV.

The paper presents a qualitative study of five households (19 people) that were recruited and sampled through an online questionnaire deployed on online car forums targeting people who owned photovoltaics or wind turbines. Data collection was based on a combination of informal conversational technology tours exploring the technology available to the households and two rounds of elaborating semi-structured interviews, first with each household member, and then with the household as a whole. Data was transcribed, coded, and analysed thematically.

The paper presents the findings in five themes of: attitudes towards aligning, willingness and leveraging convenience, household mobility, charging routines and electricity production, and technology-assisted charging. The first theme describes participants' attitudes. Most participants thought that aligning was a good idea, partly for reasons of sustainability and partly for monetary reasons. The second theme indicates that participants' willingness towards aligning was low, as it was a matter of convenience, i.e. the amount of work required was too high compared to the outcome. The third and fourth theme describe that charging on electricity produced in the household was seen as hard because the EV would often be away during the day when electricity was being produced. The fifth theme describes that combining electric vehicles and electricity production is currently not well supported by existing technology. To cope with this, some householders created their own solutions, for example, using charge timers to plan to charging when not home and power metres to be able to track consumption.

From the findings, I have identified two examples of **simultaneous** interaction with electric vehicles to support the activity of charging. Firstly, the use of feedback applications was seen as important to get information about the current charging status to collaborate in the household on scheduling alternative charging or future trips. This was an example of collaboration, as many users were participating, e.g. one plugged in the charger and another scheduled charging. Secondly, the use of complementary features such as controlling charging, was used to stop charging. This was seen as a way to postpone charging to more favourable times, and could be done from participant smartphones. This did not require the presence of the participants, and therefore saved them time. This is an example of complementarity, as several interactive technologies were used at the same time, i.e. the car, the charger, and a smartphone to control it.

3.2 PAPER 2

Rikke Hagensby Jensen, **Michael K. Svangren**, Mikael B. Skov, and Jesper Kjeldskov; 2019. Investigating EV Driving as Meaningful Practice. Accepted for inclusion in *the 31st australian conference on human-computer-interaction* (2019).

The study described in the the second paper investigates electric vehicles and how owners find meaning in driving and using interactive technology to support it. The paper offers an understanding of how sequential interaction with connected cars can support driving and charging the EV.

The paper describes a qualitative study of five households (19 people) that were recruited and sampled through an online questionnaire deployed on online car forums targeting people who owned photovoltaics or wind turbines. Data collection was based on a combination of informal conversational technology tours exploring the technology available to the households and two rounds of elaborating semi-structured interviews, first with each household member and then with the household as a whole. Data was transcribed, coded, and analysed thematically using an inductive approach. Because mobility is closely tied to people's daily lives, we used practice theory as a lens in the analysis.

The paper presents the findings in five themes of: joyful electric driving, transitioning into EV driving, planning through interactive technologies, and (un)sustainable driving expectations. The first theme explains that people find meaning in EV experiences which are different than the ones experienced in a fossil-fueled car. Participants mentioned that driving is a nicer experience with less noise, less stress, and the feeling of using a technically-advanced car. The second theme describes the challenges that participants experienced in the transition to EV driving, such as getting used to a shorter driving range and learning how the infrastructure works. The third theme describes how these challenges are mitigated through the use of interactive technology that can support driving. As such, much of the use of the EV requires planning which was done by many households by interacting across devices and applications. The last theme indicated how EV driving for the participants caused an increase in miles driven, which could indicate unsustainable outcomes.

From the findings, I have identified examples of **sequential** interaction with electric vehicles to support the activities of planning and driving. Driving an EV requires planning, especially when going for a long ride. When planning a ride, participants used a number of different applications to find public chargers. These applications were used both on smartphones and in the cars. Participants typically started planning on their smartphones and then continued their planning when they got into their car. This is exemplified in the paper as continuity, where users' data is syncronised on several platforms, and they switch between them on different devices to plan to charge on public, proprietary, and private charging infrastructure respectively. This is an example of sequential interaction, as it indicates users start working on one device and continue on another.

3.3 PAPER 3

Michael K. Svangren, Mikael B. Skov, and Jesper Kjeldskov. 2017. The Connected Car: An Empirical Study of Cars as Connected Digital Devices. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services* (2017).

The study described in the third paper investigates how households that own a connected electric vehicle use connectivity to support mobility in their everyday lives. The paper contributes to the framework with findings on both simultaneous and sequential interaction with connected cars. It illustrates how participants interact with devices in collaboration with others, but also continue to support activities related to driving and owning an EV.

The paper presents a qualitative study of 13 Danish households (19 participants) owning at least one connected car. Participants were recruited and sampled through a questionnaire deployed on online car forums. Data collection was based on fieldwork with informal conversational technology tours for exploring their use of technology and two rounds of semi-structured interviews to elaborate on the tours. Data was transcribed, coded, and analysed thematically using an inductive approach.

The paper presents findings in three themes of interaction through connectivity, updating and upgrading car software, and security and privacy. The first theme describes how the participants interacted with their car. Most participants saw their car as a digital device on wheels, which was comparable to a smartphone. Furthermore, the participants mentioned useful functionality such as planning, monitoring, and remote controlling their vehicle from their smartphone. The second theme describes how software updates and upgrades were an important part of using the car. For most participants, installing software on their smart devices could complement the functionality of the car or get them new car functionality through manufacturer updates. The third theme explains that although participants liked much of the functionality that connectedness provided, they also had concerns about security and privacy in using their car. Many participants had privacy concerns such as the data being collected by the car could be exploited by other people or companies.

I have identified examples of both sequential and simultaneous interaction relating to activities of charging, driving, and using an EV. The paper illustrates **sequential** interaction with electric vehicles. Examples of sequential interaction are the use of music applications that allowed participants to continuously move between several devices, i.e., their phone and in their car. Music was distributed through online services. The study also highlights examples of **simultaneous** interaction. For example, in one case, letting the spouse know the location of the car through the app to see when the partner got off work was used as a way of collaboration to know when to initiate dinner preparations. Sometimes households would also collaborate around charging, for example, if a person had forgotten to start charging another could initiate it from his phone. Additionally, complementary functionality through remote control using a smartphone to control the car was also found to be important, especially for EV's to start heating up the car remotely while charging instead while driving.

3.4 PAPER 4

Michael K. Svangren, Mikael B. Skov, and Jesper Kjeldskov. 2018. Passenger Trip Planning using Ride-Sharing Services. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (2018).

The study described in the fourth paper investigates how ride-sharing passengers use online services to support planning their journeys. The paper provides findings on simultaneous interaction with non-connected cars. It illustrates how people use ride-sharing services to plan their trips.

The paper presents a qualitative study of 19 ride-sharing passengers from Denmark and how they used the two online ride-sharing platforms; GoMore and Facebook. Data collection were done in three phases. Firstly, the authors participated in five rides in-situ and interviewed four of our fellow passengers about their experiences and use of ride-sharing services. Secondly, the authors observed and conducted informal interviews with five participants centred around planning a ride in-situ. Finally, semi-structured interviews with ten passengers were used to ask specific questions informed about the prior two parts. Data was based on a mix of audio files and researcher notes. Data was transcribed, coded, and analysed thematically.

The paper presents the findings in six themes of finding rides based on price, time, and place, ride pick-up and drop-off negotiation, using public transportation to reduce uncertainty, ad-hoc handling of the unforeseen, using social media to plan conversation topics, driver reliability and privacy. The first theme illustrates the difference in preferences across participants when finding a ride, which was often based on leveraging price, time, and drop off and pick up places. The second theme concerns how passengers and drivers often use the ride-sharing platforms to negotiate the preferences for a trip. The third theme concerns using public transportation as a backup to support the full journey of a passenger. The fourth theme involves how passengers would often plan their trip ad-hoc using devices such as smartphones. The fifth theme describes how participants look up fellow passengers on social media to plan conversations. The final theme illustrates that although participants were users of many online ride-sharing services, they were cautious about giving too much information to their fellow passengers and drivers due to issues of trust.

In relation to my framework, the paper illustrates examples of **simultaneous** interaction with non-connected cars enabled through sharing services. A central activity in ride-sharing is planning, which was done by several users collaborating around a ride on the online sharing platforms. Two examples of simultaneous interaction could be observed here. Firstly, sharers and owners often used online platforms as a place for negotiating a price and pick-up location. This is an example of collaboration, as several participants are engaged in the activity through a platform. Secondly, sharers also used multiple mobility-related services extended to their smartphones to plan ad-hoc to be able to continue their trip. This would often include the comparison of different preferences on the various platforms. This is an example of complementarity services, and devices complement each other.

3.5 PAPER 5

Michael K. Svangren, Margot Brereton, Mikael B. Skov, and Jesper Kjeldskov; 2019. Investigating the Use of an Online Peer-to-Peer Car Sharing Service. In *Proceedings of the 17th IFIP TC.13 International Conference on Human-Computer Interaction* (2019).

The fifth paper investigates how car sharing users interact with a digital service that supports them in planning, finding, and picking up shared cars. The paper contributes to findings on sequential interaction with non-connected cars. It illustrates how participants move across different modes of transportation and services.

The paper presents a qualitative study of 16 users of car sharing (ten car-borrowers and six car-owners) which used the car sharing platform Car Next Door in Brisbane, Australia. Participants were recruited in collaboration with the company behind the platform, where questionnaires were sent out gathering initial data for sampling purposes. Data collection were based on a mix of three qualitative methods; Firstly, we asked participants to fill out diaries about their experiences with car sharing. Secondly, semi-structured interviews were conducted with both owners and borrowers. Thirdly, we observed borrowers using their smartphones to book cars. The data were transcribed, coded, and analysed thematically.

This paper presents four themes of; fueling individual motivation, supporting daily mobility, facilitating car sharing purposes, and socialising P2P car sharing services. The first theme illustrates how participants used car sharing to fuel both practical and intrinsic motivational factors. The second theme describes how car sharing was used in a variety of situations ranging from mundane small trips to extraordinary long journeys. The fourth theme describes how car sharing services facilitate these different situations such as different preferences of cars, location convenience, and price. The final theme describes the challenges of using an online service for car sharing. While some participants were happy accessing cars in a fast way without having any face-to-face communication, others felt like it was an alienating experience, especially when they knew that they were borrowing other people's cars.

In relation to my framework, I identified **sequential** interaction supporting the activity of car sharing with non-connected cars. Participants are not users of single modes of transportation but use multiple to stitch together their journeys. For example, car sharing was useful for a number of purposes, e.g. short mundane trips or extraordinarily long trips. However, it often required participants to combine different types of mobility to actually get to a car, e.g., taking a bus or train to the location of the car. Moving across modes of transportation required planning, which was done using different transportation services. Planning how a journey could be facilitated was carried out across these services, taking into account preferences such as location, price, and type of car. This is an example of sequential interaction as it is done across devices by moving between platforms and mobility modes.

4 DISCUSSION

This thesis has described a framework for understanding interaction in digital ecologies with cars. It has also presented empirical findings in five papers that investigate interaction in digital ecologies with cars. In this chapter, I will take a step back and discuss the framework and papers. In Section 4.1, I will revisit the framework and discuss my considerations towards its use. Section 4.2 will discuss design considerations based on the papers included in the thesis.

4.1 FRAMEWORK REVISITED

The purpose of the framework described in this thesis is to characterise interaction in digital ecologies with cars. This section will discuss the focus of the framework and its components in describing a digital ecology as a whole. I will do this in three parts; these are depicted in Figure 3 below. The first part will address the framework as a whole discussing commonality across the framework dimensions. The second will discuss how the papers have been placed within the framework. The last part will discuss interaction as a scope and which understandings lie beyond this.

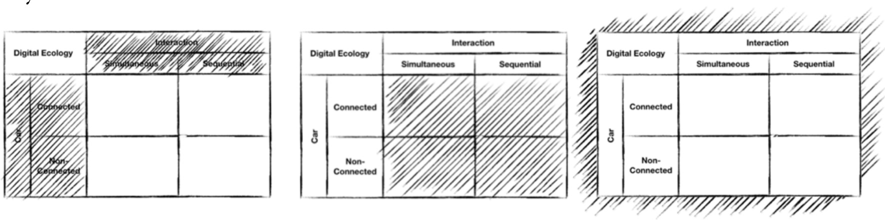

Figure 3: Three areas of discussion for the framework. From left to right, 1) Looking across dimensions, 2) Placement of papers, and 3) Interaction as a scope.

4.1.1 LOOKING ACROSS DIMENSIONS

In the five paper contributions, I have presented empirical findings on interaction in digital ecologies with cars. In this section, I will take a step back and consider interaction in digital ecologies across dimensions of the framework.

For simultaneous and sequential interaction, there are differences in how people interact with the interactive technologies composing digital ecologies. For connected cars, Paper 1 describes how people interact with technologies to complement car functionality (e.g. remote controlling through several devices) or collaborate around an activity (e.g. one user checking the location of the car while another is driving it). This describes interaction happening at the same time. On the other hand, Paper 2 describes continuous interaction (e.g., a user switching between devices) which is characterised by occurring at different times. Similarly, non-connected cars are characterised by the same types of communication. For example, Paper 4 describes collaboration (e.g., several users collaborating around negotiating rides) and Paper 5 describes continuity (e.g., how individual users change between transportation modes). One can argue that these distinctions are a relationship between the users and the interactive technologies they use in an activity. As such, simultaneous interaction can be described as a *many-to-one* or *many-to-many* type of relationship. The focus is here on groups of users or interactive technologies. Sequential interaction, on the other hand, reflects a *one-to-many* where the focus is on the single user and many devices in sequence. Although these distinctions are not formally described by Sørensen et al. [97], I believe they are helpful characteristics of interaction in digital ecologies.

For interaction across connectivity and non-connectivity in cars, there are similarities in the devices people interact with in a digital ecology. Bridging both connectivity and non-connectivity it seems in the papers that the smartphones are central devices for interaction. The focus of the interaction with smartphones in digital ecologies through connectivity was mostly directed towards activities using specific car functionality. For example, Paper 3 describes using devices to get real-time information or remote-controlling to support driving. On the other hand, smartphone use in digital ecologies where cars were non-connected, the purpose of interaction was directed towards activities such as planning to access infrastructure. For instance, Papers 4 and 5 primarily illustrate how people use digital services to plan how to access cars. Jung et al. [51] provide a similar characterisation of the use of devices. They argue that technology has different meanings depending on the activity they are used in, e.g. for cars, a smartphone might be used for both planning, navigation, and remote controlling. The paper contributions provide similar findings on the use of smartphones that serves different purposes for people across dimensions.

4.1.2 PLACEMENT OF PAPERS

Capra argues that understanding a digital ecology means understanding it as a whole [17]. The papers placed in the framework can be seen as understanding parts of a digital ecology. Placing a specific paper in a quadrant of my framework implies a certain focus. It can be argued that by placing them differently, other perspectives might be obtained. In this section, I will discuss the paper placement and how placing the paper contributions differently can contribute to a broader understanding of the digital ecologies investigated.

In understanding a digital ecology, the division of interaction has been useful as boundaries to narrow the scope of focus and to identify specific concepts of interaction. The papers have been placed in the framework to characterise these interactions in digital ecologies with cars. However, the placement of the papers should not be seen as defining. Each paper can be understood from different perspectives of interaction, although it will require a change in focus. As such, each of the papers that have been described with one perspective on interaction could be described as the other. For instance, Paper 5 describes the sequential interaction of how individual borrowers interact continuously across different types of transportation. However, we might also describe simultaneous interaction, such as how borrowers plan their trip simultaneously by comparing options on several devices. In understanding interaction in a digital ecology, it could be useful to consider multiple perspectives, and doing so could help provide a broader understanding of interaction within a particular digital ecology.

Using the definitions of connectivity from Coppola et al. [22], the individual papers have been placed in the framework with respect to connectedness. The cars studied in the papers had different levels of connectedness and can be classified as both connected and non-connected. For instance, Paper 5 describes a study of car sharing placed in the framework as being non-connected. However, the car-sharing service had installed connected features in the car, such as a lockbox with a real-time location accessible through an online service. As such, one could argue that this functionality approximates both that of non-connected and connected cars. I believe that this observation provides a useful perspective on cars in digital ecologies as not only being connected or non-connected, but should sometimes be characterized as both. As an example, Paper 5 describes non-connected cars where additional technology has been installed to provide basic connected functionality (e.g., a location and lockbox). However, interaction could also be described from a connected perspective. Similarly, Paper 3 illustrates how participants used their smartphones to plan trips, and how to access charging infrastructure. As such, a connected car perspective could be applied, as such planning did not involve interaction with their car.

4.1.3 INTERACTION AS A SCOPE

In this thesis, I focus on interaction as a scope for understanding a digital ecology. It can be argued that focusing on interaction in itself is a boundary and that there are understandings beyond this that the framework cannot tell us about. Hornbæk and Oulasvirta argue that different perspectives on interaction offer *'different vocabularies for phenomena with their own distinct boundary'* [41]. Similarly, I argue that providing understandings beyond the framework will require a different vocabulary. In the following, I will discuss what the framework can provide understandings about, and which understandings are beyond its use.

The focus on concepts of interaction as described by Sørensen et al. [97] provides boundaries in the sense that they focus on temporal aspects of interaction. This is the focus for the framework, and is also reflected in how interaction in digital ecologies with cars are described in the paper summaries. However, it could be argued that other dimensions exist besides the temporal one that I have adopted in my framework. For example, Paper 3 describes that simultaneous interaction occurs between a person driving a car and a spouse checking up on his location. Using the terminology of Sørensens et al. [97], this would be understood as collaborative or complementary interaction, because it is interaction with several devices at the same time. However, adding to this perspective, one could also argue that interaction has spatial aspects as also argued by Johansen, who describes interaction happening in both *time* and *space* [49]. As such, while the above interactions might happen at the same time, they might happen in two different places, e.g., considering if people are located remotely or are collocated. Although the concept of space is beyond the use of my framework, such concepts could, for instance, provide more detailed descriptions of interaction.

Although the framework provides conceptualisations of how people interact in digital ecologies with cars, the concepts can only explain interaction. The papers included in this thesis present examples of more than just interaction. An example is how people do not use technology. These examples were identified as a result of the research methods that gave the prerequisites for using the framework, that is, a broad understanding of interactive technology, the users, and their activities. For example, Paper 3 illustrates how participants use various applications for their smartphones to support mobility. However, the paper also illustrates that they disengage from using certain applications because they do not trust that developers can keep their credentials safe. Although these people might seem like bad users to a developer, there is, in fact, much to be learned from them. Satchell and Dourish argue that there is just as much to learn from how and why people *disengage* from the interaction as there is to actual interaction [93]. In the HCI literature, there are similar examples of why people disengage from using technology as discussed by Bødker et al. [11]. They present ways of explaining why disengagement occurs. For instance, people *actively resist* particular technologies and people rely on others as *mediators for use*. For example, Paper 3 describes how participants actively resist interacting with some smartphone applications because they fear data compromisation. Furthermore, it describes how some participants disengage from interacting with a digital ecology because they rely on a spouse as a mediator to facilitate use. The above examples are beyond the scope of my framework. To provide such explanations (e.g., a vocabulary for why disengagement occurs) researchers might find inspiration in other perspectives on digital ecologies. Considering the paper contributions such insights into digital ecologies might come from accounts of practice and values as also argued by Forlizzi [35] and Nardi and O'day [77].

4.2 DESIGN CONSIDERATIONS

This thesis contributes to the existing HCI literature by providing empirical findings on the activities supported by digital ecologies with cars. Considering the papers in this thesis, it is evident that digital ecologies are used to facilitate people's mobility with cars. Furthermore, though their use, it could seem that many of the challenges found in the HCI literature relating to electric and shared are mitigated. In this section, I discuss design considerations of my work in two themes. The first theme will discuss design opportunities for interaction in digital ecologies with cars. I will discuss and provide considerations for activities that can be supported through digital ecologies. The second theme will discuss design challenges for interaction in digital ecologies with cars. I will discuss considerations and give examples from the papers of activities where challenges were found.

4.2.1 DESIGN OPPORTUNITIES FOR INTERACTION IN DIGITAL ECOLOGIES WITH CARS

The papers in thesis show that a number of activities related to mobility with cars can be supported through digital ecologies. I believe that interaction in digital ecologies will become increasingly relevant in the future as society moves towards different ways of using cars. For instance, in autonomous cars, designers are working on less interaction with the car itself [19]. This development could require interaction with complementary devices, e.g., the smartphone to monitor and control the self-driving cars. Further, many observers argue that society is moving towards mobility as a service (MaaS) defined by more access and less ownership [13,38,48]. This will require new ways of accessing cars through people's digital ecologies.

The papers in this thesis suggest that many of the challenges of EV and shared driving can be mitigated through interaction with digital ecologies. For instance, participants in our EV studies used their digital ecologies to support charging and expressed that it made them care less about depletion of the batteries, i.e., range anxiety [52]. Similarly, planning overhead of car sharing [24,75] was perceived as insignificant because participants' digital ecologies supported combining transportation modes as they pleased. These are examples of different activities that call for their own set of people involved, and devices and services to be interacted with. This is what Bødker refers to as the *dynamics* of digital ecologies [10], that is, how people appropriate interactive technology in various ways to support their activities. I believe that these combinations are an opportunity that designers can learn from. The paper contributions in this thesis have identified some activities supported in the cases of electric and shared cars. In the following section, I will give my recommendations and provide examples of activities that can be supported through interaction using concepts from the framework. Three types of interaction and how they support activities in people's lives are described: collaborative, complementary, and continuous interaction.

Collaborative interaction

Collaboration can be used to support activities where people are interacting simultaneously but are located remotely. For the papers describing connected electric cars' information such as location and car state was used as a way for family household members to collaborate. Paper 3 describes that in one household, the car's location was used as a way to signal when household members would cook dinner. In another household, monitoring a car's charge status allowed one household member to start charging from the phone if the spouse forgot. In this way, family members could collaborate and support each other. For car sharing with non-connected cars, collaboration was seen as a way of coordinating and negotiating with others on sharing services. Paper 4 describes that people who ride-share use several devices and online services to plan a complete trip. In this way, multiple platforms were a way to combine the best possible trip together with other sharers.

Complementary interaction
Connectivity opens up extending and remote controlling the cars' functionality, and can be used to support activities where people and cars are located remotely. For the papers concerning electric cars, complementary interaction with digital ecologies supported activities such as charging and controlling temperature settings. These examples describe activities interacting with the car without requiring a physical presence. Paper 1 describes people complementing the use of their car through an application on their smartphone by remotely start and schedule charging Papers 2 and 3 describe people who control temperature settings on their smartphones. For shared cars, both Papers 4 and 5 describes how services are extended to smartphones that can be used to support planning ad-hoc.

Continuous interaction
Moving across technologies and can be used to support activities where interactive technology and people are collocated. For the papers concerning electric cars, continuous interaction with digital ecologies supported activities such as planning where to charge. This was often done with the devices at hand. Paper 3 describes how people starts to plan their journeys and charging points on their smartphones and then continue when they get to the car. For papers concerning car sharing, it should be considered that sharers do not only transport themselves by car. Rather, they are users of many modes of transportation that complement each other to facilitate car sharing. As such, continuous interaction supported the activity of moving across different services to plan a journey, but also moving across transportation modes. Paper 5 illustrates that besides personal devices, people move across different transportation modes (e.g., bus, train, and car) to complete their journey while car sharing. This is supported by careful planning and leveraging of preferences on different service provider applications.

4.2.2 DESIGN CHALLENGES FOR DIGITAL ECOLOGIES WITH CARS

The papers in thesis show that challenges exist for the design of digital ecologies with cars. In this section, I will discuss these challenges in two themes as considerations for design. Firstly, I will discuss trust and privacy as contributors to why people disengage from interacting with interactive technology in digital ecologies. Secondly, I will discuss how designs should support people's differences.

Trust and privacy
While digital ecologies with connected and non-connected cars can support a number of activities, they can also be a source of privacy and trust concerns. In the papers, this was described as a contributor to people deliberately disengaging from using certain applications and services.

In the papers concerning connected cars, participants were cautious about which connected interactive technologies they use together with their car. Paper 3 describes participants using smartphone applications to support functionality, such as live location and remotely controlled heating to support driving activities. However, they were also aware that data was being collected from the car and that 3rd party applications required and stored credentials. This led some participants to raise questions about privacy and data security. Designers should consider the car as a connected mobile device and could look to the HCI literature for inspiration for designs. For the papers concerning non-connected cars, it was illustrated that some participants wanted information about others to gain trust, but others gaining information about them was a privacy concern. Paper 4 illustrates that while interaction with many different online services was seen as supportive towards trusting others, paradoxically, many participants did not want these others to know too much about them. The possibility for drivers to gain information about other passengers through online platforms were seen as a contributor to trusting them. However, the amount of personal information available about themselves when interacting online was considered a privacy concern. Towards this end, the ride-sharing platform was seen as extra security because the provided user reviews.

Although concerns about privacy and security are not new in HCI research, the paper contributions show that they also apply to interaction in digital ecologies with cars. However, designers needs to take such accounts into consideration for their designs. As such, the HCI literature can serve as inspiration. As examples, for trust, simple mechanisms such as the use of ratings linked across platforms could be useful (e.g. [25,42,95]). Increasing the visibility of data logging or simply enabling users to turning off features such as location services (e.g., [67]) could help with privacy.

Designing for diversity

The paper contributions highlight that each user's interaction in digital ecologies is highly individual. I will focus this discussion on designing for two types of users described in the paper contributions. The below examples are based on observations across papers and are not an exhaustive list; there are, of course, individual differences not captured in these descriptions.

The first type of user is one that is inherently interested in and motivated by technology. They find meaning in combining different technologies into a digital ecology and orchestrate their digital ecologies to the activities they participate in. As such, they appropriate and interact with many different devices, applications, and services. In the paper contributions, we refer to these users as 'tinkerers' and 'early adopters' with references to Yolande Strenger's *resource man* [99]. As also described in the HCI literature, they are typically the driving force behind bringing new technology into the household and using it [46,71,99]. I believe that these users should be supported in their interest in appropriating technology. As such, it could be of interest for designers to consider designing technology that *can* rather than *should* be used as part of a digital ecology.

The other type of user is one that resists or is behind in the adoption of technology. They interact with digital ecologies consisting of the same set of interactive technologies and are not willing to compromise comfort for combining technologies. This type of user is exemplified in Paper 3 as one that relies on others to mediate interaction (i.e., driving or planning through different technologies). Failing to find a mediator resulted in reverting to old familiar technologies (i.e., fossil-fueled cars). Paper 1 describes the user as a person who values comfort over resources spent on learning new technology describe that these users often disengage from using complex digital ecologies (i.e. interacting with too many interactive technologies to facilitate an activity). Considering design, as also discussed by Bødker et al. [11], it is important to consider that users simply are not ready or willing to use a complex digital ecology, but rely on other people with a higher degree of interest, digital literacy, and willingness to mediate their interaction. They are not bad users, but simply have different requirements [27]. As also discussed by Jensen et al. [46,47] and Strengers [99], these users could require much simpler solutions such as automation that can reduce complexity.

5 CONCLUSIONS

This thesis has contributed with a framework for characterising interaction in digital ecologies with cars. It has also provided empirical understanding on how digital ecologies support user activities. This chapter concludes the thesis by answering the research questions, describing limitations of the thesis, and outlining future work.

5.1 RESEARCH QUESTIONS

RQ1: *What characterises interaction in digital ecologies with cars?*

Interaction in digital ecologies with cars can be characterised in two dimensions. The first dimension describes interaction in digital ecologies. This can be characterised by two concepts of *simultaneous* or *sequential* interaction. The second dimension describes how cars are part of digital ecologies. Cars in digital ecologies can be characterised through two concepts of being *connected* or *non-connected*.

A contribution of the thesis is a framework that characterises interaction in digital ecologies with cars. The framework merges the above concepts for characterising interaction in digital ecologies with cars. For describing interaction, I adopted the terminology and concepts of interaction as either being simultaneous or sequential. When using the concept of simultaneous interaction, I refer to users interacting with several digital artefacts at the same time, and sequential as when users start interaction on one digital artefact and then continue on another. Cars can be part of digital ecologies in two ways: connected and non-connected. When using the term 'connected', I refer to cars that are capable of interacting with other devices and capable of accessing the Internet and its services. When using the term 'non-connected', I refer to cars that are not connected and therefore not capable of interacting with other devices through the Internet. The use of the framework builds on the notion of a digital ecology as consisting of '*a network of nodes of users and digital artefacts, that is dynamically bound by interaction in users' activities*'. As such, an understanding of these concepts is part of an investigation to provide a prerequisite for using the framework.

Discussing the framework across dimensions, I argue that a useful analogy for interaction in digital ecologies can be the relations between people and devices, such as one-to-many or many-to-one. I also argue that connected and non-connectedness can be seen as scales, as many cars today can be characterised as both, depending on the focus. Discussing each dimension, I argue that both simultaneous and sequential interaction along with connected and non-connected cars should be seen as complementary perspectives for describing a digital ecology as a whole. Discussing the scope of the framework, I argue that there are understandings that are beyond the use of the framework. For example, the framework tells us little about the place in which interaction occurs and similarly cannot provide us with understandings about non-use and practice.

RQ2: *Which activities can be supported by digital ecologies with cars?*

The paper contributions in this thesis illustrate that digital ecologies are used in a number of activities to support mobility in everyday life. For instance, for electric vehicles, complementing car functionality and collaboration through other devices support the activity of charging. For sharing cars, collaboration between people through sharing platforms can be used to negotiate trips and continuity moving across modes of mobility can support the planning of journeys.

In this thesis, I have presented five paper contributions illustrating how digital ecologies with cars are interacted with in everyday life. To do this, the constructed framework has been used as an analytic lens. The papers investigate the cases of electric vehicles and shared cars and interaction have been described as either simultaneous or sequential interaction;

Two papers describe either simultaneous or sequential interaction with connected electric vehicles. An addidional paper bridges both simultaneous and sequential interaction with electric vehicles. These papers investigate the interaction with electric vehicles. Paper 1 illustrates that people complement the functionality of their car using several devices and services to support charging. Paper 2 shows that people interact continuously interact across a number of services to plan their journeys, e.g., by planning on their smartphone and then continuing in their car. Paper 3 illustrates that people collaborate simultaneously around activities where the car is central, for example, one person drives the car while another looks up their position to be able to know when to cook dinner. Paper 3 also illustrates sequential interaction by describing how people move across devices by between listening to music on their smartphone and then continuing that activity in their car. Two papers describe either simultaneous or sequential interaction with non-connected cars. These papers investigate the interaction with shared cars in the cases of ride and car sharing. Paper 4 investigates ride-sharing and shows that people collaborate through a number of services to plan and negotiate rides. Paper 5 investigates car sharing and shows that people move across transportation modes and services to support their journey.

Although this thesis focuses on understanding digital ecologies with cars, I have provided implications for design in two themes. In the first theme, I outline design opportunities for interaction in digital ecologies. I argue that designer should draw inspiration from the dynamics of how people combine interactive technology in their daily lives. I provide three examples of 1) how collaborative interaction can be used to support activities where people are interacting simultaneously but are remotely located, 2) how complementary interaction can be used to support activities where people and cars are remotely located, and 3) how continuous interaction can be used to support interaction in digital ecologies where devices and people are collocated. In the second theme, I outline two design challenges for interaction in digital ecologies with cars: 1) how trust and privacy can be a contributor to people resisting the use of particular interactive technologies, and 2) that people are diverse and designers need to consider these differences in their designs.

5.2 LIMITATIONS

The work in this thesis does have some limitations in terms of the constructed framework and studies described through the papers. These are described below.

Firstly, the choice of Sørensen et al.'s concepts of interaction for the framework is limited in their understandings. For instance, the framework has a focus on interaction over time and does not explicitly say anything about non-use or the place in which interaction takes place. This is a boundary of choice to focus on interaction and thus beyond the scope of the framework. However, as discussed in Chapter 4, these are also important aspects of a digital ecology and something that adopting researchers should have in mind.

Secondly, the two cases of electric and shared cars chosen for the papers to exemplify interaction within the framework is in no means fully exhaustive for all modes of cars. These two modes were chosen for practical reasons and fit into the framework's dimension of connected and non-connected cars in digital ecologies. Despite this, I recognise that other modes would be interesting to pursue and would fit into the framework as well. For instance, traditional fossil-fueled, hybrid, or autonomous cars could similarly provide interesting findings.

Thirdly, the studies described in the papers included in this thesis are based on qualitative methods such as observations, participation, and interviews. These methods were used as a mean for triangulation and to get in-depth and explorative initial insight about the area of concern as described in each paper. Because these studies are qualitative, I do not claim that they are generalisable across a wider population. I acknowledge that other methods are required to provide statistical generalisability.

Fourthly, since the studied technologies and services are relatively unique, i.e., EVs and shared cars, the focus has primarily been on those people who are actively using them. This means that a large number of the participants recruited could be classified as early adopters, which many of the results also reflect. While I do believe that insight into interaction in digital ecologies for this group of people are important, I also recognise that other groups have different preferences and prerequisites for interaction in digital ecologies. Further investigations will be needed if insight must be provided about other groups of people.

5.3 FUTURE WORK

This thesis has contributed with a framework for understanding interaction in digital ecologies with cars and provided insight into how digital ecologies support mobility with cars. Based on this, the research gives rise to future work on both understandings and designing for digital ecologies with cars.

Firstly, it would be interesting to conduct further studies in further pursuit of understanding interaction in digital ecologies with cars. As described in the limitation section, it would be interesting to conduct studies across a wider population other than first movers or early adopters. This would also enable us to tell how interaction is manifested across various groups of people. Furthermore, it would be interesting to explore other perspectives of investigating the interaction with digital ecologies than just the one adopted in this thesis. Based on the papers, an analysis of practice that provides deeper insight about why people use a particular set of technologies would also be interesting.

Secondly, while the framework is primarily seen as a tool for understanding interaction for digital ecologies with cars, it would be interesting to unify the knowledge obtained with design aswell. As described in Chapter 4, digital ecologies have been studied with the purposes of understanding but provide implications for design as well. As described by Brudy et al. [15], there is a gap between design and understanding in the literature. The design of digital ecologies often lack an understanding of real-life activities, and thus, their real-life applications are hard to predict. From my perspective, the abstractions of interaction obtained through the papers in this thesis allow us to move towards this unification that can give inspiration to designers. I think it would be interesting to pursue designs based on the findings from studies such as the ones described in this thesis. To learn more about how these designs work (or not), field evaluations could be beneficial.

6 LIST OF REFERENCES

[1] ACEA - European Automobile Manufacturers Association. 2016. Future mobility: The challenges we face | ACEA - European Automobile Manufacturers' Association. Retrieved December 20, 2018 from https://www.acea.be/news/article/future-mobility-the-challenges-we-face

[2] Amna Asif and Susanne Boll. 2010. Where to turn my car? In *Proceedings of the 2nd International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '10*, 64. DOI:https://doi.org/10.1145/1969773.1969786

[3] Kenneth Majlund Bach, Mads Gregers Jæger, Mikael B. Skov, and Nils Gram Thomassen. 2008. You can touch, but you can't look. In *Proceeding of the twenty-sixth annual CHI conference on Human factors in computing systems - CHI '08*, 1139. DOI:https://doi.org/10.1145/1357054.1357233

[4] Kenneth Majlund Bach, Mads Gregers Jæger, Mikael B. Skov, and Nils Gram Thomassen. 2009. Interacting with in-vehicle systems: understanding, measuring, and evaluating attention. *Proceedings of the 23rd British HCI Group Annual Conference on People and Computers: Celebrating People and Technology*, 453–462. Retrieved April 26, 2019 from https://dl.acm.org/citation.cfm?id=1671070

[5] Sebastiano Bagnara and Simone Pozzi. 2016. The Third Wave of Human Computer Interaction: From Interfaces to Digital Ecologies. *Digit. - Sci. J. Digit. Cult.* 1, 1 (2016), 59–65. DOI:https://doi.org/10.4399/97888548960247

[6] Fleura Bardhi and Giana M Eckhardt. 2012. Access-Based Consumption: The Case of Car Sharing. *J. Consum. Res.* 39, 4 (December 2012), 881–898. DOI:https://doi.org/10.1086/666376

[7] Genevieve Bell. 2002. *Making sense of museums: The museum as' cultural ecology'*. Intel Labs.

[8] BlaBlaCar. BlaBlaCar - Trusted carpooling. Retrieved September 12, 2017 from https://www.blablacar.com/

[9] Susanne Bødker and Clemens Nylandsted Klokmose. 2011. The Human–Artifact Model: An Activity Theoretical Approach to Artifact Ecologies. *Human–Computer Interact.* 26, 4 (December 2011), 315–371. DOI:https://doi.org/10.1080/07370024.2011.626709

[10] Susanne Bødker and Clemens Nylandsted Klokmose. 2012. Dynamics in artifact ecologies. (2012), 448. DOI:https://doi.org/10.1145/2399016.2399085

[11] Susanne Bødker, Peter Lyle, and Joanna Saad-Sulonen. 2017. Untangling the Mess of Technological Artifacts. (2017), 246–255. DOI:https://doi.org/10.1145/3083671.3083675

[12] Shadan S. Borojeni, Susanne C.J. Boll, Wilko Heuten, Heinrich H. Bülthoff, and Lewis Chuang. 2018. Feel the Movement: Real Motion Influences Responses to Take-over Requests in Highly Automated Vehicles. *Proc. 2018 CHI Conf. Hum. Factors Comput. Syst. - CHI '18* (2018), 1–13. DOI:https://doi.org/10.1145/3173574.3173820

[13] Rachel Botsman and Roo Rogers. 2011. *What's Mine Is Yours - How Collaborative*

Consumption is Changing the Way we live. London: Collins.

[14] Barry Brown and Eric Laurier. 2012. The normal natural troubles of driving with GPS. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12*, 1621. DOI:https://doi.org/10.1145/2207676.2208285

[15] Frederik Brudy, Christian Holz, Roman Rädle, Chi-Jui Wu, Steven Houben, Clemens Nylandsted Klokmose, and Nicolai Marquardt. 2019. Cross-Device Taxonomy: Survey, Opportunities and Challenges of Interactions Spanning Across Multiple Devices. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems - CHI '19*, 1–28. DOI:https://doi.org/10.1145/3290605.3300792

[16] Business Insider. New cars increasingly crammed with distracting technology - Business Insider. Retrieved August 4, 2019 from https://www.businessinsider.com/ap-new-cars-increasingly-crammed-with-distracting-technology-2017-10?r=US&IR=T

[17] Fritjof Capra. 1996. *The web of life: a new synthesis of mind and matter*. HarperCollins.

[18] CarNextDoor. Car Next Door. Retrieved September 5, 2018 from https://www.carnextdoor.com.au

[19] Stephen M. Casner, Edwin L. Hutchins, and Don Norman. 2016. The challenges of partially automated driving. *Commun. ACM* 59, 5 (April 2016), 70–77. DOI:https://doi.org/10.1145/2830565

[20] Mario Chiesa, Riccardo Toppan, Alessandro Branciforti, and Francesco Posca. 2014. Social parking. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (AutomotiveUI '14), 1–6. DOI:https://doi.org/10.1145/2667239.2667283

[21] Brian Coltin. 2013. Towards Ridesharing with Passenger Transfers. In *Proceedings of the 2013 international conference on Autonomous agents and multi-agent systems* (AAMAS '13), 1299–1300.

[22] Riccardo Coppola, Maurizio Morisio, and Politecnico Torino. 2016. Connected Car : Technologies , Issues , Future Trends. *ACM Comput. Surv.* 49, 3 (2016), 1–36. DOI:https://doi.org/http://dx.doi.org/10.1145/2971482

[23] Chandrika Cycil, Mark Perry, Eric Laurier, and Alex Taylor. 2013. "Eyes free" in-car assistance. In *Proceedings of the 15th international conference on Human-computer interaction with mobile devices and services - MobileHCI '13*, 332. DOI:https://doi.org/10.1145/2493190.2493207

[24] Tawanna R. Dillahunt and Amelia R. Malone. 2015. The Promise of the Sharing Economy among Disadvantaged Communities. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (CHI '15), 2285–2294. DOI:https://doi.org/10.1145/2702123.2702189

[25] Tawanna R Dillahunt, Vaishnav Kameswaran, Linfeng Li, and Tanya Rosenblat. 2017. Uncovering the Values and Constraints of Real-time Ridesharing for Low-resource Populations. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (CHI '17), 2757–2769. DOI:https://doi.org/10.1145/3025453.3025470

[26] Verena Distler, Carine Lallemand, and Thierry Bellet. 2018. Acceptability and Acceptance of Autonomous Mobility on Demand. In *Proceedings of the 2018 CHI*

Conference on Human Factors in Computing Systems - CHI '18, 1–10. DOI:https://doi.org/10.1145/3173574.3174186
[27] Paul Dourish. 2001. Chapter 1: A History of Interaction. In *Where the Action Is - The Foundations of Embodied Interaction*. MIT Press.
[28] Robyn Dowling, Sophia Maalsen, and Jennifer L. Kent. 2018. Sharing as sociomaterial practice: Car sharing and the material reconstitution of automobility. *Geoforum* 88, October 2017 (2018), 10–16. DOI:https://doi.org/10.1016/j.geoforum.2017.11.004
[29] E.ON. E.ON. Retrieved June 19, 2019 from https://www.eon.dk/privat.html
[30] Ronald Ecker, Verena Broy, Andreas Butz, and Alexander De Luca. 2009. pieTouch. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services* (MobileHCI '10), 1. DOI:https://doi.org/10.1145/1613858.1613887
[31] Henrik Enquist, Konrad Tollmar, and Aino Vonge Corry. 2004. Interaction Ecologies. *Wksp Pervasive Comput.* (2004), 1–11.
[32] European Commission. *Cell phone use while driving 2015*. Retrieved August 8, 2019 from https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/erso-synthesis-2015-cellphone-detail_en.pdf
[33] Jodi Forlizzi. 2007. How robotic products become social products. In *Proceeding of the ACM/IEEE international conference on Human-robot interaction - HRI '07*, 129. DOI:https://doi.org/10.1145/1228716.1228734
[34] Jodi Forlizzi. 2007. How robotic products become social products. In *Proceeding of the ACM/IEEE international conference on Human-robot interaction - HRI '07*, 129. DOI:https://doi.org/10.1145/1228716.1228734
[35] Jodi Forlizzi. 2008. The product ecology: Understanding social product use and supporting design culture. *Int. J. Des.* 2, 1 (2008), 11–20.
[36] Mareike Glöss, Moira McGregor, and Barry Brown. 2016. Designing for Labour. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI '16*, 1632–1643. DOI:https://doi.org/10.1145/2858036.2858476
[37] GoMore. GoMore. Retrieved September 17, 2017 from https://gomore.dk/
[38] Lisa Gransky. 2014. *The mesh - why the future of business is sharing*. Portfolio Penguin. DOI:https://doi.org/10.1007/s13398-014-0173-7.2
[39] Nicole Gridling, Alexander Meschtscherjakov, and Manfred Tscheligi. 2012. I need help! In *Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work Companion - CSCW '12*, 87. DOI:https://doi.org/10.1145/2141512.2141549
[40] Hanna Hasselqvist, Mia Hesselgren, and Cristian Bogdan. Challenging the Car Norm: Opportunities for ICT to Support Sustainable Transportation Practices. DOI:https://doi.org/10.1145/2858036.2858468
[41] Kasper Hornbaek and Antti Oulasvirta. 2017. What Is Interaction? (2017). DOI:https://doi.org/10.1145/3025453.3025765
[42] Maarten Ter Huurne, Amber Ronteltap, Rense Corten, and Vincent Buskens. 2017. Antecedents of trust in the sharing economy: A systematic review. *J. Consum. Behav.* 16, 6 (November 2017), 485–498. DOI:https://doi.org/10.1002/cb.1667

[43] Ohad Inbar and Noam Tractinsky. 2011. Make a trip an experience. In *Proceedings of the 2011 annual conference extended abstracts on Human factors in computing systems - CHI EA '11*, 1243. DOI:https://doi.org/10.1145/1979742.1979755
[44] Independant. Norway to "completely ban petrol powered cars by 2025." Retrieved July 30, 2019 from https://www.independent.co.uk/environment/climate-change/norway-to-ban-the-sale-of-all-fossil-fuel-based-cars-by-2025-and-replace-with-electric-vehicles-a7065616.html
[45] Brit Susan Jensen, Mikael B. Skov, and Nissan Thiruravichandran. 2010. Studying driver attention and behaviour for three configurations of GPS navigation in real traffic driving. In *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10*, 1271. DOI:https://doi.org/10.1145/1753326.1753517
[46] Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2018. Assisted Shifting of Electricity Use. *ACM Trans. Comput. Interact.* 25, 5 (2018), 1–33. DOI:https://doi.org/10.1145/3210310
[47] Rikke Hagensby Jensen, Yolande Strengers, Jesper Kjeldskov, Larissa Nicholls, and Mikael B Skov. 2018. Designing the Desirable Smart Home: A Study of Household Experiences and Energy Consumption Impacts. (2018). DOI:https://doi.org/10.1145/3173574.3173578
[48] Peraphan Jittrapirom, Valeria Caiati, Anna-Maria Feneri, Shima Ebrahimigharehbaghi, María J. Alonso González, and Jishnu Narayan. 2017. Mobility as a Service: A Critical Review of Definitions, Assessments of Schemes, and Key Challenges. *Urban Plan.* 2, 2 (2017), 13. DOI:https://doi.org/10.17645/up.v2i2.931
[49] Robert Johansen. 1988. *Groupware: Computer support for business teams*. The Free Press.
[50] Ing-Marie Jonsson, Helen Harris, and Clifford Nass. 2008. How accurate must an in-car information system be? In *Proceeding of the twenty-sixth annual CHI conference on Human factors in computing systems* (CHI '08), 1665. DOI:https://doi.org/10.1145/1357054.1357315
[51] Heekyoung Jung, Erik Stolterman, Will Ryan, Tonya Thompson, and Marty Siegel. 2008. Toward a framework for ecologies of artifacts. In *Proceedings of the 5th Nordic conference on Human-computer interaction building bridges - NordiCHI '08*, 201. DOI:https://doi.org/10.1145/1463160.1463182
[52] Malte F. Jung, David Sirkin, Turgut M. Gür, and Martin Steinert. 2015. Displayed Uncertainty Improves Driving Experience and Behavior. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (CHI '15), 2201–2210. DOI:https://doi.org/10.1145/2702123.2702479
[53] Jennifer L. Kent and Robyn Dowling. 2013. Puncturing automobility? Carsharing practices. *J. Transp. Geogr.* 32, 2013 (2013), 86–92. DOI:https://doi.org/10.1016/j.jtrangeo.2013.08.014
[54] Dagmar Kern, Albrecht Schmidt, Jonas Arnsmann, Thorsten Appelmann, Nillakshi Pararasasegaran, and Benjamin Piepiera. 2009. Writing to your car. In *Proceedings of the 27th international conference extended abstracts on Human factors in computing systems* (CHI EA '09), 4705. DOI:https://doi.org/10.1145/1520340.1520724

[55] Jesper Kjeldskov. 2014. Mobile Interactions in Context: A Designerly Way Toward Digital Ecology. *Synth. Lect. Human-Centered Informatics* 7, 1 (2014), 1–119. DOI:https://doi.org/10.2200/s00584ed1v01y201406hci021
[56] Till Koglin. 2017. Drivers and Barriers for Integrated Mobility Services. (2017). DOI:https://doi.org/10.13140/RG.2.2.14619.26403
[57] Andrew L. Kun, Susanne Boll, and Albrecht Schmidt. 2016. Shifting Gears: User Interfaces in the Age of Autonomous Driving. *IEEE Pervasive Comput.* 15, 1 (January 2016), 32–38. DOI:https://doi.org/10.1109/MPRV.2016.14
[58] Jos Lelieveld, Klaus Klingmüller, Andrea Pozzer, Ulrich Pöschl, Mohammed Fnais, Andreas Daiber, and Thomas Münzel. 2019. Cardiovascular disease burden from ambient air pollution in Europe reassessed using novel hazard ratio functions. *Eur. Heart J.* 40, 20 (May 2019), 1590–1596. DOI:https://doi.org/10.1093/eurheartj/ehz135
[59] Gilly Leshed, Theresa Velden, Oya Rieger, Blazej Kot, and Phoebe Sengers. 2008. In-car gps navigation. In *Proceeding of the twenty-sixth annual CHI conference on Human factors in computing systems* (CHI '08), 1675. DOI:https://doi.org/10.1145/1357054.1357316
[60] Andreas Löcken, Heiko Müller, Wilko Heuten, and Susanne Boll. 2014. "Should I stay or should I go?" In *Proceedings of the 8th Nordic Conference on Human-Computer Interaction Fun, Fast, Foundational - NordiCHI '14*, 1031–1034. DOI:https://doi.org/10.1145/2639189.2670268
[61] Andrés Lucero, Jussi Holopainen, and Tero Jokela. 2011. Pass-them-around. In *Proceedings of the 2011 annual conference on Human factors in computing systems* (CHI '11), 1787. DOI:https://doi.org/10.1145/1978942.1979201
[62] Anders Lundström. 2014. Differentiated Driving Range : Exploring a Solution to the Problems with the " Guess - O - Meter " in Electric Cars. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (AutomotiveUI'14). DOI:https://doi.org/10.1145/2667317.2667347
[63] Anders Lundström, Cristian Bogdan, Filip Kis, Ingvar Olsson, and Lennart Fahlén. 2012. Enough power to move. In *Proceedings of the 14th international conference on Human-computer interaction with mobile devices and services - MobileHCI '12*, 201. DOI:https://doi.org/10.1145/2371574.2371605
[64] Anders Lundström, Cristian Bogdan, Filip Kis, Ingvar Olsson, and Lennart Fahlén. 2012. EVERT: Energy representations for probing electric vehicle practice. *Proc. 2012 ACM Annu. Conf. Hum. Factors Comput. Syst. (CHI '12)* (2012), 2141–2146. DOI:https://doi.org/10.1145/2212776.2223766
[65] Anders Lundström and Fredrik Hellström. 2015. Getting to know electric cars through an app. In *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '15*, 289–296. DOI:https://doi.org/10.1145/2799250.2799272
[66] Karthik Mahadevan, Sowmya Somanath, and Ehud Sharlin. 2018. Communicating Awareness and Intent in Autonomous Vehicle-Pedestrian Interaction. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18*, 1–12. DOI:https://doi.org/10.1145/3173574.3174003
[67] Clara Mancini, Yvonne Rogers, Keerthi Thomas, Adam N. Joinson, Blaine A. Price, Arosha K. Bandara, Lukasz Jedrzejczyk, and Bashar Nuseibeh. 2011. In

the best families. In *Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11*, 2419. DOI:https://doi.org/10.1145/1978942.1979296

[68] Vince Mancuso. 2009. Take me home. In *Proceedings of the 27th international conference extended abstracts on Human factors in computing systems* (CHI EA '09), 4591. DOI:https://doi.org/10.1145/1520340.1520705

[69] Nicolai Marquardt, Robert Diaz-Marino, Sebastian Boring, and Saul Greenberg. 2011. The proximity toolkit: prototyping proxemic interactions in ubiquitous computing ecologies. *Proc. 24th Annu. ACM Symp. User interface Softw. Technol. - UIST '11* 11, (2011), 315–326. DOI:https://doi.org/10.1145/2047196.2047238

[70] Andrii Matviienko, Andreas Löcken, Abdallah El Ali, Wilko Heuten, and Susanne Boll. 2016. NaviLight. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services* (MobileHCI '16), 283–294. DOI:https://doi.org/10.1145/2935334.2935359

[71] Sarah Mennicken, Jo Vermeulen, and Elaine M. Huang. 2014. From today's augmented houses to tomorrow's smart homes. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing - UbiComp '14 Adjunct*, 105–115. DOI:https://doi.org/10.1145/2632048.2636076

[72] Merriam-Webster. 2019. Definition of Ecosystem. Retrieved February 27, 2019 from https://www.merriam-webster.com/dictionary/ecosystem

[73] Hidde van der Meulen, Andrew L Kun, and Christian P Janssen. 2016. Switching Back to Manual Driving. In *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Automotive'UI 16), 229–236. DOI:https://doi.org/10.1145/3003715.3005452

[74] Johanna Meurer, Dennis Lawo, Lukas Janßen, and Volker Wulf. 2016. Designing Mobility Eco-Feedback for Elderly Users. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (CHI EA '16), 921–926. DOI:https://doi.org/10.1145/2851581.2851599

[75] Johanna Meurer, Martin Stein, David Randall, Markus Rohde, and Volker Wulf. 2014. Social dependency and mobile autonomy. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems* (CHI '14), 1923–1932. DOI:https://doi.org/10.1145/2556288.2557300

[76] Johanna Meurer, Martin Stein, and Volker Wulf. 2014. Designing Cooperation for Sustainable Mobility: Mobile Methods in Ridesharing Contexts. In *Proceedings of the 11th International Conference on the Design of Cooperative Systems (COOP '14), 27-30 May 2014, Nice (France)*. Springer International Publishing, Cham, 345–359. DOI:https://doi.org/10.1007/978-3-319-06498-7_21

[77] Bonnie A. Nardi and Vicki. O'Day. 1999. *Information ecologies : using technology with heart*. MIT Press.

[78] Clifford Nass, Ing-Marie Jonsson, Helen Harris, Ben Reaves, Jack Endo, Scott Brave, and Leila Takayama. 2005. Improving automotive safety by pairing driver emotion and car voice emotion. In *CHI '05 extended abstracts on Human factors in computing systems* (CHI '05), 1973. DOI:https://doi.org/10.1145/1056808.1057070

[79] United Nations. Sustainable Development Goals. Retrieved July 9, 2019 from

https://www.un.org/sustainabledevelopment/sustainable-development-goals/
[80] Heidi Selmer Nielsen, Marius Pallisgaard Olsen, Mikael B. Skov, and Jesper Kjeldskov. 2014. JuxtaPinchh: Exploring Multi-Device Interaction in Collocated Photo Sharing. *Proc. 16th Int. Conf. Human-computer Interact. with Mob. devices Serv. - MobileHCI '14* (2014), 183–192. DOI:https://doi.org/10.1145/2628363.2628369
[81] Nissan Motor. Nissan CARWINGS®. Retrieved February 8, 2017 from https://www.nissanusa.com/blog/carwings-app
[82] OICA. • Number of vehicles in use worldwide 2015. Retrieved March 25, 2019 from https://www.statista.com/statistics/281134/number-of-vehicles-in-use-worldwide/
[83] World Health Organization. Noise Health Effects. Retrieved July 9, 2019 from https://www.euro.who.int/en/health-topics/environment-and-health/noise/
[84] Mattias Östergren. 2004. Sound Pryer: Adding Value to Traffic Encounters with Streaming Audio. In *Entertainment Computing - Icec 2004*. 541–552. DOI:https://doi.org/10.1007/978-3-540-28643-1_71
[85] Nicole Perterer, Petra Sundström, Alexander Meschtscherjakov, David Wilfinger, and Manfred Tscheligi. 2013. Come drive with me. In *Proceedings of the 2013 conference on Computer supported cooperative work - CSCW '13*, 1539. DOI:https://doi.org/10.1145/2441776.2441952
[86] Nicole Perterer, Petra Sundström, Alexander Meschtscherjakov, David Wilfinger, and Manfred Tscheligi. 2013. Come drive with me. (2013), 1539. DOI:https://doi.org/10.1145/2441776.2441952
[87] PlugShare. PlugShare. Retrieved June 19, 2019 from https://www.plugshare.com/
[88] Dimitrios Raptis. 2014. What is a Digital Ecology? Theoretical Foundations and a Unified Definition. In *Australian Journal of Intelligent Information Processing Systems*, 83–92.
[89] Bryan Reimer, Anthony Pettinato, Lex Fridman, Joonbum Lee, Bruce Mehler, Bobbie Seppelt, Junghee Park, and Karl Iagnemma. 2016. Behavioral Impact of Drivers' Roles in Automated Driving. In *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Automotive'UI 16), 217–224. DOI:https://doi.org/10.1145/3003715.3005411
[90] Reuters. Denmark embraces electric car revolution with petrol and diesel ban plan - Reuters. Retrieved July 30, 2019 from https://www.reuters.com/article/us-denmark-autos/denmark-embraces-electric-car-revolution-with-petrol-and-diesel-ban-plan-idUSKCN1MC121
[91] Yvonne Rogers. 2005. New theoretical approaches for human-computer interaction. *Annu. Rev. Inf. Sci. Technol.* 38, 1 (September 2005), 87–143. DOI:https://doi.org/10.1002/aris.1440380103
[92] William Ryan, Erik Stolterman, Heekyoung Jung, Martin Siegel, Tonya Thompson, and William R Hazlewood. 2009. Device ecology mapper: a tool for studying users' ecosystems of interactive artifacts. *CHI '09 Ext. Abstr. Hum. Factors Comput. Syst.* (2009), 4327–4332. DOI:https://doi.org/10.1145/1520340.1520661
[93] Christine Satchell and Paul Dourish. 2009. Beyond the user. In *Proceedings of the*

21st Annual Conference of the Australian Computer-Human Interaction Special Interest Group on Design: Open 24/7 - OZCHI '09, 9. DOI:https://doi.org/10.1145/1738826.1738829

[94] Susan A. Shaheen, Mark A. Mallery, and Karla J. Kingsley. 2012. Personal vehicle sharing services in North America. *Res. Transp. Bus. Manag.* 3, (August 2012), 71–81. DOI:https://doi.org/10.1016/J.RTBM.2012.04.005

[95] Susan A. Shaheen, Elliot Martin, and Apaar Bansal. 2018. Peer-To-Peer (P2P) Carsharing: Understanding Early Markets, Social Dynamics, and Behavioral Impacts. *UC Berkeley Res. Rep.* (2018). DOI:https://doi.org/10.7922/G2FN14BD

[96] Susan Shaheen, Daniel Sperling, and Conrad Wagner. 1998. Carsharing in Europe and North American: Past, Present, and Future. (1998). DOI:https://doi.org/10.1111/ina.12046

[97] Henrik Sørensen, Dimitrios Raptis, Jesper Kjeldskov, and Mikael B. Skov. 2014. The 4C framework. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing - UbiComp '14 Adjunct*, 87–97. DOI:https://doi.org/10.1145/2632048.2636089

[98] Linda Steg. 2005. Car use: Lust and must. Instrumental, symbolic and affective motives for car use. *Transp. Res. Part A Policy Pract.* 39, 2-3 SPEC. ISS. (2005), 147–162. DOI:https://doi.org/10.1016/j.tra.2004.07.001

[99] Yolande A.A. Strengers. 2011. Designing eco-feedback systems for everyday life. In *Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11* (CHI '11), 2135. DOI:https://doi.org/10.1145/1978942.1979252

[100] Tesla. Tesla App Support. Retrieved July 30, 2019 from https://www.tesla.com/support/tesla-app?redirect=no

[101] Volkswagen Group. VW Car-Net Connect. Retrieved February 8, 2017 from http://www.vwcarnetconnect.com/

[102] Chao Wang, Jacques Terken, Jun Hu, and Matthias Rauterberg. 2016. Improving Connectedness between Drivers by Digital Augmentation. In *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct* (Automotive'UI 16), 135–140. DOI:https://doi.org/10.1145/3004323.3004339

[103] Chao Wang, Jacques Terken, Bin Yu, and Jun Hu. 2015. Reducing driving violations by receiving feedback from other drivers. In *Adjunct Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (AutomotiveUI Adjunct '15), 62–67. DOI:https://doi.org/10.1145/2809730.2809736

[104] David Wilfinger, Alexander Meschtscherjakov, Martin Murer, Sebastian Osswald, and Manfred Tscheligi. 2011. Are We There Yet? A Probing Study to Inform Design for the Rear Seat of Family Cars. In *IFIP Conference on Human-Computer Interaction*, 657–674. DOI:https://doi.org/10.1007/978-3-642-23771-3_48

PAPER CONTRIBUTIONS

This chapter contains the following accepted papers that are included in this thesis:

1. **Michael K. Svangren**, Rikke Hagensby Jensen, Mikael B. Skov, and Jesper Kjeldskov; 2018. Driving on Sunshine: Aligning Electric Vehicle Charging and Household Electricity Production. In *Proceedings of the 10th Nordic Conference on Human-Computer Interaction.* (NordiCHI'18).
   DOI: https://doi.org/10.1145/3240167.3240179

2. Rikke Hagensby Jensen, **Michael K. Svangren**, Mikael B. Skov, and Jesper Kjeldskov. 2019. Investigating EV Driving as Meaningful Practice. Accepted for inclusion in *the 31st australian conference on human-computer-interaction* (OZCHI'19). DOI: To appear.

3. **Michael K. Svangren**, Mikael B. Skov, and Jesper Kjeldskov. 2017. The connected car. An Empirical Study of Cars as Connected Digital Devices. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services* (MobileHCI '17).
   DOI: http://dx.doi.org/10.1145/3098279.3098535

4. **Michael K. Svangren**, Mikael B. Skov, and Jesper Kjeldskov. 2018. Passenger Trip Planning using Ride-Sharing Services. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (CHI'18).
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5. **Michael K. Svangren**, Margot Brereton, Mikael B. Skov, and Jesper Kjeldskov. 2019. Investigating the Use of an Online Peer-to-Peer Car Sharing Service. In *proceedings of the 17th IFIP TC.13 International Conference on Human-Computer Interaction* (INTERACT'19).
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6.1 Driving on Sunshine: Aligning Electric Vehicle Charging and Household Electricity Production

Michael K. Svangren, Rikke Hagensby Jensen, Mikael B. Skov, Jesper Kjeldskov

Abstract. Electric vehicle seems to go well together with the growing societal trend of becoming more self-supplying with renewable electricity produced in the household. However, aligning household electricity production and electric vehicle charging have received little attention in HCI although both areas have been pursued separately for a number of years. In this paper, we present findings from a qualitative study that explore the potential of aligning electric vehicle charging with times where renewable electricity is being produced in the household. We present an empirical qualitative study of 5 households (19 persons) that own electric vehicles and also produce their own renewable electricity. Our findings, described in five themes, reveal that aligning charging and electricity production can be a challenge and tension exist for aligning consumption such as motivation, roles, mobility patterns, and electricity producing technology. We further discuss our findings and possible directions for future HCI research in the field.

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Driving on Sunshine: Aligning Electric Vehicle Charging and Household Electricity Production

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ABSTRACT
Electric vehicle seems to go well together with the growing societal trend of becoming more self-supplying with renewable electricity produced in the household. However, aligning household electricity production and electric vehicle charging have received little attention in HCI although both areas have been pursued separately for a number of years. In this paper, we present findings from a qualitative study that explore the potential of aligning electric vehicle charging with times where renewable electricity is being produced in the household. We present an empirical qualitative study of 5 households (19 persons) that own electric vehicles and also produce their own renewable electricity. Our findings, described in five themes, reveal that aligning charging and electricity production can be a challenge and tension exist for aligning consumption such as motivation, roles, mobility patterns, and electricity producing technology. We further discuss our findings and possible directions for future HCI research in the field.

Author Keywords
Electric vehicles; household electricity production; user study; sustainability

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

INTRODUCTION
In the last years we have seen an increasing growth and adoption of electricity producing technologies for the home, such as wind turbines and photovoltaic panels have allowed households to become more self-supplying with energy [7]. The produced electricity can be used in several household activities like heating, lighting, washing, and cooking. Further, mobility can also be added to the set of self-supplying activities, as adoption rates of electric vehicles (EVs) that have the ability to be charged from home have increased in the last years [7]. However, producing electricity from renewable energy sources might present a challenge when trying to combine it with EVs as the supply from renewables is not constant, but rely heavily on weather conditions. Unless the electricity can be stored, it must be consumed when it is available, at the right time [28,42].

In the HCI research community, we have seen an interest in studying how to be self-supplying with electricity and how to align production with the consumption of various appliances in the household. However, aligning EV consumption with produced electricity is still a unique combination and HCI research has mostly treated them as two separate topics [7]. As such, HCI research into EVs has had a strong focus on driving related challenges, for example, range anxiety [18,33,38] and the lack of driving feedback [32,34]. In contrast, HCI research into household production has looked into how to assist appliance consumption of produced electricity. As examples, assisting electricity consumption through smart-agents [2,23] and eco-feedback [20] through lighting [25,39], art and ambience [22,47], or physical materials [9,45,59]. Much of this research suggests that consuming energy is deeply woven into household structures and requires a deeper understanding of not only technologies but also the practices of the home [30,43,44].

The technologies associated with both electricity production in the home and EVs are moving quickly forward and into our everyday lives. However, despite ongoing research, we lack studies that provide detailed understandings of how and if they can be aligned. In this paper, we extend current HCI literature with an empirical qualitative study of 5 households (19 persons) that both produce their own electricity and owns an EV. We combine in-depth semi-structured interviews and informal conversational technology tours to answer the questions of if and how EVs and home-produced electricity can be aligned and who is involved in the process. To do this we investigate household structures, practices, and the opportunities and challenges householders face in the combination of these two technologies. We present our findings in five themes revealing that aligning faces challenges by current household structures, such as motivation, roles, mobility patterns, and electricity producing technology We further discuss the opportunities and challenges in relation to our findings under four headings that provide inspiration for future HCI research and design.

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RELATED

In the next two sections, we will unfold the current HCI research. Firstly, we describe research that has focused on aligning electricity consumption and production and second, we describe research with electric vehicles and household integration.

Aligning Electricity Consumption and Production

The HCI research community has for at least a decade engaged in design challenges surrounding raising awareness of the consumption of resources as a mean to promote sustainable behaviour [4]. Different resources have been investigated such as, consumption of water (e.g., [20,37]), heat (e.g., [1,2,15,23,60]), food [62] and electricity (e.g., [8,16,24,28,29,40,48,49]). A considerable amount of this work investigates how to influence consumption through the design of eco-feedback [19] by using different means to visualise resource consumption e.g., lighting [25,39], art and ambience [22,47], or physical materials [9,45,59].

A body of research falls into a more technical category with a goal of automating energy alignment through smart agents, for example, Alan et al.'s Tariff Agent [2], Jensen et al.'s HeatDial [23], Yun et al.'s Intelligent Dashboard [61], and Alan et al.'s SmartThermo [1]. Together these studies illustrate a potential of letting an automated system assist households to align consumption. However, some of these studies also report a loss of engagement over time that potentially may undermine the sustainable benefits of the smart agent [60].

Recent research has suggested that desires to become self-sufficient with renewable electricity (e.g., through home-owned technologies like photovoltaics and wind turbines) appear to positively influence a households' engagement with their electricity consumption [8,29,41]. However, due to the varying output of these technologies (a photovoltaic panel only produces electricity when the sun shines), sustainable behaviour also becomes a matter of a household's willingness to change electricity-consuming activities in time and place to be able to *align* these activities to when renewable electricity is available [41,42]. Towards this end, a number of papers address the potential of aligning or shifting the consumption of electricity. For example, Kjeldskov et al. [28], Pierce and Paulos [41], Simm et al. [49], and Rasmussen et al. [46] investigate the potential of aligning electricity consumption and renewable production by studying the impact of forecasting various information about electricity consumption via feedback displays.

More recent research suggests that energy consumption is woven into household practices that involve complex social dynamics and expectations [53]. Changing the consumption requires a broader understanding that also involve the energy-consuming practices, we are attempting to intervene in through our designs [30,43,44]. Towards a deeper understanding of household practices, some HCI studies aim at understanding specific situations, most noticeable washing, for example, Costanza et al. [16], Bourgeois et al. [8], and Jensen et al. [24]. Findings from these studies suggest that there is a difference in the kinds of practices households are willing to change in an effort to align consumption. For example, it appears households are more willing to align consumption of practices where some tasks have already been delegated to semi-automated technology [14] such as washing (washing machines) [8,16], or heating (smart agents) [15,23] while people are less willing to align practices such as cooking [28,41,46,48].

Electric Vehicles and Household Integration

Electric vehicles (EVs) have had the attention of the HCI community for some time. A considerable amount of research on EVs has focused on the challenges related to adopting and driving them as they form a new kind of driving experience compared to the traditional car experience [12,31,32]. For EVs, there has been a strong focus on drivers worrying about the depletion of the battery, which is often referred to as range anxiety [27]. As such, this has resulted in research addressing these challenges (e.g., [26,31,32,34,54]]). As examples, Jung et al. explore impact of displayed uncertainty in instrumental estimates of range [27], while Landau focuses on creating an interface that makes up for the lack of feedback in EVs, for example, the lack of sound or vibration, or knowing when the EV is ready to drive [31]. More recently, we have also seen research focusing on the connected features of EVs and how they support daily practices [55].

A number of papers (e.g., [10,13,58]) are addressing more technical aspects of how EV charging can be merged into the household by, for example, investigating algorithms for EV energy storage during off-peak hours [10]). In contrast, there are significantly fewer HCI studies that address the merging of EVs and home-produced electricity, with an outset in household practices and if the combination is even feasible. One HCI study that has explored this unique combination is Bourgeois et al. [7]. In their study, they investigated the feasibility of self-sustaining electrical mobility and provide an understanding of how EVs are integrated into the household. They further argue that there is a need for technology to increase the visibility of produced electricity and improve and personalise how its managed.

STUDY

With an emerging societal interest of electric vehicles along with a desire of becoming more self-supplying with energy, we argue that there is a need for research on combining the two. In this paper, we address this gap and contribute to HCI research with an understanding of current household structures and practices that surround the combination of EVs and home-produced electricity. We do this by reporting from an empirical study of five Danish households with both EVs and household electricity production.

Participants

We recruited 5 households for our study. We recruited the participants through online forums for renewable energy and EV (for example, through Facebook groups). To ensure diversity, we chose the five households from the following five criteria: (i) either PVs or wind turbines, (ii) different EV models, (iii) different composition of the households (e.g. couples or with/ without children), (iv), how long they have had their EV, and (v) with and without a secondary fossil-fuelled car.

As seen in Table 1, the five households consisted of 19 persons of which 11 were adults (with a driving license) and 8 were children. Four households owned PVs. However, to present a different perspective, we also chose to include one household owning a wind turbine. Although household PVs are far more common in Denmark, an alternative is household wind turbines, that present a rather unique combination when combined with electric vehicles. Four households had children living at home and the remaining had children that had moved away from home. All households were located in Denmark in city suburbs or in rural areas. Two households were exclusively EV households (H1 and H2) while the remaining three households were hybrid households owning both an electric EV and a secondary fossil-fuelled car. Adults in all households were in permanent jobs, except (H2), were both adults had retired. All families were middle-class households, where four were living in single-family houses and one (H2) lived in an apartment during winter and in a rural residency in the summer. Household mobility needs would vary between 15.000 km pr. year (H2) to 70.000 km pr. year (H1).

The households owned either solar panels or wind turbines, thus producing their own electricity. Four households (H1, H3, H4, H5) were connected to the power grid and could, therefore, export part of their production to influence their import and consequently their electricity bill. The import price (buy from the grid) of electricity in Denmark is around \$0.40. The Danish energy system consists of a number of different schemes that apply to home electricity producers that allow households to export (sell to the grid) electricity. These schemes are supported through political decisions and vary on a number of factors such as; the year equipment was acquired, type of equipment, and production capacity. Effectually, for most of our participating households, the income of exporting electricity to the power grid was one of the following three schemes; i) they export to the same price as they import from the grid which is around \$0.40 pr. kWh (H1, H3), ii) they export to a reduced rate approximately 2/3 of the import price (\$0.25 pr. kWh), and iii) they export to a very reduced rate of the import price (\$0.1 pr. kWh) (H4). None of these households had the option of storing electricity apart from their battery on the EV. The remaining household (H2) was not connected to the grid, meaning they were not able to export their own produced electricity. Consequently, they had to use this electricity when it was available, as it would otherwise go to waste. Their produced electricity they used to charge small batteries, power small household appliances and charge their EV.

	H1	H2	H3	H4	H5
Adults (kids)	3 (2)	2	2 (2)	2 (2)	2 (2)
Years w. EV	4,5	2	1	3	2
Years w. home production	6	2	3	7	1
Number of EVs	3	1	1	1	1
Electricity source	PV	PV	PV	Wind turbine	PV
Living area	Rural	City	City	Rural	Rural
Second fossil fuelled car	No	No	Yes	Yes	Yes
Production capacity	6 kW	1 kW	4 kW	11 kW	4 kW

Table 1: Overview of participating households.

Data Collection and Analysis

Data collection was based on semi-structured interviews. We interviewed the primary users of the household's cars (the ones that had a driving license) who were between the age of 17 and 70. We conducted informal, conversational technology tours with each household before the actual interview [5]. Here we asked the participants to show us their EV(s), their charging facilities, their households electricity production. Further, we asked them to show examples of how they used these technologies and how they did not use them. The purpose of the technology tour was twofold. Firstly, we wanted the participants to speak more openly about their EV and electricity production by revealing possible tacit knowledge. Secondly, we wanted to be able to get a richer and concrete understanding of their EV and electricity producing technology. This sometimes resulted in the participants wanted us to try their EV (H1, H4), or show us how certain technologies such as apps and charging infrastructure worked. We took notes, pictures, and recorded audio during the technology tour for later analysis.

The following semi-structured interviews consisted of two parts where we first interviewed the individual household members and afterward did an interview with all household members. The first part consisted of questions related to motivation, charging their EV, electricity consumption and production, and mobility. For example, we asked them individually about motivation towards owning the EV, individual activities involved in charging, and awareness towards electricity consumption for their EV along with production from renewables. The purpose of the first part was to identify individual opinions and use, but also to highlight differences. The second part of the interviews consisted of an interview session with all adult household members. In the second part, we asked more general questions about social structures in the households and technologies used to assist them in charging. We grounded this interview in the prior individual interviews that sometimes this would result in some discussion between our participants about what opinion was the "most correct". Questions asked here were more about household activities and how they as a family ensured that the EV was charged when they needed it.

The interviews were audio-recorded. A total of ten and a half hours of audio were transcribed and coded for thematic analysis by two of the authors. The analysis was done in three steps. Firstly, we familiarised ourselves with the data by reading the transcribed interviews several times and identified suggestions for codes (e.g., "charging technology"). Secondly, we added specific codes to interview quotes (e.g., the code "tinkering" for this quote "*I find it fascinating that you can buy stuff from eBay and create new more effective stuff, so logically I've applied that line of thought to my home*"). Thirdly, we created themes using affinity diagramming [3], where quotes were put on a bulletin board and reorganised into themes over several iterations. From this analysis, five themes emerged.

FINDINGS

Surprisingly, we found that although all members of the participating households were aware and interested in aligning their EV consumption with their electricity production, it wasn't reflected in their behaviour. Our findings indicate that charging the household EV relies on many different factors such as mobility patterns, charging routines and household attitudes. Towards this end, aligning household production with EV consumption indicates dynamic and complex relationships. In the following sections these relationships will be presented in 5 themes of; *Attitudes Towards Aligning, Willingness and Leveraging Convenience, Household Mobility, Charging Routines and Electricity Production,* and *Technology Assisted Charging.*

All data presented have been anonymized, and we refer to them as H1-H5 (as in Table 1). Occasionally, we refer to the number of households behind an observation, for example, (3/5) would mean three out of five households.

Attitudes Towards Aligning

During the interviews the underlying structure of the members of the households became evident. When we asked the different members about aligning EV consumption, some were very interested and were very motivated, and others had no real interest which was also reflected in their roles in the household and their attitudes.

Household Roles and Motivation

At least one member of the households was very interested in the production and consumption of electricity. This member was very empowered to optimise consumption and who knew the exact amount of produced electricity without having to resort to looking at an app. It was also this member of the household who initially had suggested an investment in the electricity producing technology of the household (Illustrated in figure 1). Further, it was this member who kept up to date with production and ensured that the production facility was always produced at an optimal level. For example, as a member of **H4** articulated: "*I simply cannot ignore that our wind turbine is not running optimal, even if it's just for half a day. Even though we won't lose a lot of money on it it's still important to me, it was my idea to get it and I'm responsible for it running. I like it, then I get to tinker with all sorts of tech*".

Figure 1. PV installation in H3 (left) and wind turbine in H4 (right).

We found a number of reasons why these members were interested in producing energy. None of them had chosen renewables solely with a purpose of wanting to earn money or because they were technology interested. For example, **H1** articulated: "*Yeah, I don't know how to divide it, but it was probably 75-80 percent resource or environmental awareness or something like that. But then again there's also an economic aspect. I have an expectation that it won't cost us any money, on the contrary, I think that it's a reasonable business case. And then I think it's interesting and fun*". These members with a strong interest in producing and consuming electricity seemed very motivated by the idea of aligning although they saw some difficulties, for example, **H3**: "*it's a good idea, then we can save even more. However, there are some practical issues such as production time that make it difficult*".

Although all members of our households agreed that producing their own electricity was a good thing, many members (typically persons with less interest in technology and optimising it) seemed less motivated. We found that they would often not share the same reasons for becoming producers of energy, for example, **H3**: "*I just think it's nice to earn money on our PVs, I don't really have an interest in the technology or being green*" and **H5**: "*It's my spouse who* *does all the technical stuff with the PVs and know how much is being produced, I just think it's nice being green*".

Willingness to Align and Leveraging Convenience

To most household members aligning electricity consumption with production was perceived as an inconvenience. Although some members (usually one) of the households did seem interested and willing to align, we found that economic factors such as tariff schemes and convenience played a role.

Willingness to Align

During the interviews, we asked households about aligning the consumption of different appliances with their production. We noticed a difference in how willing some members of the household were to actually align their consumption with the household production of electricity. The difference was best exemplified between household members that were very interested in household electricity consumption and the rest of the members of the household. These individuals seemed willing to optimise their consumption and was very positive to the idea of aligning the consumption of different appliances, and some even had suggestions of how to increase how much of their own electricity the household could consume, for example, **H4**: "*I've played around with the idea of installing a new water heater that consumed our own electricity when we produce it*" and **H2**: "*Since we cannot export our electricity to the grid it makes sense to store it, so what I've done is that I have installed two batteries so that I can save it for later, we're still producing more than that, so in the future, if we could get more batteries then we could also run ordinary appliances from them like a curling iron that takes up a lot of power*".

Although the more willing members of the households seemed willing to change consumption behavior if they could remaining members were not as enthusiastic. As this annoyed the members with a higher willing we found several indications that they had tried to convince other members of the household to change behavior which was not always received positively. Members of the household with little interest in changing consumption behavior often related aligning to other everyday practices such as doing the laundry or washing dishes, that had a high priority for them, for example, **H1**: "*He has told me several times that it's time to wash the clothes or dishes because the sun shines, but I don't, because the sun doesn't decide when I'm supposed to wash*" and to **H4**: "*Sometimes if I'm about to do the laundry he tells me to look out at the turbine if it's running, but that's impractical. For me, the laundry basket always has to be empty. It's the same with the EV, if you need to drive you plug it in, you don't wait for the wind*".

Leveraging Price and Convenience

Although some members of the households found the idea of aligning interesting we found that actual behaviour towards aligning was reflected through perceived convenience and how it was judged. For the households (H1, H3) who imported electricity to the same price as they bought it, it mattered less when they charged and they had no real incentive for aligning other than ideological reasons, as **P1** articulated: "*I've thought about plugging in when the sun shines many times, I like the thought of being green, but it doesn't matter, I pay the same anyway, I think humans are like, you know, lazy*". For the household that exported at a lower price (H5) it still didn't seem to matter because they weighted convenience over the little they could save in the long run, **H5**: "*We have to charge the EV during the night, but maybe if I got home in the afternoon and there was still some hours of sun left, but then I have to remember an hour or two later to go out and stop it and then set the timer to at night. I'm not doing that, that would require too much planning. Then it's easier to just charge once. It is convenience over price and the monetary benefit is too small for me*". It was very important for the household (H4) with the very low export price to use as much of their produced electricity as possible. Consequently, the one that was technology interested used as much as he could for powering their EV along with other appliances, **H4**:

"*The more I export, the more I'm punished by myself. I will almost do anything to use the electricity I produce. I'm not supposed to earn anything, but the finances should even out*"

Household Mobility

It became evident to us that all households were active users of the EV, which meant that often it wasn't home and thus were difficult to align with their own electricity production.

Mobility Patterns

During the interviews, we found that the EV was the preferred type of transportation in the households. We identified two ride patterns; planned and ad-hoc rides. Everyday trips such as going to work had become routine and therefore required less or no planning. For household driving every day, residents knew the EV and that it could drive the distance to make the full trip, as **H3** articulated: "*I know the EV and I know that I can get from home to work on a single charge*". We also found that trips connected with going on holidays fell under the planned pattern because routes would be researched well in advance.

Although EVs take some time getting used to, all household members felt comfortable driving it for planned rides. In contrast to planned rides, we found rides with an ad-hoc nature required more planning in the form of thinking about the available range and the need for additional charging. Examples of these rides from the households included getting groceries and driving kids to and from sports or friends, as **H4** expressed:

"*When you run out of milk and have to go get it you have to think about available range because if you've just come home for work there's sometimes not enough power*".

Secondary Vehicles

While the EV was the households primary and preferred kind of transportation, some households (3/5) also owned a secondary fossil-fuelled car that served a backup purpose for ad-hoc driving. Interestingly, we found that if the household had more members there was also more ad-hoc driving and that they could report of incidents where they had to take the secondary car because the EV didn't have sufficient charge. We found that this was closely connected to the amount of planning that could be done, as **H5** articulated: "*We try to plan the day, but every now and then you just need to drive somewhere and the EV is unavailable because it's charging, for example, if my spouse drove it to work. Then we just take the secondary car*". In contrast, in the household where the adults had retired (**H2**), we found a less strict structure: "*We always know where we're driving, there are very few surprises, and if there are we'll just wait, we're not in a rush*".

The secondary cars primary function was as a mean for transportation for the person with the shortest distance to work, like **H5**: "*It's my wife that drives the EV to work because she has to drive the furthest, then I will have to suffice with the other one. However, I'm changing jobs soon, so I'll get the EV, that's how it is, it's the rule*". The secondary car also served as an extra security for some persons in the households (typically the driver with less experience driving the EV), especially on longer trips. For example, a member of **H4** explained:

"*The other car serves as a backup. I'm not as comfortable driving it as my spouse especially not on long trips if I'm driving far I'd much rather drive the diesel car rather than electricity*".

Charging routines and Electricity Production

All members of the households agreed that charging their EV was important and they all helped facilitate that the car would have available range. We found that they were motivated in doing so because many had unfortunate experiences in the past due to lack of charging. To support the availability of range in the EV, households had developed a set of charging routines. However, these routines also seemed to clash with household electricity production.

Charging Routines

One of the more regular routines that we found in all households was to always begin charging their EV when returning home after a drive. This was often connected with returning home from work late in the afternoon. The purpose of this routine was to leave the EV charging overnight where its use was very minimal. To the households with only one EV, this was a simple activity, as the rule was that the person who drove the EV plugged it in when returning home. However, in the household with several EVs (**H1**) we found that it was more difficult to schedule charging as the infrastructure of their house didn't allow multiple EVs to be plugged in at the same time (Figure 2): "*Right now it's a practicality, but we can only charge one car at a time. If we charge two the fuses will blow*".

Figure 2. H1's garage. Three EVs had to be charged in sequence and overnight.

To all households, the most preferred place to charge the EV was in the home. This enabled most households to drive to work and back again with power from their household. Because charging was often scheduled to overnight, households ensured continuous charging. However, we did find situations where charging had to be done in a more ad-hoc manner in the home. We found a greater need for mobility during the day for ad-hoc driving, although households explained that then the EV would just be charged for a brief amount of time. Such situations were often connected with the small ad-hoc trips where the EVs state of charge wasn't perceived to be enough to drive them all the way, for example, **H4**: "*Sometimes we just have to charge the EV a little during the day, especially if we go on many smaller trips, it probably has enough charge, better be safe than sorry*"

A scenario that householders often faced was charging while the EV was away from home, for example for work or holidays. In such situations, charging had to be done on public chargers. Surprisingly, we found that charging on most public chargers was disliked by all household as it would often be associated with an additional fee. As an example of this, a member of **H4** that had to charge at work every day to be able to make it home had made an agreement with a friend to charge on his power, thus avoiding the additional fees of the public chargers. Another example is **H5** that had used the power outlets of different hotels when going on vacation to avoid the fees. We also found a household that frequently used free public chargers. A member of **H3** explained that she often used charging on public free chargers on her way to and from work as an explicit strategy to always have enough charge to drive and to minimise charging at home to avoid importing too much electricity: "*We use the free public charger at least twice a week rather than charging at home, it's a strategy because the car consumes a lot of power and it's very expensive if we have to buy it*".

Electricity Production

Not surprising, the PV owning households mentioned charging on households produced electricity as a major challenge, as production from PVs during night time is minimal. The household owning a wind turbine (**H4**), didn't seem to have the same challenges, as wind occurred frequently during the night especially during the winter: "*The* *wind is usually more powerful during the night and that's great, then we can use the electricity to charge the car*". To the PV owners, not being able to use their produced power during the night, was an unfortunate consequence of solar panels which they hoped that their production during the day would make up for, however for **H1** this was an annoyance that had made him, without luck, experiment with combining PV's and wind turbines: "*The reason why I played around with a wind turbine was that it was supposed to produce during the night and then the PV's would produce during the day. That way we would always produce power, but unfortunately, it broke down*". It should be noted that all participants agreed that charging the EV using the produced electricity potentially wasn't a problem during the day on weekends when they were home and the car was plugged in.

We also found that time of the year would have a potential impact on aligning. For the households owning solar panels charging on produced electricity was perceived significantly more flexible during the summer months, with more sun hours, as mentioned by **H3**: "*It's easier during the summer because we can charge when we get home. We can't do that during winter because when we get home the sun has already set*". In contrast, the household that owned a wind turbine explained that they produced significantly less electricity during the summer months, because of lacking wind. However, this wasn't perceived as a big problem, because even though they sometimes had to import electricity during the summer months they used more electricity during winter months **H4**:

"*The wind turbine and the seasons go well hand in hand. It produces a lot of electricity during the winter when it's cold and we need the power. So, the power I produce in the winter more than makes up for the power I have to import in the summer when there's no wind*".

Technology Assisted Charging

During our technology tours, we found several indications of technology supporting EV charging. Most households (4/5) explained that charging their EV, was much easier done with the aid of technologies.

Using Existing Technology

We found two technologies which were important to our household in relation to charging their EV; feedback displays and charging timers. Feedback displays include information on charging status and remaining charging time. This feedback was accessed through an app on their smartphone or the EVs display. The importance of this feature is expressed by **H4**: "*I often use the charging feedback I get from the EV to see how much time it takes to charge the car just enough to make it to the grocery store. If I can see that it will just be 15 minutes I'll wait, and I won't have to take our secondary car*".

Charging timers, included features to time charging, for example during the night. The functionality of timing charging could in most of the households EVs be accessed through the EVs display or the app. This importance of this functionality was exemplified by **H5**:

"*I use the timer in the car to make sure it stops charging just before I leave in the morning. In an EV you really want to stop charging right before you drive as the battery will be warm and the car brakes work much better*"

One household (**H4**), however, with older children was not using the timer functionality due to mobility needs also during the night: "*I was trying to get the charger to postpone charging until just before we leave in the morning, but I gave up, because what if we had to pick up one of our children somewhere, that's just not ideal*". Feedback and timers were also used together, which seemed powerful combination to **H1**, with three EVs:

"*Typically, we plug in the Fluence when we get home, then that charges during the evening and then we start charging the Tesla when that's done, we can schedule that because it has a timer function and I can see in the display of the Fluence when it's scheduled to be fully charged*".

Improving Technology and Tinkering

We found a potential of aligning electricity production and EV charging through tinkering with technology. As there was at least one member of the household that was interested in technology all households had experimented with tinkering and modifying technologies to fit their needs and were part of their personality, for example, **H4**: "*I'm originally a technician but I've always been interested in technology, I think that's where I got it from, I need to tinker with everything*" and **H1**: "*I find it fascinating that you can buy stuff from eBay and create new and more effective stuff, so logically I've applied that line of thought to my home*". However, not surprisingly, tinkering did not meet the same enthusiasm from the rest of the household members, as exemplified by **H5**: "*I don't need to tinker with the EV, I just need it to be able to have a full charge in the morning so that I can drive to work*" and **H3**: "*I don't share the same enthusiasm for tinkering as my spouse, if the EV is able to drive, I'm happy*".

Interestingly, it was through the discussion of tinkering that we found that technology support for aligning electricity production and EV charging could be a challenge to some households, for example, as **H3** explained: "*The real challenge for me is that I can't see when I produce electricity and therefore it's hard to know when to consume it, there's simply no technical support for that, well there is, there's a web portal but that requires a username and a password, and I'm not going to go there every time*". We found that this lack of control had made some households (4/5) to make or tweak technologies. During our technology tours, we found several indications of household members tinkering with technology and creating their own solutions to their problems. We found that many of the households had installed additional electricity monitoring meters to check how much power was used for charging the EV and then later plotting the numbers into homemade spreadsheets, as **H3** explained: "*I don't trust the numbers in the car, so I have installed a second power meter on my EV charger. I plot those numbers into a homemade spreadsheet and track that the numbers match*". Further, we also found homebuilt timers to automate scheduling charging between EVs, as **H1** articulated: "*I have created my own timer that tracks power consumption and starts charging our third EV when we're not home*". Examples of the homemade technologies are illustrated in Figure 3.

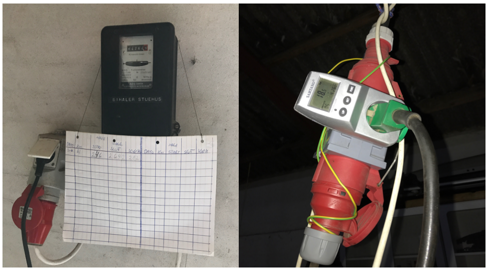

Figure 3. Examples of tinkering, additional power meter from H3 to keep track consumption (left) and homebuilt timer from H1 (right).

DISCUSSION

Our findings indicate that aligning EV consumption with electricity production in the household can seem like a difficult accomplishment for many householders. As an extension of our findings, we will in the following sections outline and discuss four topics that relate to aligning EV consumption and household electricity production.

Relying on People to Align

A tendency in our findings seems to indicate that ideology alone is not enough to overcome aligning EV consumption with household electricity production, at least when relying on them taking an initiative to align themselves. It was clear from both observations and interviews that most household members thought that it was a good idea to align EV consumption and electricity production. However, in reality, practicality and monetary reasoning were two reasons for why it was not worth going through the hassle of postponing charging, i.e., the amount money they could earn or save was not enough to make them actually align consumption and production. This tendency also has a strong link to the type of electricity export scheme the household had, which is exemplified by H4 that was on an export scheme that paid of poorly which had actually made them invest in an EV to use some of the produced electricity. Many studies in HCI also find similar results. For example, Kjeldskov et al. [28] and Jensen et al. [24] both find that it can be difficult to make people change their consumption patterns by themselves without considerable motivation such earning or saving money.

In a similar study to ours, Bourgeois et al. [7], has a related discussion and concludes that householders need increased visibility of green electricity and personalized management to make smarter decisions. Thus, another line of enquiry could also be how smart-agents can assist these households to align charging EV's and home-produced electricity by automating some of the decision making like explored in similar studies with heating [1,2,23,60]. Some of these studies also suggest that other household members with less interest in alignment and rational energy decision making may adapt these smart agents into everyday life if it is convenient and comfortable to do so [2,23].

Electricity Production and Mobility

It was clear that challenges such as the EV actually being available in the household for charging made it difficult for householders to align charging with the production of electricity from PVs. Firstly, EVs were often away from home during the day where most of the electricity was produced and secondly, the preferred charging time was at night when no electricity was produced. Using home-produced electricity from PVs during the daytime might, therefore, seem difficult and might, be utilized more efficiently on other household appliances. Similarly, Bourgeois et al. [7] find that household mobility is a challenge for consuming household-produced electricity from PVs. Our findings reveal that several households actually saw a potential to charge the EV during the few hours of production time when they came home from work, although they suggested that technology was probably needed to support it due to convenience. For PVs, it might be interesting to investigate this further to see if aligning can be done in smaller intervals.

Charging an EV was mostly done at night and according to our households takes a considerable amount of time (almost all night). Even though this might not seem like an optimal choice when considering self-supply of electricity, it potentially solves another difficult challenge in sustainable HCI which is moving consumption away from peak hours on the grid. As other research looking at household appliances points out (e.g., [40]), consuming electricity during the night might actually contribute to lowing load on the grid. In contrast to PVs, the one household with a wind turbine did not have the same problems as the wind often is stronger during the night where the car is at home. Although seasonal weather changes play a role in electricity generation it would seem like wind turbines, that could perhaps complement PVs during the night, are prime candidates for supporting EV mobility and aligning charging with electricity production. However, we argue that further investigation into how household mobility patterns can be supported better through different electricity production technologies.

Supporting the Engaged and Tinkering Householder

While many studies illustrate that eco-feedback rarely leads to changed behaviour that is sustained over a long time [43], our study shows that engagement, tinkering with technology, and ‘micro-management’ of energy become imminent for some householders when they start to produce their own energy. This finding is aligned with studies conducted by Zapico et al. [62] and Simm et al. [49] that highlights that people are more likely to use technologies, such as eco-feedback, in everyday life if they are already committed and involved themselves in sustainable issues. Hence, the participating householders that engaged themselves with using, improving and tinkering with the technology resemble Strengers’ Resource Man [51,52] - an ideal, rational energy consumer empowered by information and functional tools.

We agree with the critique that the design of eco-feedback and forecasting [20,28,36] can be limiting in instigating desired change in energy-consuming practices [11,53]. However, based on the findings in this study, we also see a potential of better our understandings of what ‘triggers’ this engagement in the Resource Man and looking for ways to better support this through our design efforts. The ‘resource men’ in our study found little assistance in the tools they had at hand. However, their engagement seemed to be carried by a burning curiosity to explore and tinker ‘first movers’ technology. Hence, this engagement resembles the bricolage [57] and maker [56] movement. We believe support for such practices is an interesting a line of enquiry for HCI researchers to engage in as it is a fairly unexplored topic in sustainable HCI.

Spatial Alignment of Consumption

An interesting observation we found while interviewing the households was that they were restricted in charging when they were not at home. They had the option of charging out, but this was disliked by many due to extra fees on electricity. From a self-sufficient perspective being away from home can indeed seem like a restriction which also is reflected in the literature. Pierce [42] talks about the term shifting consumption, as being in time and place. However, looking through the HCI literature aligning consumption in time has had a strong focus (e.g., [8,16,24,28,46,49]), however, moving consumption in place seems to have received little attention. Nonetheless, we believe that the question of aligning consumption in place becomes highly relevant in relation to mobility and charging the EV. We argue that this is indeed a challenge that will need the attention from HCI researchers and practitioners.

An observation we did during our interviews was that householders that needed to charge out sometimes borrowed electricity from others to avoid fees on public chargers. Research in HCI has for many years been interested in the sharing resources, for example in transportation, such as cars and rides (e.g., [17,35,50]). Further, many see sharing as one of the future economies (e.g., [6,21]) However, sharing could also be applied to other resources, for example, electricity. A different perspective on aligning in place could, therefore, be to enable and support sharing amongst householders with self-sufficient electricity. This could potentially enable sharing in place although it is not their own produced power. We encourage other researchers in this field to pursue this line of thought.

CONCLUSIONS

In this paper, we have presented a study of households' potential to align electric vehicle charging with electricity production. Through a mixed-methods study with interviews and informal technology tours with five Danish households, we identified five themes that describe current household structures such as motivation, routines, and technologies. Our findings reveal that although some members of the households find the concept of aligning very interesting and were motivated by it, aligning electricity production and charging is challenged by mobility patterns, charging routines and household attitudes.

To inspire further research in HCI with aligning electric vehicle charging and household produced electricity, we have discussed our findings. Drawing on current research in sustainable HCI we have discussed that even though potential exist for aligning EV consumption with produced electricity we currently see challenges such as lack of motivation for householders to align by themselves. Further, due to the mobile nature of EVs we also discuss how mobility patterns, spatiality, and individual household roles could pose a challenge for aligning We further discuss future directions for HCI research building on the discussion points mentioned above.

Our study has some limitations. Firstly, it should be noted that we only recruited one household with a wind turbine (H4). This is primarily due to the fact that this is still a rather unique combination in Denmark. Further investigation into this technology might, therefore, be interesting to pursue in further studies. Secondly, we would also like to point out that some of our households might have been early adopters of PV, Wind turbines, and EVs. We realise that this might influence how the different household members perceive and use the technologies.

REFERENCES

1. Alper T. Alan, Mike Shann, Enrico Costanza, Sarvapali D. Ramchurn, and Sven Seuken. 2016. It is Too Hot: An In-Situ Study of Three Designs for Heating. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (CHI ’16), 5262–5273. https://doi.org/10.1145/2858036.2858222
2. Alper T Alan, Enrico Costanza, Sarvapali D Ramchurn, Joel Fischer, Tom Rodden, and Nicholas R Jennings. 2016. Tariff Agent: Interacting with a Future Smart Energy System at Home. *ACM Transactions on Computer-Human Interaction* 23, 4. https://doi.org/10.1145/2943770
3. Hugh Beyer and Karen Holtzblatt. 1999. Contextual design. *interactions* 6, 1: 32–42. https://doi.org/10.1145/291224.291229
4. Eli Blevis. 2007. Sustainable interaction design. In

Proceedings of the SIGCHI conference on Human factors in computing systems (CHI '07), 503. https://doi.org/10.1145/1240624.1240705

5. Mark Blythe, Andrew Monk, and Jisoo Park. 2002. Technology biogarphies. In *CHI '02 extended abstracts on Human factors in computing systems - CHI '02* (CHI '02), 658. https://doi.org/10.1145/506443.506532
6. Rachel Botsman and Roo Rogers. 2010. *What's mine is yours: How Collaborative Consumption is changing the way we live*.
7. Jacky Bourgeois, Stefan Foell, Gerd Kortuem, Blaine A. Price, Janet van der Linden, Eiman Y. Elbanhawy, and Christopher Rimmer. 2015. Harvesting green miles from my roof: An Investigation into Self-Sufficient Mobility with Electric Vehicles. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '15), 1065–1076. https://doi.org/10.1145/2750858.2807546
8. Jacky Bourgeois, Janet van der Linden, Gerd Kortuem, Blaine A. Price, and Christopher Rimmer. 2014. Conversations with My Washing Machine: An In-the-wild Study of Demand Shifting with Self-generated Energy. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '14), 459–470. https://doi.org/10.1145/2632048.2632106
9. Loove Broms, Cecilia Katzeff, Magnus Bång, Åsa Nyblom, Sara Ilstedt Hjelm, and Karin Ehrnberger. 2010. Coffee maker patterns and the design of energy feedback artefacts. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems* (DIS '10), 93. https://doi.org/10.1145/1858171.1858191
10. A. J. Bernheim Brush, John Krumm, Sidhant Gupta, and Shwetak Patel. 2015. EVHomeShifter. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '15), 1077–1088. https://doi.org/10.1145/2750858.2804274
11. Hronn Brynjarsdottir, Maria Håkansson, James Pierce, Eric Baumer, Carl DiSalvo, and Phoebe Sengers. 2012. Sustainably Unpersuaded: How Persuasion Narrows Our Vision of Sustainability. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '12), 947. https://doi.org/10.1145/2207676.2208539
12. Stephen M. Casner, Edwin L. Hutchins, and Don Norman. 2016. The Challenges of Partially Automated Driving. *Communications of the ACM* 59, 5: 70–77. https://doi.org/10.1145/2830565
13. Niaz Chowdhury, Blaine Price, Andrew Smith, Gerd Kortuem, Janet van der Linden, and John Moore. 2016. EV Charging: Separation of Green and Brown Energy Using IoT. *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct*: 674–677. https://doi.org/10.1145/2968219.2968346
14. Toke Haunstrup Christensen and Freja Friis. 2016. Materiality and automation of household practices : Experiences from a Danish time shifting trial. In *Demand Conference 2016 Papers*.
15. Adrian Clear, Adrian Friday, Mike Hazas, and Carolynne Lord. 2014. Catch My Drift? Achieving Comfort More Sustainably in Conventionally Heated Buildings. In *Proceedings of the 2014 conference on Designing interactive systems* (DIS '14), 1015–1024. https://doi.org/10.1145/2598510.2598529
16. Enrico Costanza, Joel E. Fischer, James A. Colley, Tom Rodden, Sarvapali D. Ramchurn, and Nicholas R. Jennings. 2014. Doing the Laundry with Agents: A Field Trial of a Future Smart Energy System in the Home. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '14), 813–822. https://doi.org/10.1145/2556288.2557167
17. Tawanna R Dillahunt, Vaishnav Kameswaran, Linfeng Li, and Tanya Rosenblat. 2017. Uncovering the Values and Constraints of Real-time Ridesharing for Low-resource Populations. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (CHI '17), 2757–2769. https://doi.org/10.1145/3025453.3025470
18. Thomas Franke, Isabel Neumann, Franziska Bühler, Peter Cocron, and Josef F. Krems. 2012. Experiencing Range in an Electric Vehicle: Understanding Psychological Barriers. *Applied Psychology* 61, 3: 368–391. https://doi.org/10.1111/j.1464-0597.2011.00474.x
19. Jon Froehlich, Leah Findlater, and James Landay. 2010. The Design of Eco-feedback Technology. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '10), 1999–2008. https://doi.org/10.1145/1753326.1753629
20. Jon Froehlich, Shwetak Patel, James A. Landay, Leah Findlater, Marilyn Ostergren, Solai Ramanathan, Josh Peterson, Inness Wragg, Eric Larson, Fabia Fu, and Mazhengmin Bai. 2012. The Design and Evaluation of Prototype Eco-feedback Displays for Fixture-level Water Usage Data. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '12), 2367–2376. https://doi.org/10.1145/2207676.2208397
21. Lisa Gransky. 2014. *The mesh - why the future of business is sharing*. Portfolio Penguin. https://doi.org/10.1007/s13398-014-0173-7.2
22. Anton Gustafsson and Magnus Gyllenswärd. 2005. The power-aware cord: energy awareness through ambient information display. In *CHI '05 extended abstracts on*

Human factors in computing systems (CHI '05), 1423. https://doi.org/10.1145/1056808.1056932

23. Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2016. HeatDial: Beyond User Scheduling in Eco-Interaction. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction* (NordiCHI '16). https://doi.org/10.1145/2971485.2971525
24. Rikke Hagensby Jensen, Dimitrios Raptis, Jesper Kjeldskov, and Mikael B Skov. 2018. Washing with the Wind: A Study of Scripting towards Sustainability. In *Proceedings of the 2018 Conference on Designing Interactive Systems* (DIS '18). https://doi.org/https://doi.org/10.1145/3196709.3196779
25. Li Jönsson, Loove Broms, and Cecilia Katzeff. 2010. Watt-Lite. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems* (DIS '10), 240. https://doi.org/10.1145/1858171.1858214
26. Heekyoung Jung, Erik Stolterman, William Ryan, Tonya Thompson, and Marty Martin Siegel. 2008. Toward a framework for ecologies of artifacts: how are digital artifacts interconnected within a personal life? *Proceedings of the 5th Nordic conference on Human-computer interaction: building bridges*: 201–210. https://doi.org/10.1145/1463160.1463182
27. Malte F. Jung, David Sirkin, Turgut M. Gür, and Martin Steinert. 2015. Displayed Uncertainty Improves Driving Experience and Behavior. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (CHI '15), 2201–2210. https://doi.org/10.1145/2702123.2702479
28. Jesper Kjeldskov, Mikael B. Skov, Jeni Paay, Dennis Lund, Tue Madsen, and Michael Nielsen. 2015. Eco-Forecasting for Domestic Electricity Use. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (CHI '15), 1985–1988. https://doi.org/10.1145/2702123.2702318
29. Charlotte B.A. Kobus, Ruth Mugge, and Jan P.L. Schoormans. 2013. Washing when the sun is shining! How users interact with a household energy management system. *Ergonomics* 56, 3: 451–462. https://doi.org/10.1080/00140139.2012.721522
30. Lenneke Kuijer. 2017. Practices-oriented design. In *Design for behaviour change: Theories and practices of designing for change*, K. Niederer, G. Ludden and S. Clune (eds.).
31. Marc Landau, Sebastian Loehmann, and Moritz Koerber. 2014. Energy Flow: A Multimodal "Ready" Indication for Electric Vehicles. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (AutomotiveUI'14). https://doi.org/10.1145/2667239.2667301
32. Sebastian Loehmann, Marc Landau, Moritz Koerber, and Andreas Butz. 2014. Heartbeat: Experience the Pulse of an Electric Vehicle. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (AutomotiveUI '14). https://doi.org/10.1145/2667317.2667331
33. Anders Lundström. 2014. Differentiated Driving Range : Exploring a Solution to the Problems with the " Guess - O - Meter " in Electric Cars. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (AutomotiveUI'14). https://doi.org/10.1145/2667317.2667347
34. Anders Lundström, Cristian Bogdan, Filip Kis, Ingvar Olsson, and Lennart Fahlén. 2012. EVERT: Energy representations for probing electric vehicle practice. *Proceedings of the 2012 ACM Annual Conference on Human Factors in Computing Systems (CHI '12)*: 2141–2146. https://doi.org/10.1145/2212776.2223766
35. Johanna Meurer, Dennis Lawo, Lukas Janßen, and Volker Wulf. 2016. Designing Mobility Eco-Feedback for Elderly Users. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (CHI EA '16), 921–926. https://doi.org/10.1145/2851581.2851599
36. Jeni Paay, Jesper Kjeldskov, Mikael B Skov, Dennis Lund, Tue Madsen, and Michael Nielsen. 2014. Design of an appliance level eco-feedback display for domestic electricity consumption. In *Proceedings of the 26th Australian Computer-Human Interaction Conference on Designing Futures the Future of Design* (OzCHI '14), 332–341. https://doi.org/10.1145/2686612.2686663
37. Rahuvaran Pathmanathan, Jon Pearce, Jesper Kjeldskov, and Wally Smith. 2011. Using mobile phones for promoting water conservation. In *Proceedings of the 23rd Australian Computer-Human Interaction Conference* (OzCHI '11), 243–252. https://doi.org/10.1145/2071536.2071575
38. Nathaniel S. Pearre, Willett Kempton, Randall L. Guensler, and Vetri V. Elango. 2011. Electric vehicles: How much range is required for a day's driving? *Transportation Research Part C: Emerging Technologies* 19, 6: 1171–1184. https://doi.org/10.1016/j.trc.2010.12.010
39. James Pierce and Eric Paulos. 2010. Materializing Energy. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems* (DIS '10), 113–122. https://doi.org/10.1145/1858171.1858193
40. James Pierce and Eric Paulos. 2012. Beyond Energy Monitors: Interaction, Energy, and Emerging Energy Systems. In *Proceedings of the SIGCHI Conference on*

Human Factors in Computing Systems (CHI '12), 665. https://doi.org/10.1145/2207676.2207771

41. James Pierce and Eric Paulos. 2012. The Local Energy Indicator: Designing for Wind and Solar Energy Systems in the Home. In *Proceedings of the Designing Interactive Systems Conference* (DIS '12), 631–634. https://doi.org/10.1145/2317956.2318050

42. James Pierce, Diane J. Schiano, and Eric Paulos. 2010. Home, Habits, and Energy: Examining Domestic Interactions and Energy Consumption. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '10), 1985–1994. https://doi.org/10.1145/1753326.1753627

43. James Pierce, Yolande Strengers, Phoebe Sengers, and Susanne Bødker. 2013. Introduction to the Special Issue on Practice-oriented Approaches to Sustainable HCI. *ACM Transactions on Computer-Human Interaction* 20, 4. https://doi.org/10.1145/2494260

44. Sarah Pink, Kerstin Leder Mackley, Val Mitchell, Marcus Hanratty, Carolina Escobar-Tello, Tracy Bhamra, and Roxana Morosanu. 2013. Applying the Lens of Sensory Ethnography to Sustainable HCI. *ACM Transactions on Computer-Human Interaction* 20, 4. https://doi.org/10.1145/2494261

45. Dimitrios Raptis, Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2017. Aesthetic, Functional and Conceptual Provocation in Research Through Design. In *Proceedings of the 2017 Conference on Designing Interactive Systems* (DIS '17), 29–41. https://doi.org/10.1145/3064663.3064739

46. Majken K. Rasmussen, Mia Kruse Rasmussen, Nervo Verdezoto, Robert Brewer, Laura L. Nielsen, and Niels Olof Bouvin. 2017. Exploring the Flexibility of Everyday Practices for Shifting Energy Consumption through ClockCast. In *Proceedings of the 29th Australian Conference on Computer-Human Interaction* (OzCHI' 17), 296–306.

47. Johnny Rodgers and Lyn Bartram. 2010. Ambient and artistic visualization of residential resource use. *CEUR Workshop Proceedings* 588, 12: 17–19. https://doi.org/10.1109/TVCG.2011.196

48. Johann Schrammel, Cornelia Gerdenitsch, Astrid Weiss, Patricia M. Kluckner, and Manfred Tscheligi. 2011. FORE-Watch – The Clock That Tells You When to Use: Persuading Users to Align Their Energy Consumption with Green Power Availability. In *Ambient Intelligence*. Springer Berlin Heidelberg, 157–166. https://doi.org/10.1007/978-3-642-25167-2_19

49. Will Simm, Maria Angela Ferrario, Adrian Friday, Peter Newman, Stephen Forshaw, Mike Hazas, and Alan Dix. 2015. Tiree Energy Pulse: Exploring Renewable Energy Forecasts on the Edge of the Grid. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (CHI '15), 1965–1974. https://doi.org/10.1145/2702123.2702285

50. Martin Stein, Johanna Meurer, Alexander Boden, and Volker Wulf. 2017. Mobility in Later Life. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (CHI '17), 5716–5729. https://doi.org/10.1145/3025453.3025672

51. Yolande Strengers. 2013. *Smart Energy Technologies in Everyday Life*. Palgrave Macmillan UK, London. https://doi.org/10.1057/9781137267054

52. Yolande Strengers. 2014. Smart Energy in Everyday Life: Are You Designing for Resource Man. *interactions* 21, 4: 24–31. https://doi.org/10.1145/2621931

53. Yolande A.A. Strengers. 2011. Designing Eco-feedback Systems for Everyday Life. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '11), 2135. https://doi.org/10.1145/1978942.1979252

54. Helena Strömberg, Pontus Andersson, Susanne Almgren, Johan Ericsson, MariAnne Karlsson, and Arne Nåbo. 2011. Driver interfaces for electric vehicles. In *Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (AutomotiveUI '11), 177. https://doi.org/10.1145/2381416.2381445

55. Michael K. Svangren, Mikael B. Skov, and Jesper Kjeldskov. 2017. The connected car: an empirical study of electric cars as mobile digital devices. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services* (MobileHCI '17), 1–12. https://doi.org/10.1145/3098279.3098535

56. Sophie Landwehr Sydow, Jakob Tholander, and Martin Jonsson. 2017. "It's a Bomb!"; -- Material Literacy and Narratives of Making. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (CHI '17), 121–132. https://doi.org/10.1145/3025453.3025529

57. Anna Vallgårda and Ylva Fernaeus. 2015. Interaction Design as a Bricolage Practice. *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction*, January 15-19: 173–180. https://doi.org/10.1145/2677199.2680594

58. Remco A. Verzijlbergh, Marinus O. W. Grond, Zofia Lukszo, Johannes G. Slootweg, and Marija D. Ilic. 2012. Network Impacts and Cost Savings of Controlled EV Charging. *IEEE Transactions on Smart Grid* 3, 3: 1203–1212. https://doi.org/10.1109/TSG.2012.2190307

59. Stina Wessman, Rebekah Olsen, and Cecilia Katzeff. 2015. That's the smell of peacetime – Designing for

electricity load balancing. In *Nordes, Nordic Design Research Conference 2015*.

60. Rayoung Yang, Mark W. Newman, and Jodi Forlizzi. 2014. Making Sustainability Sustainable: Challenges in the Design of Eco-interaction Technologies. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '12), 823–832. https://doi.org/10.1145/2556288.2557380

61. Ray Yun, Azizan Aziz, Peter Scupelli, Bertrand Lasternas, Chenlu Zhang, and Vivian Loftness. 2015. Beyond Eco-Feedback: Adding Online Manual and Automated Controls to Promote Workplace Sustainability. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (CHI '15), 1989–1992. https://doi.org/10.1145/2702123.2702268

62. Jorge Luis Zapico, Cecilia Katzeff, Ulrica Bohné, and Rebecka Milestad. 2016. Eco-feedback Visualization for Closing the Gap of Organic Food Consumption. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction* (NordiCHI '16), 1–9. https://doi.org/10.1145/2971485.2971507

6.2 Investigating EV Driving as Meaningful Practice

Rikke Hagensby Jensen, Michael K. Svangren, Mikael B. Skov, Jesper Kjeldskov

Abstract: Studies show that people find meanings such as freedom and independence in driving. However, the transition towards electric vehicles (EV's) challenges these meanings as they present different driving experiences such as shorter driving range and missing supportive infrastructures. This suggests that people find other meaning in EV driving. This paper presents a qualitative study with 11 Danish participants who reflect on their experiences of driving EV's in everyday life. As driving is embedded in many practices along with being a practice in itself, we draw on social practice theory as a frame-work to unfold how participants make use of technology to make EV driving a meaningful and desirable practice. We report on how participants facilitate their driving practices using interactive technology and charging infrastructure. We discuss these findings under three headings with ideas to inspire future HCI research and design for meaningful, sustainable EV driving practice.

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Investigating EV Driving as Meaningful Practice

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ABSTRACT

Studies show that people find meanings such as freedom and independence in driving. However, the transition towards electric vehicles (EV's) challenges these meanings as they present different driving experiences such as shorter driving range and missing supportive infrastructures. This suggests that people find other meaning in EV driving. This paper presents a qualitative study with 11 Danish participants who reflect on their experiences of driving EV's in everyday life. As driving is embedded in many practices along with being a practice in itself, we draw on social practice theory as a framework to unfold how participants make use of technology to make EV driving a meaningful and desirable practice. We report on how participants facilitate their driving practices using interactive technology and charging infrastructure. We discuss these findings under three headings with ideas to inspire future HCI research and design for meaningful, sustainable EV driving practice.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**.

KEYWORDS

Electric vehicles, sustainability, mobility, practices

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1 INTRODUCTION

The car is massively important in today's society. Although many transport alternatives exist, the car remains the most widely adopted means of mobility across more than 947 million vehicles worldwide, accounting for approximately 70 per cent of all journeys [1]. The act of efficiently moving between places has become crucial to access our surroundings, such as going to work, on holidays, or simply getting the groceries. Further, owning and driving cars have been associated with shared expectations, e.g. a high degree of personal freedom, comfort, and independence [28, 53].

In recent years, the increasing adoption of electric vehicles (EVs) has challenged the traditional use and understanding of the car. Studies show adoption barriers such as shorter driving range and missing supportive infrastructures. Towards this end, HCI research has studied how to design interfaces to reduce drivers worrying about battery depletion (e.g. [26, 34, 36, 37]). However, few HCI studies have investigated actual use in peoples everyday lives and how people find meaning in electric driving. These studies have studied the EV as a mobile household appliance and how it is integrated into existing households [5, 58]. Despite this research, a limited amount of research exists, which investigates actual driving experiences with EV's in everyday life.

In this paper, we extend HCI research on EV's with an empirical understanding of how and why EV owners find meaning in driving practices and if charging with own-produced electricity influences desirable driving experiences. We report from a study of 11 EV drivers (five households with own-produced electricity) where we conducted informal conversational technology tours and semi-structured interviews. We use social practice theory as an analytic lens, guided by questions such as what role digital technology plays in shaping EV driving, what kind of expectations people embed into their EV driving practices, and how people adjust driving an EV compared to the traditional fossil-fuelled car.

We present findings in four themes of Joyful Electric Driving, Transitioning into EV Driving, Planning through Interactive Technologies, and (Un)Sustainable Driving Expectations. Findings indicate that EV driving is an enjoyable and meaningful practice and that planning and technology support is essential aspects in shifting to EV driving. Finally, experiences of EV driving indicate increased driving activity. We discuss these findings under three headings with ideas that may inspire future HCI research and design for the EV.

2 RELATED WORK

Studying interactions with the car has been a subject of research in HCI for years. A body of literature exists on studies describing the driving situation and how to ensure the driver eyes on the road. This research predominantly focuses on using various technologies in the car and how this affects the driving situation. Several papers have presented results related to the above, for example on interacting with existing in-car car technology (e.g. [6, 20, 35]), novel interfaces (e.g. [10, 30, 38, 39]), and how drivers appropriate interactive technologies (e.g. [2, 26]).

In HCI research, we have seen a shift in how people use the car that is closely related to the development of technology. One of these shifts is the use of connected features of the car. Many cars today are shipped with an internet connection, which means that people can interact with the car both from the inside and the outside using other mobile devices (e.g. [7, 42, 62, 63]). Chiesa et al. ([7]) demonstrate ideas for collaborative parking utilising connectedness. Ostergren ([42]) suggest a system for social music experiences by tuning into music experiences of cars nearby.

HCI studies are also investigating different ways of using cars. Studies of traditional car ownership have found that usage of cars indicate that people find meaning in a high degree of freedom and independence that they provide instead of practical values such as saving time [28, 53]. However, today, there are many alternatives to traditional car usage, e.g. car and ride-sharing that allow for the car to be accessed as a service. Studies of such services indicate that people find meaning in other qualities. For example, in a study of car sharing, Shaheen et al. found that people found meaning in social and environmental aspects of car use [48].

HCI Research on Electric Vehicles

Following HCI discourses on sustainability, we have seen an interest in electric vehicles (EV's) in later years. A significant number of HCI studies on EV's have focused on the challenges and opportunities in adopting and driving these, as they form a new kind of driving experience compared to a fossil-fuelled car [26, 34, 36]. To this end, several studies investigate range-related issues such as range anxiety where drivers worry about the depletion of the battery before they reach their destination [26]. As such, this work has resulted in more design-oriented research addressing challenges related to range anxiety and lack of feedback (e.g. [26, 36, 37, 57]). As examples, Jung et al. [26] explore the impact of displayed uncertainty in the car's instrumental estimates of range, while Landau [34] focuses on creating an interface that makes up for the lack of feedback in EVs, for example, the lack of sound or vibration, or knowing when the EV is ready to drive.

In contrast to design-oriented research, empirical studies that investigate how people find meaning in the use of EV's, have received less attention within HCI. Most HCI research in this area has addressed how and why owners use EV's and how they appropriate these in their daily lives. This work suggests that people own and drive EV's for reasons such as becoming more sustainable [5, 14, 58] and interests in novel technology [59]. Bourgeois et al. [5], for instance, investigated the feasibility of self-sustaining electrical mobility and provided an understanding of owning and integrating EV's into household routines. The authors found that utilising own-produced electricity, and the feeling of being sustainable was a reason for owning and driving an EV. Svangren et al. [59], investigated connected cars and the use of digital technology. They found that some challenges related to EV driving, like range anxiety, are mitigated through the use of digital ecologies. However, despite the above research, there is still a gap in exploring actual EV driving and how people find meaning in the experience through use of technology.

Sustainable Change and Social Practice Theory

In later years, we have seen a growing interest in the HCI research community to engage in the design of digital technology and sustainable change. In this line of work, different theoretical frameworks have been applied to both understand and discover means to design interventions for sustainable change [9]. In particular, suggestions to use practice-oriented methods [32] have been advocated within sustainable HCI studies to better account for the social values and norms influencing how resources are consumed [11, 22, 31, 44]. As most resource consumption is interwoven in mundane routines people perform in everyday life (e.g. cleaning, cooking, heating, and driving), practice theory highlights that changes to such routines are shaped by what people find meaningful and desirable. Therefore, designing meaningful and desirable experiences of interactions with technology may shape practice [19], and thus influence resource consumption.

While social practice theories originate from social science, we also see a growing research interest in HCI that focuses on understanding why early adopters desire to use and interact with new digital technology. Commonly, these studies aim to help uncover both the sustainable benefits and pitfalls of new digital technology use. Strengers [56], for example, use social practice theory to understand the influence of eco-feedback design in everyday life to help frame alternative design directions for HCI. Pink et al. [45] explore heating practices through sensory ethnography as an approach to inform future sustainable design for heating. Hasselqvist et al. [18] use social practice theory to study three families' experiences of car-free living, while Ganglbauer et al. [15] investigate food practices from a social practice theory perspective, to suggest design strategies of related practices to influence more sustainable food waste practices.

Practice as a Framework. To help frame practices and understand how they change, Shove and colleagues provide a concise framework of social practice change [50]. In this work, the authors argue that practices change when elements (competences, materials, and meanings) of practice is mixed in different ways. Importantly, Shove [49] also argues that desired social-shared expectations, which people associate with performing a practice, contribute to or undermine sustainability outcomes. This is exemplified by Jensen et al.'s [23] empirical investigation that draws on the concept of 'desiderata' and social practice theory to uncover the energy impacts of peoples' desires to use smart home technology. Kent et al. [28] also investigated traditional car practices and found that the shift to more sustainable transportation forms, is undermined by social expectations of driving, such as flexibility, freedom, autonomy, and comfort.

3 STUDY DESIGN

This paper aims to investigate peoples' use and experiences of driving an electric car. At the same time, the paper explores if and how own-produced electricity influence desirable driving experiences. In contrast to previous studies in this area [5, 14, 58], the purpose of this study is to unfold how early adopters of such perceived sustainable technologies adjust practices to make the EV a meaningful and desirable means of transportation when they can charge their car with own-produced electricity. Moreover, we aim to uncover the kinds of energy implications EV driving practice may have in everyday life. To this end, we use social practice theory as a lens [50], and are guided by questions such as what role technology and infrastructures play in shaping EV driving (materials), what kind of meanings and expectations people embed into their EV driving practices (meanings), and how people adjust driving an EV compared to a traditional fossil-fuelled car (competences). In the following, we describe in detail; the background of EVs in Denmark, an overview of participating households, data collection, and analysis.

Electric Vehicles in Denmark

The reported research in this paper is part of a larger research project investigating future sustainable scenarios for energy and transportation systems in Denmark. Actors in the Danish energy sector envision householders to play a significant role in the transition into a more sustainable energy future. The scenario of electric vehicles that can be charged at home by electricity produced from small wind turbines and solar panels is often promoted as a step towards a more sustainable future in this vision. Using this argument, the Danish government has introduced economic incentives to promote households to invest in these technologies by, for instance, reducing registration tax on EVs compared to fossil-fuelled cars. These incentives have led to an increased Danish EV fleet, with sales increasing from 0.25 per cent of total car sales at the beginning of 2017 to 3 per cent at the beginning of 2019 [12]. Yet, while EVs can be charged at home, public available charging infrastructure is also starting to emerge from a range of private companies. Most commonly, these public charging stations require a subscription to the particular provider. However, there is no standard for EV charging spots. Sometimes, charging spots are marked for EVs with a symbol or a sign to signal that only they can park there. However, in many cases, they are just regular parking lots with a charger next to it.

Participants

Five households (11 people) participated in this study. Each household also produced electricity from their own solar panels or wind turbines. Participants were between the age of 16 and 72. All participants were driving at least one of the household's EVs. All participants had a drivers licence except Adam (Household A) who were currently acquiring his. A demographic overview can be found in Table 1. The participants from each household are referred to in the table by anonymised pseudonyms (e.g., Kirsty) and household number (e.g., A). In the following, we will describe each of the five households in depth.

Household A. The household owns a Tesla, a Renault Fluence, and a Mahindra Reva. They mainly drive in the Tesla (50.000 km a year) and Renault (20.000 km a year). The Reva was bought for Adam, who plans to drive to school when he gets his driver licences. Today, Adam uses the bus or an Air Wheel (a small electric one-wheeled scooter). The household drives more after getting the Tesla, as driving sometimes replaces flying on holiday. Jim also started to drive the Tesla for business trips instead of flying. The household owns solar panels that produce 18.000 kWh of electricity a year. However, the household uses three times as much electricity yearly. Two-thirds of this is used to charge their three EVs. The family drives around 70.000 km a year.

H	Name	Age	Adults (Children)	Occupation	Living area	EV Model
A	Kirsty, Jim, Adam	46, 47, 16	3 (2)	Nurse, Assoc. Prof., Student	Rural	Tesla M. S, Renault Fluence, Mahindra Reva
B	Ina, Jeffery	70, 72	2	Both Retired	City (winter) and Rural (summer)	BMW I3
C	Irene, Franky	50, 48	2 (3)	Healthcare Helper, Early Retirement	City	Tesla M. S
D	Clara, Tony	53, 52	2(3)	Retail Assistant, Military Consultant	Rural	VW E-Golf
E	Isabel, Jett	34, 38	2(2)	Regional Clerk, Consultant	Rural	Tesla M. S

Table 1: Description of participant households.

Household B. The household bought the new hybrid car last year. Before this, they used to have an older EV model. The new car has an electric motor, and a backup petrol generator that can produce electricity to run the motor in the case it runs out of electricity. The electric car-range is about 150 km and 150 km for gasoline. The adults spend most of their summer in their rural summerhouse where they have solar panels as the only source of electricity. In the winter they live in their city flat, where they have a power charging set up. They drive around 17.000 km a year, and this has not changed with their new model. In the summer months, they use about half of their produced electricity for their car.

Household C. The household owns a Tesla that drives 40.000 km a year and a fossil-fuelled Mustang that drives 20.000 km a year. The Tesla is the preferred car because they believe this is the most economical choice for driving. Before they got the Tesla, they would drive about 30.000 in their former cars. The children also use buses, mopeds and bikes for transport purposes as they do not have a driver licence. The household has solar panels. The family produce 7200 kWh of electricity a year, which is about the same amount they use yearly.

Household D. The family owns two cars; an E-golf and a fossil-fuelled Audi. Tony also has a fossil-fuelled motorbike, while the children use bikes. They drive around 30.000 km a year in the E-Golf, about 10.000 km in the Audi and 8.000 km on the motorbike. The children bike every day to school or take the bus if the weather is terrible. As the only household, the family produce between 25.000 and 30.000 kWh a year from an 11 kW wind turbine. The electricity, they do not use themselves, is sold at a flat rate of 0.78 DKK (0.14 USD) per kWh. From 2021 they have to transfer to dynamic trading conditions, meaning they might have to pay money to sell electricity due to high amounts of wind energy in Denmark.

Household E. This household owns two cars; a Tesla and a 20-year-old fossil-fuelled Golf. They drive around 30.000 km a year in the Tesla and 10.000 km in the Golf. Occasionally, they take a train or bike to work. The family owns solar panels that produce 4.000 kWh a year, which covers ordinary household energy-consuming activities. They use about an extra 6.000 kWh for charging their only EV.

Data Collection

In order to get an understanding of why households desire to electrify car transportation, we conducted an in-depth qualitative study with early adopters that already embed electric cars in their everyday life and also produce micro-generated electricity. To this end, we designed our study to consist of four steps; an informal, conversational technology tours, individual interviews, group interviews and a debriefing session between two researchers.

Informal Conversational Technology Tours. To get an understanding of the access to and use of different technologies, we conducted informal, conversational technology tours [3] with each of the households. Here, we asked participants to show us their EVs and what technology they used for charging it. We asked them to give examples of how they used technologies individually and in collaboration. The purpose of the technology tours was twofold. Firstly, we wanted to get a richer and more concrete understanding of how the individual households used their cars. Secondly, we wanted the participants to be able to speak more openly about technology and reveal possible tacit knowledge. This approach resulted in many participants not only demonstrating but also sometimes wanting us to try out their technology so we could get first-hand experiences.

Individual and Joint Interviews. Following the technology tours, we conducted individual and joint semi-structured [33] interviews with all participating household members. The purpose of the individual interviews was to reveal individual opinions, such as competences and meanings for the technologies touched upon in the technology tours. For example, we asked them individually about motivation towards owning and driving the EV, individual routines involved in driving and charging it, along with individual driving patterns.

We conducted joint semi-structured interview sessions with all participating household members. The purpose of this session was to understand shared social values and practices and to reveal possible tensions between household members. Here we asked more general questions about the structure of the households, the driving patterns as a household, and common motives for driving an EV. These sessions would sometimes result in discussions between our participants about their reflections on the "most correct" way of doing things.

Two researchers participated in the data collection sessions. Right after each visit to the households, the researchers had a debriefing sessions [61]. The purpose of this session was to support *"the research team to discuss and work through the successes, issues, and challenges encountered"* [61]. These debriefing sessions facilitated the process of sharing thoughts and reflections on the researchers' observations and impressions that were not verbalised by the participants. The debriefing sessions were audio-recorded.

Data Analysis

We took notes, pictures, and recorded audio with consent during the technology tours. All interviews were documented through researcher notes and audio recordings. A total of ten and a half hours of audio were transcribed for analysis by two of the authors.

We coded the transcriptions accordingly. We identified broad themes using inductive coding [46, 47]. Next, we used the three elements of social practice theory as a lens to guide the thematic analysis (materials, competencies, and meanings). The analysis resulted in four themes. As part of the analysis, participants were given a pseudonym (see Table 1).

4 FINDINGS

Our findings highlight different aspects of how EV driving is experienced as meaningful practice, focussing specifically on driving and adaptation of the EV into household routines. Drawing on our analysis, we structured the findings into four overall themes; *Joyful Electric Driving, Transitioning into EV Driving, Planning through Interactive Technologies, and (Un)Sustainable Driving.*

Joyful Electric Driving

The first theme describes how participants find joy in driving their EV compared to the vehicle they owned before. Further, the theme describes how expectations of playfulness and new sensory experiences of coolness shape how the EV becomes infused in driving practices.

Playful Technology. The households were generally characterised by a high level of interest in technology. All the participants reflected that many of the technologies related to the EV gave them a feeling of driving a car of the future, which in turn added a layer of comfort. Because of this added comfort, most participants thought that driving non-electric cars felt like a step down technologically. They used words as *"feels like a step backwards"*, *"old fashioned"* and *"inconvenient"*. This, for example, was reflected by Jim in household A that owned three EVs;

> *"For the Tesla, one doesn't even have to control it [...] That completely convinced me that there was no reason why our car shouldn't be electric in the future because it seemed technically superior - I like that"* - **Jim (A)**

Playfulness was also associated with getting to know a technologically advanced car, which resulted in time being spent on exploring and playing around different features. We found that many of the participants were very interested in technology (at least one on every household), thus figuring out how the EVs worked or could be modified became a hobby for many of them. This meant time spent acquiring competencies to incorporate these technologies into everyday life was seen as enjoyable as the participants found these amusing and fun to play around with. Jeffery exemplifies this;

> *"I have to admit that I was a little tempted by all that technology and there is also a lot of it in this car. Yes, I think it's fun, and I like the principles. [..] Anyway, that's how it is with toys, so when I then got the car in my hands I played with it"* - **Jeffery (B)**.

The combination of playful EVs technology and using electricity from the solar panels or wind turbines each household owned, meant it became highly engaging to integrate the EV into overall household activities;

> *"So the technology I think is very interesting, that is, something that is as annoying as the f***ing wind can be turned in to something useful. It fascinates me, and then, of course, I am also very aware that it is environmentally correct that I do not have to burn off gasoline or oil. It fascinates me tremendously!"* - **Tony (D)**

Under the technology tours, we saw several homemade devices meant to support charging when the car was at home, which made us ask if this also applied while driving. We found that sharing knowledge through digital technology with other people owning an EV were quite important for these participants. One aspect of this was sharing experiences and useful advice through social media and forums on everything from charging infrastructure to how to hack software in the cars;

> *"The forums [Facebook], and the social aspects are quite important to us. We share experiences on everything from unavailable chargers to advice on how to polish our Tesla with people who also own an EV. Once every now and then we also arrange hackathons through them where we tinker with our cars. We share both our success and frustration"* - **Jett (E)**

Sensory Experiences and Coolness. Another aspect making EV driving a joyful experience was related to the creation of new sensory experiences through the new technologies found in these cars. The new sensory experiences added to expectations of comfort and pleasure of the time spent in the car. These expectations also further enhanced the feeling of being in a "cocoon of the car" because *"you just drive silently - no noise, no diesel noise, there is only noise from the road"* - **Jim (A)**. Because of this, driving the EV was popular in these households, which meant it became the preferred means of transport in their daily activities. As a result, who drove the EV would often be up for debate, as it was an attractive alternative to those who also had a fossil-fuelled car;

> *"It's my wife that drives the EV to work because she has to drive the furthest, then I will, sadly, have to suffice with the other one. However, I'm changing jobs soon, so I'll get the EV, that's how it is, it's the rule. But I'm certainly not going to complain about that"* - **Jett (E)**.

We further found that all households experienced substituting driving a fossil-fuelled car with an EV had made speed less relevant. A slower speed was foremost to save range, however enjoying the drive also became important;

> *"When I take the diesel, I find myself rushing to my goal constantly thinking about when to overtake the car in front of me. It's very stressful. However, when I drive the EV, I slow down, thinking about how I drive and I enjoy the trip. It's sort of this zen thing"* - **Tony (D)**

Another aspect the participants reflected upon was the experience of feeling cool owning and driving an EV. Part of this was related to the uniqueness of the technology. For instance, electric cars do not feature a gearbox as conventional cars. Many also offer different forms of autonomous driving, and interactive applications making it possible to interact with the cars through other devices. We also found that coolness was associated with having a special car that few people own, making the EV something cool and desirable to show to friends and family. Adam, the older son in household A, for example, thought that having his own electric car was;

> *"Iconic in some ways because it is a special, little car. I have some friends who have seen it, and they think it's cool"* - **Adam (A)**

Especially for the Tesla owners, the feeling of uniqueness, was partly due to how Tesla's ecology of technologies worked together. This uniqueness contributed to making the EV cool to own;

> *"There has been talk of a Jaguar and a BMW. And then we looked into these Teslas — you cannot say anything other than it's a brilliant car and it's just an even bigger idea"* - **Franky (C)**

Transitioning into EV Driving

In this section, we describe how participants transitioned into EV driving from previously owned vehicles. Although there were many aspects related to this (e.g., getting used to driving with regenerative breaking), we found that planning for available driving range was the most important aspect of this transition.

Planning Household Charging. As participants reflected on questions about driving range, most of them described they had been through an adaption period to accommodate charging their EV. One aspect was experiencing a limited driving range and the consequences of forgetting to charge;

> *"Yes, we've tried sometimes that I, for example, forgot to charge. Yes, then there is nothing you can do. I can't just ride down to the petrol station and pick up a dunk of gas. You'll just have to wait it out"* - **Kirsty (A)**

In the beginning, some households experienced they had to compromise on comfort features. They would, for instance, turn heaters and wipers off during the winter months in their old EV to save range to make it home. Household B expressed their early experiences with EVs as; *"not suitable for Danish winter weather"* - **Ina (B)**. However, when asked about how to overcome the limited range, most households agreed that many of the issues could be mitigated through planning and new routines. As such, it quickly became a new routine to plug in the car when arriving home and plan charging points while driving, to ensure they were ready for driving when needed;

> *"We are used to all the cars are parked and ready for charging during the night, and that they are ready to drive in the morning. When we come home, we just plug it in"* - **Adam (A)**

Because it had become routine to charge at home it also enhanced the expectation that the car was always fully charged when leaving home. This could sometimes lead to problems for households switching between EVs and fossil-fuelled cars: *"She ended up running of petrol because, whoops, it had not been refuelled like with the Fluence that is freshly charged every morning"* - **Jim (A)**. However, the participants saw this availability of electricity as flexibility and convenience when compared to fuelling at gas stations, which compensated the inflexible time aspect of charging the electric car;

> *"Finding time to charge is not a problem for me. I would say that I on average spend one minute a day with charging activities — and yes that's even a high estimate. I just have to plug it right in and out. How long do you think people spend on a gas station in a month?"* - **Jim (A)**

Charging Away from the Household. Available charging infrastructure outside the households, both public and private, was regarded as a useful means to reduce experiencing the EV's limited driving range. When away from home, many participants explained they would plan holidays by finding hotels where they could charge the car when arriving at the hotel. As electricity is available in many places, all the participants also spoke of the convenience of being able to charge their car in other peoples' homes.

> *"When I visit my son, the first thing I do, is to put the car in the socket. It's become quite expensive for him to have us come by for a coffee"* - **Jeffery (B)**

One challenge of having to charge in different households was the non-standardised charging infrastructure (e.g. different sockets and power availability). This meant not all cars were able to charge in all charging outlets with a standard plug. In household D, Tony was well prepared for the different situations. He had various cables and extension cords, so he was always able to charge when away from home.

> *"I've become more used to it. It is very much habitual that I have to think a bit about where I go and the electricity options. Therefore, I bring different adaptors. Most often, if we have to visit the family or the likes, we can just charge the car there. I don't think there's anyone who would say no if you bring an adaptor"* - **Tony (D)**

Having to wait to charge in the middle of a drive at available public charging stations was not regarded as an inconvenience by these participants. This was mainly because these stops had been planned beforehand, and often in combination with a bathroom or coffee break. Some participants even regarded the charging time as additional time to do desirable activities, not normally fitting into busy family life;

> *"I like to read a book, and I never have the time elsewhere because I always have so many projects. But now I have the time for it, and then I sit there for an hour, and I read a book. I really just use this time to disconnects, and I think of it as my relax or leisure time"* - **Irene (C)**

Some participants experienced that charging was free at their workplace; *"they have a free charge for the staff's electric car, so if they come in the morning they plug the EV in and then it is finished when they go home in the afternoon"* - **Ina (B)**. This option was often considered if the EV was discharged and no public charger was nearby; *"And I was thinking about a parking garage near where I work - there's an outlet with grounding outside."* - **Irene (C)**. Tony did not have the option to charge at work, and his EV's range was not sufficient to drive both ways. Therefore, he had an agreement with a friend to charge at his house, near his workplace. To compensate for the electricity he used, he kept track of the consumption using a measuring device;

> *"I have to charge while at work because otherwise, I can't make it back. I have an agreement with a friend that lives just by my workplace. It fits very well with my driving patterns"* - **Tony (D)**

Planning through Interactive Technologies

We found that participants used various digital applications to help them plan their drives. Being able to plan a drive influenced how limited range and scattered charging infrastructure was disregarded as a major inconvenience. Therefore, participants expressed that planning through digital technologies had become a major part of their routines. The use of digital technology, however, depended on the kind of drive they needed planning for: mundane driving for everyday purposes or extraordinary, longer, and more uncertain drives. Tony, for example, differentiated between the two;

> *"For everyday mundane driving, I don't care. I just drive and charge when I get home and check the EV feedback when it's done. Almost like a regular car. I want to say that it's a habit. And if we are going to have that extraordinary trip, then I sit down with this [a smartphone app] and say, okay*

we should do that and that and then we have to adjust the drive a bit to charge" - **Tony (D)**

Mundane driving. We found the most common use of participants EVs was for mundane purposes such as going to work, getting groceries, and driving kids to events. For these purposes, planning was minimal, and something that had become routine quite fast. Mainly two technologies were used to support charging for such drives; feedback displays providing information about charging status and remaining charging time, and charging timers that provided an opportunity to schedule charging;

> *"Usually, when we come home, we just plug it in. It has become a routine, I don't have to plan. However, I have an app that warns me if I forget, because you learn very fast how very annoying it is, if you have to go to work and it doesn't have the range"* - **Franky (C)**

Both feedback and timer functions were accessed through an app on their smartphone or the EV display. Clara described a typical scenario;

> *"I often use the charging feedback I get from the EV to see how much time it takes to charge just enough to make it to the grocery store. If I can see that it will just be 15 minutes I'll wait, and I won't have to take our secondary car"* - **Clara (D)**.

Timers were often used to ensure that the EV would be ready for the next day because charging was usually done a night when the EV was not being driven. Timing functionality could in most EVs be accessed through the EV display or an accompanying app. Isabel expressed how they used the timing function to ensure optimal conditions for their car;

> *"I use the timer in the car to make sure it stops charging just before I leave in the morning. In an EV you really want to stop charging right before you drive as the battery will be warm and the car brakes work much better"* - **Isabel (E)**

Extraordinary driving. Extraordinary driving, like going for longer drives or going to an unknown place, required more planning. For these purposes charging away from home on publicly available charging infrastructure was often required. However, the participant spoke of several challenges beside ensuring available range, emphasising the necessity for planning extraordinary trips. For example, in Denmark, most public charging stations require a subscription, and subscriptions do not work across providers, meaning planning also entails finding the right chargers. At the same time, a charger can be unavailable either because it is broken, it is being used by another EV, or because the parking space where the charger is located is blocked by other fossil-fuelled vehicles. Especially the latter scenario annoyed Tony;

> *"I saw that some people just park in dedicated parking spots meant for EVs. That really, really annoys me. If I come to a spot and a diesel car is parked there, I simply can't accept it. If I'm there and can't get to my destination because I need to charge, then I get upset. You don't see me park at their gas station"* - **Tony (D)**

Although it was possible to avoid the above challenges through ad-hoc use of technology while driving, the preferred way of overcoming these challenges was to plan ahead of a drive. Most often, participants adjusted a driving route according to where chargers were available by using various apps providing such information. Some households (Tesla owners) could plan a trip in their car or on the smartphone using the vendor app for dedicated Tesla chargers. However, all households were using a variety of applications to complement each other. Examples include; applications with different functionality developed by charging infrastructure providers (restricted to chargers of that particular provider), or open applications giving an overview of different providers;

> *"We have different apps for all sorts of situations — this one gives me an overview of public chargers available to me, this one gives me access to Tesla chargers, and this one gives me an overview of chargers that private persons borrow out"* - **Franky (C)**.

Going for longer drives to unfamiliar places was not for everyone. Although the majority of participants could explain in detail how they would plan a trip, not all members of the households felt comfortable going on long drives. This was primarily due to inexperience with the technologies used for planning, although they might feel comfortable driving the EV. For example, for everyday purposes Clara would often use their EV, but would take their other car (diesel) when going for a long trip alone;

> *"I don't feel comfortable driving for longer trips alone because what if I run out of range? Then I have to find a charging spot, and I'm not as experienced as Tony planning that. I would much rather just take the Diesel. At least I know how the gas station works"* - **Clara (D)**

(Un)Sustainable Driving Expectations

For many participants, sustainability was considered an important aspect of buying an EV. This argumentation was strengthened as all households owned facilities capable of producing electricity (solar panels and wind turbines). However, we also found the EV driving experience resulted in unsustainable driving practices like increased driving because it was more pleasant than their former car.

Driving on Sunshine. As participants were in a unique situation of being suppliers of their own electricity, it also influenced how they thought about driving their EVs. Motivation to plan and drive on electricity households produced themselves was both rooted in sustainable and more rational concerns. To most participants, driving on their own produced electricity was an important alternative; *"I think that one should use it while it is being produced, but I also think it makes sense from a bigger perspective"* - **Jim (A)**. This further provided many householders with a unique experience of being sustainable and self-sufficient;

> *"That you drive on the sun - that feeling is fantastic!"* - **Ina (B)**

Rational reasons for driving on household produced electricity could also be observed. For households owning solar panels, saving money was also important. However, having to plan daily charging was seen as difficult because EVs were used during the day when electricity production was the highest. However, for household D that owned a wind turbine capable of delivering electricity both during the day and at night, charging was more effortless but still seen quite important as it was a cheap way to utilise the turbine's capacity for powering the car. As such, the incentives to charge the EV was also rooted in monetary reasoning; *"After we got the electric car, and started to drive more in it, and we have become better at using the EV, we have become more proficient and better at using electricity for ourselves"* - **Tony (D)**.

Increasing Driving Activities. As opposed to saving range and charging on self-produced electricity, most of the participant expressed that driving the EV had served more unsustainable routines by driving more. The families reflected that not only did they invest in sustainable technology, but for many of them, it was also an economic investment. However, one consequence of this investment meant that driving activities had increased. For example, in Household A, the decision to invest in a Tesla, an expensive car to buy compared to other makes, where partly reasoned by the possibility of free charging. These factors, combined with that they had started to take the EV on holidays to Norway and Germany instead of flying, meant an increase in driving activities;

> *"In fact, we use mostly cars, that is, our driving has increased. We don't have to go down and fill it up at the petrol station, so we think it is not so terribly harmful to the environment if we charge a little extra or if we drive a little more in the car. So we drive more in the car, there is no doubt about that. Also, we've started to take it on holiday instead of flying it's much more comfortable"* - **Kirsty (A)**

This notion of increased driving combined with the advances in the technology found in many of the EVs also influenced the participants' expectations of comfort. Indirectly, this led to an increase in electricity consumption. For example, because they could get access to the car's functions from devices such as a smartphone, some participants utilised electricity consuming features such as pre-heating on cold mornings to heat the car, so it was nice and comfortable when driving.

> *I set it to heat consistently at a certain time in weekdays, but that is probably also because we are running on flat rate so now we don't save money on limiting pre-heating. [...] pre-heating the cabin simply means that you do not come out to a cold car, which is terrible and wastes range if it has to be done while driving.* - **Jim (A)**

5 DISCUSSION

The findings in this study contribute to understandings of the kinds of aspirations and expectations people associate with everyday electrified driving activities. In the following, we discuss what implications these findings have for HCI researchers and designers attempting to understand and design for EV related driving activities and supporting services.

Towards Sustainable Desirable Driving

As Shove and colleagues argue [49–51] social shared meaningful experiences shape how people embed (or reject) designed 'things' (including digitally supported sustainable technology such as EVs) in everyday practices. Shove [49] also argue that expectations, e.g. the 3Cs (comfort, convenience and cleanliness), play an essential role in how people use a designed technology and what they expect it to do, which also have significant energy consumption effects. Kent [28] has also highlighted that expectations of flexibility, freedom, autonomy, and comfort are desirable social shared expectations influencing how people make use of the car as a means for transport.

Our study shows that expectations continue to play an important role when people embed the EVs into driving practices, despite the many regarded concerns and uncertainties associated with driving EVs [26, 34, 36]. Our findings illustrate how participants adapted expectations they associated with driving in their EVs. At the same time, our findings highlight such expectations shape how people embed technologies regarded as sustainable (Evs and own-produced energy technologies) in electric driving practices, beyond the desire of "driving on sunshine". For instance, hedonic sensory experiences of joyfulness, enhanced comfort, and coolness might actually undermine the possible sustainable benefits of these technologies. These findings are in line with similar studies investigating sustainable smart home technologies [17, 23] illustrating that expectations of desirable experiences of embedding advanced digital technologies into everyday practices, may undermine the sustainable benefits because they are actually used more. Based on the findings in this study, we argue a need to better account for such expectations in future designs of sustainable driving. One suggestion would be to look at other meaningful forms of sustainable mobility, e.g. car or ride-sharing [29, 60].

Another interesting direction could be to explore the feeling of slowing down when driving the electric car - an experience highlighted by several participants in our study. We believe such experiences relate to the notion of slow travel [8], which may be used as a means to envision other desirable experiences surrounding sustainable travel beyond "going green" visions. The qualities of slowness reflect related visions of slow technology [16], e.g. slowness with personal data [41], slow energy [27, 43], and slow living in the smart home [24] used to promote less energy-intensive activities. Thus, we believe slow mobility for sustainable driving to be a ripe area for HCI researchers and designers to engage in.

Towards Playful Tinkering

Studies have shown that it is usually one person in the household that is the driving force for bringing new technologies into the household [21, 40], which generate new forms of household work and play [23, 54, 55, 58]. Our findings in this study also highlight this particular tendency. The participants in our study experienced the EV as a playful and cool technology, which resulted in time being spent on exploring and playing around its different features. Moreover, the time spent on these tinkering activities was not experienced as inconvenient. In particular, the participants experienced the interplay of the EV and energy-producing technologies playful and found tinkering with different technologies to make them fit household needs as amusing and fun. We believe the notion of playful tinkering and time spent acquiring competencies to incorporate new technologies into everyday life is an area often disregarded when exploring sustainable interaction designs. Therefore, in order to better understand how possible sustainable futures can be practised, we believe HCI designers can obtain inspiration from the way that these early adopters of such technology improvise and tinker with new technology.

Supporting EV Driving through Digital Ecologies

Besides the car itself, using various technologies to plan a ride was considered important in the practice of meaningful EV driving. The participants described technologies such as feedback displays and timers to support charging the car, while various apps were used to gain an overview and access charging infrastructure in sequence when going on long drives. Combining different interactive technologies to support a particular practice is not new to HCI. The most common term for such systems of technologies is digital ecologies (e.g. [4, 13, 26, 52]). Towards cars in general, digital ecologies have proven useful to serve a range of novel types of mobility, for example, ride-sharing where digital platforms can support switching between different modes of transportation [60]. Further, it has been indicated that digital ecologies are important means for supporting people interacting with the EV itself as a digital device [59]. Along these lines, we especially see digital ecologies as a mean towards supporting adopters of EVs to navigate the many different available charging providers. We see an opportunity for both researchers and designers to draw inspiration in the way that people combine applications to access charging infrastructure as a meaningful whole instead of fragments. In this process, frameworks that identify interaction (e.g. [25, 52]) could be used to analyse existing digital ecologies.

6 CONCLUSIONS

In this paper, we have presented a study of practices surrounding driving electric vehicles. Through a qualitative study of interviews and informal conversational technology tours with five Danish households, we identified themes that describe how participants experience driving their EV. Our findings reveal EV driving as an enjoyable and meaningful practice and that planning- and technology support is important aspects in transitioning to EV driving. Finally, the experience of the EV also led to increased driving activity compared to their former car.

To inspire HCI future research and design on EVs, we discussed three headings with ideas to inspire future HCI research and design for meaningful EV driving practice. Firstly, we discussed which implications the EV as new technology have on peoples' experiences and use to become more sustainable. Secondly, we discussed how technology-interested people could provide further inspiration for research and design with EVs in HCI. Lastly, we discussed the importance of the role of a digital ecology, supporting EV driving.

Our study has some limitations. Firstly, the recruited households were early adopters of EVs, and many of them had a high degree of technology literacy. We realise this may influence how they understand and use their cars. Secondly, car use and opinions vary across geographical locations, and so, carrying out a similar study in a different location, such as another country, might yield different results.

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REFERENCES

[1] ACEA - European Automobile Manufacturers Association. 2016. Future mobility: The challenges we face | ACEA - European Automobile Manufacturers' Association. https://www.acea.be/news/article/future-mobility-the-challenges-we-face

[2] Kenneth Majlund Bach, Mads Gregers Jæger, Mikael B. Skov, and Nils Gram Thomassen. 2009. Interacting with in-vehicle systems: understanding, measuring, and evaluating attention. , 453–462 pages. https://dl.acm.org/citation.cfm?id=1671070

[3] Mark Blythe, Andrew Monk, and Jisoo Park. 2002. Technology biogarphies: field study techinques for home use product development. In *Conference on Human Factors in Computing Systems: CHI'02 extended abstracts on Human factors in computing systems*, Vol. 20. Citeseer, 658–659.

[4] Susanne Bødker and Clemens Nylandsted Klokmose. 2012. Dynamics in artifact ecologies. (2012), 448. https://doi.org/10.1145/2399016.2399085

[5] Jacky Bourgeois, Stefan Foell, Gerd Kortuem, Blaine A. Price, Janet van der Linden, Eiman Y. Elbanhawy, and Christopher Rimmer. 2015. Harvesting green miles from my roof: An Investigation into Self-Sufficient Mobility with Electric Vehicles. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '15)*. 1065–1076. https://doi.org/10.1145/2750858.2807546

[6] Barry Brown and Eric Laurier. 2012. The normal natural troubles of driving with GPS. https://doi.org/10.1145/2207676.2208285

[7] Mario Chiesa, Riccardo Toppan, Alessandro Branciforti, and Francesco Posca. 2014. Social parking. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '14)*. ACM Press, New York, New York, USA, 1–6. https://doi.org/10.1145/2667239.2667283

[8] Janet E. Dickinson, Les M. Lumsdon, and Derek Robbins. 2011. Slow travel: Issues for tourism and climate change. *Journal of Sustainable Tourism* 19, 3 (2011), 281–300. https://doi.org/10.1080/09669582.2010.524704

[9] Carl DiSalvo, Phoebe Sengers, and Hrönn Brynjarsdóttir. 2010. Mapping the Landscape of Sustainable HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. ACM, New York, NY, USA, 1975–1984. https://doi.org/10.1145/1753326.1753625

[10] Ronald Ecker, Verena Broy, Andreas Butz, and Alexander De Luca. 2009. pieTouch. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '10)*. ACM Press, New York, New York, USA, 1. https://doi.org/10.1145/1613858.1613887

[11] Johanne Mose Entwistle, Mia Kruse Rasmussen, Nervo Verdezoto, Robert S Brewer, and Mads Schaarup Andersen. 2015. Beyond the Individual: The Contextual Wheel of Practice As a Research Framework for Sustainable HCI. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM Press, 1125–1134. https://doi.org/10.1145/2702123.2702232

[12] FDEL. 2019. Statistik | Dansk Elbil Alliance. https://www.danskelbilalliance.dk/statistik

[13] Jodi Forlizzi, Keywords Design Theory, Interaction Design, Product Ecology, and Social Products. 2008. The Product Ecology:. *International Journal* 2, 1 (2008), 11–20.

[14] Freja Friis and Kirsten Gram-Hanssen. 2013. Integration of Smart Grid Technologies in Households: How Electric Vehicles and Dynamic Pricing Change Social Practices in Everyday Life. *Rethink, Renew, Restart. Proceedings of the ECEEE 2013 Summer Study* (2013), 1019–1030.

[15] Eva Ganglbauer, Geraldine Fitzpatrick, and Rob Comber. 2013. Negotiating Food Waste: Using a Practice Lens to Inform Design. *ACM Transactions on Computer-Human Interaction (TOCHI)* 20, 2 (2013), 1–25. https://doi.org/10.1145/2463579.2463582

[16] Lars Hallnäs and Johan Redström. 2001. Slow Technology âĂŞ Designing for Reflection. *Personal and Ubiquitous Computing* 5, 3 (aug 2001), 201–212. https://doi.org/10.1007/PL00000019

[17] Tom Hargreaves, Richard Hauxwell, Lina Stankovic, David Murray, Tom Kane, Steven Firth, and Charlie Wilson. 2015. Smart homes, control and energy management: How do smart home technologies influence control over energy use and domestic life ? *European Council for an Energy Efficient Economy (ECEEE) 2015 Summer Study on Energy Efficiency* (2015), 1021–1032.

[18] Hanna Hasselqvist, Mia Hesselgren, and Cristian Bogdan. 2016. Challenging the Car Norm: Opportunities for ICT to Support Sustainable Transportation. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM Press, New York, New York, USA, 1300–1311. https://doi.org/10.1145/2858036.2858468

[19] Marc Hassenzahl, Kai Eckoldt, Sarah Diefenbach, Matthias Laschke, Eva Len, and Joonhwan Kim. 2013. Designing moments of meaning and pleasure. Experience design and happiness. *International Journal of Design* 7, 3 (2013).

[20] Brit Susan Jensen, Mikael B. Skov, and Nissan Thiruravichandran. 2010. Studying driver attention and behaviour for three configurations of GPS navigation in real traffic driving. In *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10*. ACM Press, New York, New York, USA, 1271. https://doi.org/10.1145/1753326.1753517

[21] Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2018. Assisted Shifting of Electricity Use: A Long-Term Study of Managing Residential Heating. *ACM Trans. Comput.-Hum. Interact.* 25, 5, Article 25 (Oct. 2018), 33 pages. https://doi.org/10.1145/3210310

[22] Rikke Hagensby Jensen, Dimitrios Raptis, Jesper Kjeldskov, and Mikael B. Skov. 2018. Washing with the Wind: A Study of Scripting Towards Sustainability. In *Proceedings of the 2018 Designing Interactive Systems Conference (DIS '18)*. ACM, New York, NY, USA, 1387–1400. https://doi.org/10.1145/3196709.3196779

[23] Rikke Hagensby Jensen, Yolande Strengers, Jesper Kjeldskov, Larissa Nicholls, and Mikael B. Skov. 2018. Designing the Desirable Smart Home: A Study of Household Experiences and Energy Consumption Impacts. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, Article 4, 14 pages. https://doi.org/10.1145/3173574.3173578

[24] Rikke Hagensby Jensen, Yolande Strengers, Dimitrios Raptis, Larissa Nicholls, Jesper Kjeldskov, and Mikael B. Skov. 2018. Exploring Hygge As a Desirable Design Vision for the Sustainable Smart Home. In *Proceedings of the 2018 Designing Interactive Systems Conference (DIS '18)*. ACM, New York, NY, USA, 355–360. https://doi.org/10.1145/3196709.3196804

[25] Robert Johansen. 1988. *Groupware: Computer support for business teams.* The Free Press.

[26] Malte F. Jung, David Sirkin, Turgut M. Gür, and Martin Steinert. 2015. Displayed Uncertainty Improves Driving Experience and Behavior. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. 2201–2210. https://doi.org/10.1145/2702123.2702479

[27] Cecilia Katzeff, Stina Wessman, and Sara Colombo. 2017. "Mama, It's Peacetime!": Planning, Shifting, and Designing Activities in the Smart Grid Scenario. *Proceedings of the Conference on Design and Semantics of Form and Movement - Sense and Sensitivity* (2017). https://doi.org/10.5772/intechopen.71129

[28] Jennifer L. Kent. 2014. Driving to save time or saving time to drive? The enduring appeal of the private car. *Transportation Research Part A: Policy and Practice* 65 (2014), 103 – 115. https://doi.org/10.1016/j.tra.2014.04.009

[29] Jennifer L. Kent and Robyn Dowling. 2013. Puncturing automobility? Carsharing practices. *Journal of Transport Geography* 32, 2013 (2013), 86–92. https://doi.org/10.1016/j.jtrangeo.2013.08.014

[30] Dagmar Kern, Albrecht Schmidt, Jonas Arnsmann, Thorsten Appelmann, Nillakshi Pararasasegaran, and Benjamin Piepiera. 2009. Writing to your car. In *Proceedings of the 27th international conference extended abstracts on Human factors in computing systems (CHI EA '09)*. ACM Press, New York, New York, USA, 4705. https://doi.org/10.1145/1520340.1520724

[31] Lenneke Kuijer and Conny Bakker. 2015. Of chalk and cheese: behaviour change and practice theory in sustainable design. *International Journal of Sustainable Engineering* 8, 3 (may 2015), 219–230. https://doi.org/10.1080/19397038.2015.1011729

[32] Kari Kuutti and Liam J. Bannon. 2014. The turn to practice in HCI: towards a research agenda. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM Press, New York, New York, USA, 3543–3552. https://doi.org/10.1145/2556288.2557111

[33] Steinar Kvale. 1994. *Interviews: An introduction to qualitative research interviewing.* Sage Publications, Inc.

[34] Marc Landau, Sebastian Loehmann, and Moritz Koerber. 2014. Energy Flow. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '14)*. ACM Press, New York, New York, USA, 1–6. https://doi.org/10.1145/2667239.2667301

[35] Gilly Leshed, Theresa Velden, Oya Rieger, Blazej Kot, and Phoebe Sengers. 2008. In-car gps navigation. In *Proceeding of the twenty-sixth annual CHI conference on Human factors in computing systems (CHI '08)*. ACM Press, New York, New York, USA, 1675. https://doi.org/10.1145/1357054.1357316

[36] Sebastian Loehmann, Marc Landau, Moritz Koerber, and Andreas Butz. 2014. Heartbeat. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '14)*. ACM Press, New York, New York, USA, 1–10. https://doi.org/10.1145/2667317.2667331

[37] Anders Lundström, Cristian Bogdan, Filip Kis, Ingvar Olsson, and Lennart Fahlén. 2012. Enough power to move. In *Proceedings of the 14th international conference on Human-computer interaction with mobile devices and services (MobileHCI '12)*. ACM Press, New York, New York, USA, 201. https://doi.org/10.1145/2371574.2371605

[38] Vince Mancuso. 2009. Take me home. In *Proceedings of the 27th international conference extended abstracts on Human factors in computing systems (CHI EA '09)*. ACM Press, New York, New York, USA, 4591. https://doi.org/10.1145/1520340.1520705

[39] Andrii Matviienko, Andreas Löcken, Abdallah El Ali, Wilko Heuten, and Susanne Boll. 2016. NaviLight. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '16)*. ACM Press, New York, New York, USA, 283–294. https://doi.org/10.1145/2935334.2935359

[40] Sarah Mennicken, Jo Vermeulen, and Elaine M Huang. 2014. From Today' s Augmented Houses to Tomorrow' s Smart Homes: New Directions for Home Automation Research. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '14)*. 105–115. https://doi.org/10.1145/2632048.2636076

[41] William Odom, Ron Wakkary, Jeroen Hol, Bram Naus, Pepijn Verburg, Tal Amram, and Amy Yo Sue Chen. 2019. Investigating Slowness as a Frame to Design Longer-Term Experiences with Personal Data. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. ACM Press, New York, New York, USA, 1–16. https://doi.org/10.1145/3290605.3300264

[42] Mattias Östergren. 2004. Sound Pryer: Adding Value to Traffic Encounters with Streaming Audio. In *Entertainment Computing - Icec 2004*. Vol. 3166. 541–552. https://doi.org/10.1007/978-3-540-28643-1_71

[43] James Pierce and Eric Paulos. 2012. The Local Energy Indicator: Designing for Wind and Solar Energy Systems in the Home. In *Proceedings of the Designing Interactive Systems Conference (DIS '12)*. ACM Press, New York, New York, USA, 631–634. https://doi.org/10.1145/2317956.2318050

[44] James Pierce, Yolande Strengers, Phoebe Sengers, and Susanne Bødker. 2013. Introduction to the Special Issue on Practice-oriented Approaches to Sustainable HCI. *ACM Trans. Comput.-Hum. Interact.* 20, 4, Article 20 (Sept. 2013), 8 pages. https://doi.org/10.1145/2494260

[45] Sarah Pink, Kerstin Leder Mackley, Val Mitchell, Marcus Hanratty, Carolina Escobar-Tello, Tracy Bhamra, and Roxana Morosanu. 2013. Applying the Lens of Sensory Ethnography to Sustainable HCI. *ACM Trans. Comput.-Hum. Interact.* 20, 4, Article 25 (Sept. 2013), 18 pages. https://doi.org/10.1145/2494261

[46] Lyn Richards and Janice M Morse. 2012. *Readme first for a user's guide to qualitative methods.* Sage.

[47] Margrit Schreier. 2012. *Qualitative content analysis in practice.* Sage Publications.

[48] Susan A. Shaheen, Elliot Martin, and Apaar Bansal. 2018. Peer-To-Peer (P2P) Carsharing: Understanding Early Markets, Social Dynamics, and Behavioral Impacts. *UC Berkeley Research Report* (2018). https://doi.org/10.7922/G2FN14BD

[49] Elizabeth Shove. 2003. *Comfort, Cleanliness and Convenience: the Social Organisation of Normality.* Berg Publishers, Oxford. 221 pages.

[50] Elizabeth Shove, Mika Pantzar, and Matt Watson. 2012. *The dynamics of social practice: Everyday life and how it changes.* Sage.

[51] Elizabeth Shove, Matthew Watson, Martin Hand, and Jack Ingram. 2007. *The Design of Everyday Life.* Berg, Oxford.

[52] Henrik Sørensen, Dimitrios Raptis, Jesper Kjeldskov, and Mikael Skov. 2014. The 4C Framework The 4C Framework: Principles of Interaction in Digital Ecosystems. (2014), 87–97. https://doi.org/10.1145/2632048.2636089

[53] Linda Steg. 2005. Car use: Lust and must. Instrumental, symbolic and affective motives for car use. *Transportation Research Part A: Policy and Practice* 39, 2-3 SPEC. ISS. (2005), 147–162. https://doi.org/10.1016/j.tra.2004.07.001

[54] Yolande Strengers, Jenny Kennedy, Paula Arcari, Larissa Nicholls, and Melissa Gregg. 2019. Protection, Productivity and Pleasure in the Smart Home: Emerging Expectations and Gendered Insights from Australian Early Adopters. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. ACM, New York, NY, USA, Article 645, 13 pages. https://doi.org/10.1145/3290605.3300875

[55] Yolande Strengers and Larissa Nicholls. 2017. Aesthetic pleasures and gendered tech-work in the 21st-century smart home. *Media International Australia* (feb 2017). https://doi.org/10.1177/1329878X17737661

[56] Yolande A.A. Strengers. 2011. Designing Eco-feedback Systems for Everyday Life. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM Press, New York, New York, USA. https://doi.org/10.1145/1978942.1979252

[57] Helena Strömberg, Pontus Andersson, Susanne Almgren, Johan Ericsson, MariAnne Karlsson, and Arne Nåbo. 2011. Driver interfaces for electric vehicles. In *Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '11)*. ACM Press, New York, New York, USA, 177. https://doi.org/10.1145/2381416.2381445

[58] Michael K. Svangren, Rikke Hagensby Jensen, Mikael B. Skov, and Jesper Kjeldskov. 2018. Driving on Sunshine: Aligning Electric Vehicle Charging and Household Electricity Production. In *Proceedings of the*

10th Nordic Conference on Human-Computer Interaction (NordiCHI '18). ACM, New York, NY, USA, 439–451. https://doi.org/10.1145/3240167.3240179

[59] Michael K. Svangren, Mikael B. Skov, and Jesper Kjeldskov. 2017. The connected car: an empirical study of electric cars as mobile digital devices. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '17)*. ACM Press, New York, New York, USA, 1–12. https://doi.org/10.1145/3098279.3098535

[60] Michael K. Svangren, Mikael B. Skov, and Jesper Kjeldskov. 2018. Passenger Trip Planning using Ride-Sharing Services. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. 1–12. https://doi.org/10.1145/3173574.3174054

[61] Jennyfer Lawrence Taylor, Alessandro Soro, Paul Roe, Anita Lee Hong, and Margot Brereton. 2018. "Debrief O'Clock": Planning, Recording, and Making Sense of a Day in the Field in Design Research. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, Article 308, 14 pages. https://doi.org/10.1145/3173574.3173882

[62] Chao Wang, Jacques Terken, Jun Hu, and Matthias Rauterberg. 2016. Improving Connectedness between Drivers by Digital Augmentation. In *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct (Automotive'UI 16)*. ACM Press, New York, New York, USA, 135–140. https://doi.org/10.1145/3004323.3004339

[63] Chao Wang, Jacques Terken, Bin Yu, and Jun Hu. 2015. Reducing driving violations by receiving feedback from other drivers. In *Adjunct Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI Adjunct '15)*. ACM Press, New York, New York, USA, 62–67. https://doi.org/10.1145/2809730.2809736

6.3 The Connected Car: An Empirical Study of Electric Cars as Mobile Digital Devices

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Abstract: The amount of interactive digital technology in cars is increasing rapidly, and many new cars are shipped with connectivity. As a result, a new platform has emerged that holds potentials to facilitate many new and different interactions, both inside and outside the car. Within the area of HCI for cars, the focus has predominantly been on interactions with in-vehicle systems and applications of technology that is enabled through connectivity. However, we still lack in-depth empirical studies that provide details of the connected car, its use, opinions towards it, and how it integrates into people's everyday lives. We report from a qualitative study of 13 households with connected electric cars. We present our findings in 3 themes of interaction through connectivity, updating and upgrading car software, and security and privacy. We further discuss our findings in 3 themes that might inform and inspire further mobile HCI research with the connected car.

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ABSTRACT
The amount of interactive digital technology in cars is increasing rapidly, and many new cars are shipped with connectivity. As a result, a new platform has emerged that holds potentials to facilitate many new and different interactions, both inside and outside the car. Within the area of HCI for cars, the focus has predominantly been on interactions with in-vehicle systems and applications of technology that is enabled through connectivity. However, we still lack in-depth empirical studies that provide details of the connected car, its use, opinions towards it, and how it integrates into people's everyday lives. We report from a qualitative study of 13 households with connected electric cars. We present our findings in 3 themes of *interaction through connectivity, updating and upgrading car software,* and *security and privacy*. We further discuss our findings in 3 themes that might inform and inspire further mobile HCI research with the connected car.

Author Keywords
Connected car; electric car; connectivity; mobile devices

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g. HCI): Miscellaneous;

INTRODUCTION
Today, we interact with and use several digital technologies while driving, to control car settings, e.g. climate control, cruise control, or safety systems. In addition, we use other interactive digital systems in the car (sometimes also while driving), for example, mobile phones, GPS navigation systems, or entertainment systems for playing music or video. While some of these technologies are prohibited by law, e.g. texting on mobile phones while driving, it is quite evident that contemporary cars have become platforms for digital technology interaction, and several cars are further connected to the Internet enabling new kinds of interaction.

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Previous mobile HCI research involving cars and in-vehicle interaction has largely investigated and studied interaction with different kinds of in-vehicle systems and how different interaction styles and modalities impact the primary task of driving (e.g. [3,7,12,15,18]). Thus, a key concern has been how to minimize effects of interaction while driving. As an example, Jensen et al. [15] found that GPS systems highly affect driving behavior e.g. speeding, and require visual attention while driving.

While HCI research has mainly focused on interaction with in-vehicle systems, we are currently witnessing a growing interest in connected cars – that is cars that are connected to the Internet. Such connectivity provides new means and opportunities for interaction, e.g. communication between drivers using crowd-sourced data to find available parking spaces [9], or for creating social music experiences by tuning into the music of nearby cars [35]. Also, the automobile industry promotes solutions and technologies for the connected car, for example in Apple Carplay [1] or Android Auto [13], or car manufacturer apps like Nissan Carwings [33] and Volkswagen Car-Net [44]. Despite these attempts and solutions, however, we lack systematic studies that provide detailed understandings of connected cars, and how they are used and embedded into the everyday lives of people. Such insights into connected cars can be used to inform new technologies and services, and are useful not only for researchers but also for automobile designers.

In this paper, we contribute to mobile HCI research with a systematic empirical study of connected cars. We report from a qualitative study of 13 households with connected electric cars where we conducted semi-structured interviews and informal conversational technology tours. We are guided by questions such as how connected cars are being used, how users interact with them through different devices, and what users' opinions are towards owning and using them. Our findings provide a detailed understanding of the connected car, and show that it in many ways is being used and perceived as a mobile digital device in concert with other connected mobile devices, such as smartphones and laptops. We present our findings in 3 themes of *interaction through connectivity, updating and upgrading car software,* and *security and privacy*. Furthermore, we discuss these findings under three headings with ideas that might inspire further mobile HCI research and design for the connected car.

RELATED WORK

Interacting with digital technologies in the car is familiar to most people. Drivers and passengers use various digital interfaces in the car, but also through other devices with the latest advances in connectivity. In the following sections, we will unfold prior research with cars. Firstly, we describe mobile HCI research with in-car interaction. Secondly, we discuss the definitions and understanding of connected cars, and finally, we describe applications and mobile HCI research enabled through connectivity.

Interacting with Technology in the Car

Over the last years, we have witnessed a considerable amount research studies on in-car interaction with a strong focus on investigating the impact of using technologies in cars, and how this affects driving and driving performance. This research has primarily considered how to ensure that the driver's primary task of driving is maintained while interacting with technology and, in particular, reducing cognitive and mental load while driving to ensure and support the drivers' primary task of keeping their eyes on the road. Several papers have presented research into existing technologies (e.g. [7,15,24]), novel interfaces (e.g. [12,18,29,30]), and driver appropriate interaction types and techniques (e.g. [3,16]). As an example, Leshed et al. [24] studied in an ethnographically-informed study how drivers engage and disengage with the environment while driving cars using GPS navigation systems. Demonstrating novel interfaces, Matviienko et al. [30] present a prototype ambient light as an alternative to graphical GPS displays, and Ecker et al. [12] challenge deeply nested menu structures often found in regular displays. Studying interaction types, Bach et al. [3] compare tactile, touch and gesture-based interaction for in-vehicle systems. Many of these studies focus on how, and to what extend, drivers' interactions with technology affects their driving, e.g. the primary driving task performance or eye glance behavior.

More recently, researchers have been faced with the opportunities and challenges of electric cars and autonomous vehicles. These vehicles present a challenge as they form a new kind of driving experience compared to the traditional car experience [8,22]. For electric vehicles, there has been a strong focus on drivers worrying about the depletion of the battery, which is often referred to as range anxiety [17]. As such, this has resulted in research addressing these challenges (e.g. [17,22,25,26,40]). As an example, Jung et al. explore impact of displayed uncertainty in instrumental estimates of range [17], while Landau focuses on creating an interface that makes up for the lack of feedback in electric cars, for example, the lack of sound or vibration, or knowing when the car is ready to drive [22]. Autonomous vehicles and especially partly automated driving [8] has also come into focus in the later years. HCI research studies in autonomous vehicles have looked into trust in relation to handing over control to the car [23,31,37], or user interface considerations for the changing requirements from drivers [11,14].

The Connected Car

Connectivity in cars has existed for several years It was first used for voice calls and safety systems, but more recently we have seen more advanced features such as Internet access through cars equipped with modems [10].

Several definitions and understandings on connected cars have been suggested over the past years (e.g. [10,19,42]). Early research, such as Kleberger et al. [19] mentions that the connected car can be seen as a set of characteristics of the in-vehicle network of sensors and devices, the portal to the manufacturer, and the link between them. A more recent definition provided by the United States' Department of Transportation [42] further include that the connected car has "connectivity amongst and between cars or vehicles, infrastructure, and wireless devices to enable safety, mobility, environmental benefits, and continuous real-time connectivity to all system users". Extending these definitions and characteristics, Coppola and Morisio [10] add that the connected car is equipped with modern applications, capable of interacting with other smart devices, and capable of accessing the Internet and its services at any time. It seems that the above definitions are accumulative, that is, as cars develop and get increasingly advanced, new definitions and understandings emerge that adds to or extends previous definitions. Summarized, it appears that presently the connected car is being perceived as a vehicle with integrated Internet connected technology, providing new opportunities.

Applications Enabled through Connectivity

Mobile HCI research on connected cars has mostly focused on specific applications or prototypes, and evaluation of these applications or prototypes. There has been much less interest for understanding car drivers, passengers, and their needs and interaction with their connected cars. For example, some studies (e.g. [34,41]) investigate how to complement the car's functionality through connectivity. Tulusan et al. [41] demonstrate a mobile app that monitors and provides real-time eco-feedback for drivers. Research involving multi-device interaction and cars has also explored collaborative interfaces (e.g. [9,35,38,45,46]). Wang et al. [45] present different design ideas intended to improve communication and safety between drivers, and Chiesa et al. [9] illustrate ideas for the sharing of information to create systems for collaborative parking. Finally, Östergren [35] shows a music system for social experiences by tuning into the music of nearby cars.

In addition to HCI research studies, the computing and automotive industry are currently exploring solutions and systems for connected cars (e.g. Apple's Carplay [1] and Google's Android Auto [13]) or remote controlling car features, such as temperature controls, through car manufacturer apps (e.g. Nissan's Carwings [33] and Volkswagen's Car-Net [44]). However, there still seems to be a lack of focus on understanding how people is using the services in relation to their cars.

	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13
Adults (children)	2 (3)	2	2 (2)	2 (2)	2 (1)	2 (3)	2 (3)	2	2 (2)	2 (1)	2 (3)	2	2 (2)
Age of Adults	42,40	56,53	55,52	52,56	35,33	34,32	39,33	52,51	38,44	57,57	52,44	59,53	50,45
Connected car (Owned)	Tesla, Fluence (2,5)	Leaf (4)	E-Golf (2)	Leaf (1)	Tesla (1)	E-NV (1/2)	Leaf (1)	Leaf (2)	Tesla, Leaf (2)	Tesla (1)	Tesla (3)	E-Golf (1)	Leaf (3)
EC kilometers (yearly)	50.000	9.000	45.000	45.000	35.000	2.500	20.000	15.000	44.000	60.000	30.000	20.000	20.000
Second non connected car	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No	No
Living area	Rural	Rural	City	Rural	City	Rural	City	City	City	City	Rural	City	City

Table 1: Overview of the participating households. All households had 2 adult members and ten of the households had children living at home. The households included five different brands of electric cars including Nissan Leaf (6), Tesla (5), E-Golf (2), E-NV (1), and Renault Fluence (1).

STUDY

So far, mobile HCI research with cars has primarily had a focus on interaction with in-vehicle systems. Many specific systems and technologies that use connectivity are suggested in the literature, and several commercial products are already being used. However, no HCI studies provide detailed, in-depth empirical insights into the use of the connected car, how technologies connected to the car are being used, and how they integrate into in the everyday lives of people. In this paper, we address this gap and contribute to mobile HCI research with cars by reporting from an empirical study of 13 Danish families with connected cars.

Participants

We recruited 13 households to participate in our study with a total of 26 adult residents. From these households, 19 adult participants were interviewed. All households owned at least one electric car. We chose electric cars as inclusion criteria as these vehicles highly integrate connectedness. The 19 participants in the households were between 32 and 59 years old (M=47). Ten households had up to three children living at home, and the remaining three households either had no children or no children living at home. All households were distributed across Denmark in smaller towns or cities (N=8) or in rural areas (N=5) as illustrated in Table 1. Six households were exclusively electric cars households (two of them had two connected cars) while the remaining seven households were hybrid households owning both an electric car and a fossil fueled car. Two households had an electric car that was rented (H6, H13). Adults in all households were in permanent jobs, except H2, where the wife had retired and H11 where both adults were part time employed. They were all middle-class households and were living in single-family houses.

As illustrated in Table 1, the participating households drove between 2.500 km and 60.000 km per year in their electric car. Five households drove between 10.000 and 30.000 kilometers a year, and six households drove 30.000 kilometers a year, where one of them, drove just above 60.000 kilometers a year (H10). Two of them drove fewer kilometers per year since they primarily drove their electric car during summer (H2) and because they had a leased electric car with a yearly kilometer maximum (H6).

We recruited our participants through online forums aimed at electric car owners (e.g. Facebook groups for different electric car models). Our recruitment was part of another research study where we developed and deployed a survey for connected car owners (advertised through the online forums). As part of the survey, we asked if the car owners if they were willing to participate in this study. The criterion for participation was that they owned at least one electric car that was connected. Of 204 survey answers, 165 agreed to participate in this study and we chose the included 13 households from the following criteria: (i) different car models, (ii) different living areas (e.g. rural or metropolitan areas), (iii) different composition of the households (e.g. couples with/ without children), (iv), how long they have had their car, (v) participant age, and (vi) with and without a secondary non-connected car.

Data Collection and Analysis

Data collection was based on qualitative, semi-structured interviews, combined with explorative interviews [21] in the beginning to focus our study. We requested that all (adult) household members participated in the interviews, which were the case in six households. In the remaining seven, we interviewed only one person (the primary electric car driver). Before each interview, we prompted each household by email with questions about their specific car model and driving behaviour. For example, we asked owners if they could describe their driving patterns for the last three months. The purpose of this approach was to make them reflect about functionality and interactions related to their car, which would enable us to get richer data.

We conducted informal, conversational technology tours at each household before the actual interview [6]. Here we asked the participants to show us their car(s), and show examples of how they used it, and how they didn't use it. The purpose of the technology tour was twofold. Firstly, we wanted the participants to speak more openly about their cars by revealing possible tacit knowledge. Secondly, we wanted to be able to get a richer and concrete understanding of their cars and technology around their cars. This sometimes resulted in that the participants wanted us to try their cars (H1, H3, H5-H7), or show us how certain technologies, such as apps and charging infrastructure, integrated with the car. We took notes during the technology tour for later analysis.

We conducted our interviews in two rounds, inspired by Yin [47]. The goal of the first interview round was exploration where we included "what", "how" or "where" questions. The focus was on exploring the domain and learning about the usage and features of the cars. The goal of the second round was explanation, where we could follow up on findings from the first round by including "why" questions. The focus was on explaining these findings in depth.

The first interview round had a broad focus, and we didn't apply a specific interview guide, but rather we used an initial set of themes to guide our questions. An example of a theme was "devices", where we asked specific questions about which devices people used, how they used them and in which contexts. The interviews were audio-recorded. A total of nine hours of audio was transcribed and coded for thematic analysis by two of the authors. This was done in three steps. Firstly, we familiarized ourselves with the data by reading the transcribed interviews several times and identified suggestions for codes (e.g. "security"). Secondly, we added specific codes to interview quotes (e.g. the code "privacy" for this quote "I'm not sure exactly what or when data is collected"). Thirdly, we created themes using affinity diagramming [5], where quotes were put on a bulletin board and reorganized into themes over several iterations. Unsurprisingly, during the interviews, the participants also talked about issues related to their electric car, such as range estimation or charging. However, these were excluded from our analysis as our focus was on connectivity related topics. As a result of this, three themes emerged; *interaction through connectivity, updating and upgrading car software,* and *security and privacy.*

The second interview round aimed at explaining the themes we uncovered in the first interview round further. We used the themes to form a more detailed interview guide for a semi-structured interview. Examples of questions asked in this round were why they used a certain device in a particular way and why it was important to them. The interviews were recorded on audio, with supplementary notes. We collected a total of ten hours of audio recordings and several researcher notes. These were transcribed and coded similarly to the first round of analysis. However, in the second round, we grounded our analysis in the themes we found from the first round of interviews.

FINDINGS

Unsurprisingly, during the interviews, our participants mentioned and talked about various issues not related to connectivity, which confirms previous research related to cars, like range estimation, charging, in-car interaction and driver distractions. However, we also identified themes that emerged specifically because of their connected car.

Our findings showed that our participants perceived their car as being different from cars with no connectivity. This perception was also evident for the seven households with both car types. Households referred to their electric car as a digital device and used words and phrases like *"computer on wheels", "gadget", "mobile computer", "device", "Internet of Things"* . Interestingly many of them saw their electric cars as an ever-changing product that would get or receive new functionality over time, as articulated by one participant: *"You really feel that the manufacturer of our car is more a software company than a traditional car company, because they release the software incrementally and often".*

In the following, we describe three themes that illustrate a set of aspects of the connected car that was important to our participants, namely (i) *interaction through connectivity*, (ii) *updating and upgrading car software*, and finally (iii) *security and privacy*. We have anonymized our households, and we refer to them as H1-H13 (as in Table 1). Occasionally, we refer to the number of households behind an observation, for example, (3/13) would mean three out of thirteen households or (2/5) refers to two out of five Tesla owners.

Interaction Through Connectivity

Our study showed that all participants interacted with their connected cars through mobile devices. To many participants, connectivity was a primary motivation for using their car. Some would talk about the car as being in an eco-system of devices that could interact together, and that was why they were more interested in using it. For instance, H4: *"When I get into my car, the whole thing is synced, and it just seems well integrated with my other devices, that is why I like it so much. For example, I can get statistics on my phone or my laptop and the infotainment system is synced with the audiobook I am playing on my phone".* Additionally, some would even argue that connectivity was essential in their decisions to buy the car and further perceived it as a gadget:

H1: *"It is really cool that the car can do all this stuff, that is one of the primary reasons why I bought the car. It wasn't cheap, but then again, gadgets aren't cheap".*

Most of them used smartphone or tablet apps to interact with their car (11/13), while a few of them used their desktop or laptop computers, but it was apparent that the convenience and availability of smartphone technology were preferred, as stated by H4: *"I mostly use the car app for my smartphone, because it's faster and I can do more things there than on my laptop".* A single household (H10), had installed an app on a smart watch that allowed them to watch the status (e.g. battery power) of the car. Although the use of it was limited, they liked using several devices and didn't like being restricted by device types: *"I have installed the app on my smart watch. It allows me to get a quick glimpse of the status of the car and I can get notifications such as when the car has a full charge. Sometimes I find myself limited by the smart watch app so I often end up just using my smartphone. However, I find it very important that the car has an app for most platforms and I like that I have several possibilities and that I'm not restricted to one type of device"*.

Smartphones were often used to interact with the car to get data or information on things like battery level, mileage, the car's physical location, or electricity charging status. For example, it was quite noticeable that many participants occasionally checked the battery level of the car from their smartphone while being away from the car, and sometimes the car also notified or informed household members on, for example, charging levels, and several participants found this very useful:

H11: *"We travel a lot, and when we sit at a café while the car is being charged, the car will contact us on the phone when it has sufficient battery power for the remaining journey and that makes the whole system smarter"*.

Some households (6/13) were aware of various aspects of their electricity consumption and checked information about their car so that they could do calculations such as current kilometer prices. They further explained that they had often done that in their old car by checking the dashboard, however, that required them to be in the car. It was more practical for them get information on their phone any time they liked.

Controlling the Car Remotely

Besides checking information and data about the cars, most of our participants (11/13) also used their smartphone as remote controls of functionality or features in the car. Often remote controlling was done out of convenience. We identified several scenarios where remote controlling using smartphone (or tablet) apps was quite convenient and practical, in particular for controlling the temperature in the car, or for controlling battery charging. We discovered (like several previous research studies) that battery charging is an important aspect of owning and driving electric cars. Our households would often use their smartphone to handle such aspects, such as remotely controlling the charging of the battery instead of going to their car:

H7: *"We have just got a new app for our electric car, and occasionally we use this app for battery charging while sitting in our living room"*.

Interestingly, in one of the households, the person that was using the car less frequently (from H5) was able to control and initiate the battery charging if occasionally forgotten: *"Sometimes I will start the battery charging if he (the husband) has forgotten to charge the car"*. Further, some participants used the app to control charging if they had specific needs, for example, charging beyond recommended values as illustrated by H4:

H4: *"Electric cars should normally not go below 20% of battery, but they should also not go above 80%. Accordingly, I have my car configured for that. However, if I need to go for a long drive, I sometimes use the app to override the 80% rule"*.

Another common use of remote controlling was to control heating or cooling of the car remotely, and several of the participants would, in fact, use this before entering the car, as stated by H12: *"During winter when I return to the airport from a trip, I'll put on heating in the car with my app as soon as I leave the aircraft, so the car is nice and warm when I get into it"* or articulated by H1: *"I don't use the app for many purposes, but the heating control in the car is cool. I use it very often during winter"*. Further, they mentioned that they used remote controlling as a mean to personalize the cars temperature settings. Besides the pleasure of getting into a warm or cool car, several of them mentioned that this was quite important for electric cars as it naturally requires a lot of electricity to either heat or cool the car, and when parked somewhere, their cars were often connected to a charging station and thus this would not use the battery to cool or heat:

H4: *"I always use the app preheating my car in the morning from my phone. I think this practical because it's already in the charger and then I won't waste any energy that should have been used for driving"*.

The five Tesla households found that the Tesla app was quite sophisticated regarding functionality, and all of them currently used or had tried to use advanced remote functionality for thing like unlocking their car or they had even tried to start the car remotely because they had forgotten their key at home. However, the app also had some unused functionality because Tesla owners couldn't see the point, as exemplified by H1: *"I use most of the app's features. However, it also has some functionality, such as, flashing its lights or honking the horn. I've only use them for showing off because it's something you do when you are in the car"*.

Manufacturer and Third Party Applications

We identified a difference between the car brands regarding smartphone interaction and apps. One brand (Tesla) included an open platform where third parties could develop applications versus closed platforms where only the car brand themselves could develop applications. For the latter, all electric cars came with a brand-specific application where our participants typically accessed data or remote control as illustrated in the previous section. However, some of the Tesla owners mentioned third party apps that could be downloaded and used in connection with their Tesla as Tesla provides an application programming interface (API) for third-party developers. A few of them (2/5) had experiences using such third-party applications.

H1: *"I bought this app developed by some local teenager where I can get more detailed charging statistics and functionalities, which is practical as we only charge one car at a time at our house",*

H1 had experimented with several different apps, and used these them to plan charging times, and to learn about specific charging patterns, which could not be done from the originally supplied app.

The non-Tesla car owners did not have access to third-party applications and therefore only used the manufacturer app that came with the car (8/13). Some of the non-Tesla owners were frustrated with the lack of opportunities to use third-party applications. For example, H3 knew that their car workshop could retrieve data from car components such as the battery, but it annoyed him that he could not access this data through an app and H4 argued that it would be nice to transfer planned routes from his smartphone to his car.

H1 had two electric cars, but were unable to interact with one of them remotely (a Renault Fluence) because the company that supplied the connectivity to their car had gone bankrupt. Therefore they were restricted to in-car systems interaction, as H1 explained: *"We can't actually use it (the app) since the company servers are no longer running"*. It resulted in them feeling restricted compared to their other connected car. This led to further questions for all the participants about if they had experienced any moments that resulted in apps that didn't work which interestingly, had occurred to everyone. This led to them being frustrated because they would lose functionality as they did not have any means to solving the problem:

H2: *"Well, sometimes my app doesn't work, that is annoying because then you lose all the functionality you know. Furthermore, you haven't got any chance of fixing it yourself. The only thing you can do is to contact the manufacturer"*.

Updating and Upgrading Car Software

As part of the electric car being perceived as a digital device, most households (10/13) knew that software was, or could be, updated in their cars. Interestingly, some participants related updates with their phone, and some of the problems related to it. For example, as said by H1: *"I always keep my car updated, I think it is more secure that way, like my phone or my laptop, you don't want a security issue that could compromise your safety",* and as articulated by H6: *"I know that some have had some issues with security in the past, however, honestly, I don't think about updating my car, I guess it is probably as important as your phone, after all it is connected to the Internet. However, it is just easier and more visible to do on the phone, because unlike my car, it just prompts me when an update is available"*. Interestingly, one of the participants did not care for updating, because they didn't feel comfortable doing it:

H2: *"I don't know if it is possible and I wouldn't really feel comfortable about updating the software in my car myself. I don't think I have the competencies to do it, I'm not that good with a computer, so I will probably just go to the repair shop"*.

Most participants would often link an update to getting new functionality. Particularly the Tesla owners (5/5) were quite aware what new features they received in the latest software update. However, some also knew or were aware of future updates that had fixes or security corrections:

H9: *"You get the update notification directly on the screen of the car, so I'm quite aware of new updates, you don't get that with our Leaf, and I'm actually not sure if I can update it myself"*.

Three of our Tesla owners enjoyed the driving assistance feature and how it got better with software updates. One of them (H10) experienced that their car got increasingly better at driving by itself (autopilot) through software updates. Others (H9) had experienced navigation improvements: *"Our cars navigation system has recently been updated, and it is much better now, before, it used to crash so I would have to reset the system"*.

The regular updates for Tesla owners were free of charge. However, they could also upgrade the car software with new additional features, for example, the Tesla autopilot, which cost money. All our Tesla households had bought the autopilot upgrade (two of them after a limited trial period), and this was somewhat expensive (3700 USD). Other households, such as the six Leaf and two E-Golf owners received software updates less frequently compared to Teslas, and in general they were less aware of what the software updates included, H9 stated: *"I think the repair workshop updates the car but we are actually never told, so I don't know when or if they update the car"*. Finally, three households had no personal experiences with software updates for their cars, and they were, in fact, unsure or skeptical of if this was even possible, as articulated by one of the households:

H6: *"I don't think the car ever gets the software updated. I can't say if there have been some minor updates because I haven't experienced them"*.

The households were rather different regarding how often, and when, they would update their electric cars. H1 normally updated as soon as possible due to interest in new features, while H2 had chosen to deselect service on the car, which meant that they didn't receive official updates. In general, software update frequency seemed to be influenced by two aspects for our participants. The first was ease of updating. The Tesla owners could update easily according to their perception, where they could use the app (or from the car) while others had to take their car to the repair workshop. H9 articulated: *"I am pretty sure that I have to take the car to the repair workshop to get an update, but I haven't tried it yet"*. The second aspects relate to new features or functionality. Some of the households were more positive towards updates if they received new functionality, and it was easy for them to d. As expressed by H11: *"I love that I can update my car, it's really simple just clicking the update button, it makes me do it every time. Then it can suddenly drive or park by itself, makes me look forward to the next update"*.

Installing Updates

Households mentioned two ways that software updates could be installed, namely wirelessly or manually. Again, these two ways were closely related to car model. Updating the car software wirelessly involves receiving updates through an Internet connection, and this was only relevant for our Tesla participants. Three of five Tesla households said that these updates prompted them (through the app or in the car) and that updating would typically take up to 1.5 hours where the car would be unavailable. Not surprisingly, they all preferred to update the car software during the night or at other times when they did not use the car, as explained by H1: *"We can't drive it while it's updating, but it is not a problem because normally we install software updates for the car during the evening or night where we don't use the car"*. In contrast, the manual updates for the other cars took place either at their repair workshop in connection with regular car maintenance or some would do it themselves manually (8/13) as explained by one of the households:

H3: *"I have to visit the repair workshop to get the latest updates. I have learned this because I know the mechanic at the workshop. Then the car will be unavailable for several hours. However, I can do some updating myself such as updating the GPS system, but then I must use memory cards to transfer data. I don't think it is worth the hassle"*.

H1 even tried to make an unofficial and personal update to the software system in their Fluence. They modified the entertainment system as it was no longer working due to lack of network connection as the company behind went bankrupt. Five other households, some of the Leaf and Tesla households, had considered making similar installing modifications such as upgrading the in-car navigation systems. But they all articulated concerns and perceived it as expensive, and were afraid to lose benefits. As exemplified by H5: *"You can install software, it's just running Ubuntu. However, it's probably hard without voiding the warranty or losing some benefits like free charging, and I'm not willing to take that chance"*.

Surprise and Frustration

We found that the software updates sometimes caused participants to be frustrated or surprised, for example, when they experienced modified car behavior. For example, H5 articulated that the car autopilot suddenly changed behavior after a software update, where the autopilot radar identified oncoming traffic at a further distance than previously, which caused the car to automatically activate the brakes earlier. This change surprised them, and took some time to get used to. They also mentioned that their interactive dashboard would suddenly turn off:

H5: *"The dashboard would occasionally freeze, which meant that we could not see how fast we were going or see the status of the car. We had to pull over and restart the cars computer to make it work again. That was annoying and a bit scary, but I think they fixed it now"*.

Sometimes software updates would even remove existing functionality or features, which not only caused participants to be surprised but also caused them to be irritated or frustrated. As an example, H2 experienced a software update for their Leaf, where a feature for competing with other Leaf owners on mileage was removed, as articulated:

H2: *"I think they removed a feature where I could compete with other car drivers on how many kilometers I could go on one single charge. I am quite displeased with this because I used that feature quite often"*.

Security and Privacy

It was clear to most of the participants that in some cases there were security issues when interacting with their car through other devices. Many participants reflected on possible security issues of other digital devices (9/13). H1 articulated it in this way *"I think the car is safe enough and I'm not sure that you can hack it, but you could of course control some of its features by hacking the phone"*. Also, four of the six Nissan Leaf owners had heard of attempts of hacking their car model through exploiting insecure smartphone apps. H4 and H9 mentioned an error in the Leaf software system that allowed hackers to control basic functions such as the climate control or charging – H9: *"Nissan had some problems a while ago with their CARWINGS app, where you could control some car models by entering the serial number in its windshield"*. While this was already fixed in an update (which they've had to go to the repair shop to get), H4 said that this was one of the things that made them question security and quality of the software:

H4: *"It makes me question the safety and security of their systems, it's not like I wouldn't use the car, but I would probably think twice before using the app"*.

While some trust went into using the different apps from car manufacturers, Tesla driving households were more careful with which third party apps they downloaded and used due to the more open platform. While most cars only allow basic functions to be accessed and remotely controlled, like climate control and charging, Tesla allows controlling more advanced functionality through its API. Two Tesla households had experience with such third-party apps, but these apps required that their credentials, used for logging into the car were entered. H1 and H9 expressed concerns of having such information in several places, and that it requires trust in those who develops the apps, as stated by H9: *"I certainly don't like that my credentials are stored in several places, and I try to restrict the number of apps I use, because you never know if the developer knows anything about security"*.

Privacy Concerns

Almost all households (12/13) were aware that the different car manufacturers actively collected and used data. However, many had limited knowledge on what and when data was collected, and for which purposes it was used, as articulated by H12: *"I'm not sure exactly what or when data is collected, but I know must be quite a lot, because I think it is used improve the cars"*. H1 and H5 knew that data was used for updating software such as their Tesla's autopilot driving capabilities, while H3 expressed that they knew the car manufacturer was collecting data about their battery. However, it was still unclear to them, which data was collected. This resulted in frustration because they didn't know what the car maker could use those data for. We found, that some of the frustrations and uncertainties were due to lack of details in the car, that is, what manufacturers used data for, as expressed by H6: *"There is a prompt that says that it is synchronizing data, but I am not actually sure what it does, I just press OK. It's invisible to me. They could be using my data for anything without my knowledge"*. However, whether or not the car was sending or receiving data was perceived as unclear. Even though they had uncertainties about which collected data, all households found the thought of supplying data to the car manufacturers acceptable if the data was used for appropriate purposes (e.g. statistics or improvements), and was anonymized. They also expressed positive attitudes towards sharing data as this could benefit them, as mentioned by H1: *"I think it's perfectly fine that our data is used, for example, for predicting traffic flow. When you want some functionality, it's only fair that you contribute"*.

Several households (6/13) were concerned with sharing of certain kinds of data like location information because such data could be used for other purposes, as explained by H12: *"I think it's fine that my data is included in various statistics. However, I don't want them to track me or my segment to predict my habits and then sell those data to others"*. Some of them also agreed that location data could be used against them. H1, H5, and H11 mentioned that they would be unhappy if data about their location were handed over to others or even worse stolen:

H11: *"I would be unhappy if location data could be handed over to, for example, the police. They could use that to give me a fine. I don't think it's any of their business. It would be even worse if a thief got hold of them, then he could use it to see when I left my house."*

H11 had thought about this scenario a couple of times and were concerned with the implications. However, upon further reflection H11 said: *"Well, having all these data can also be positive. The same functionality could be used to protect my car. If stolen, I can just find it, because I can see where it is!"*.

Many households were already using car location to track and monitor each other in their daily routines, and they also reflected upon privacy issues. For example, in H1 and H5, they sometimes used the app to track when the other person in the household got off work and where they were. H5 explained that tracking location for them acted as a security mechanism in knowing where the other one was and that he/she was okay. H4 imposed stricter tracking rules of each other, and they argued that they never used the tracking feature because it was wrong to track each other. However, we didn't observe any occurrences of households trying to prevent data being collected, and there seemed to be a consensus that they had other devices that could be tracked, as articulated by H12: *"You can also track a phone. And you could argue that it is more interesting to track a phone than a car because that's always on me"*. One participant (H3) had quite strong opinions about collecting data and suggested that if data collection was optional, it could solve the problem: *"It's my car. I've paid for it. I think it's fine to supply data, but I want to be able to turn it off like I can on my phone"*.

DISCUSSION

Our study of connected cars revealed the three themes of *interaction through other devices, updating and upgrading car software,* and *security and privacy*. Our findings illustrated that to our participants the car is considered a device integrated into a larger eco-system of devices. In fact, sometimes the car was even being described as something like existing connected platforms such as the smartphone which have had the attention of the mobile HCI community for many years.

We believe that the findings from our study constitute a contribution to mobile HCI research on cars as connected devices. In extension of this contribution, we will in the following outline some considerations that might inform and inspire further research.

Supporting Continuous and Collaborative Interaction

It was clear that the car and related devices hold a lot of personalized information and settings unique to most users or households. However, what made the individual car even more personalized, was that many of the participants had an eco-system of devices and apps that they frequently used to interact with their car. For the connected car, the mobile phone serves a clear purpose of accessing information and data about the car, for example, battery level. We believe that existing systems could be further improved. However, we also see possibilities for other types of interaction such as continuous interaction [39] supporting migrating or synchronizing data between cars and devices.

Continuous interaction could integrate into car devices inspired by the functionality found in many devices today as for instance, Apples continuity [2], where activities can be continued from one device to another. Such functionality enables documents to be available on the phone, but also the tablet or the laptop. Furthermore, when we buy a new device, we have the option to import our settings, contacts, and applications, so that we can continue our interaction as it was the same device. We see the car as a similar device capable of continuous interaction, which is also indicated by users in a study by Raptis et al. [36]. For example, when we plan a trip on the phone, we can access that trip on the car's onboard navigation computer, the devices are synchronized. Further, we also see the possibility of synchronizing data between cars. For example, when owners buy a new car and instantly has access to his apps, services, driving data, and settings, just as if he was driving in his old car. Such scenarios are also relevant in new markets with car sharing, where drivers do not necessarily own a specific car. Further research could look into this area by exploring different possibilities for continuous interaction and perhaps find inspiration in multi-device interaction frameworks (e.g. [39]).

Our findings also indicated that our participants used several of the car's features for collaboration. We found that some used the build in features to support different practices in the home. For example, in one household the location of the spouse was used so cooking could start. In another household monitoring battery levels allowed the spouse that did not have the car to start charging if forgotten. We see collaborative interaction as being useful in various situations, such as household members that support remembering various tasks. Besides the cars' built-in features for collaboration, we also identified cases where participants would use apps that required that other users would report in data about things like traffic jams at the charging point. We see opportunities for further collaborative use and studies of the car both in-vehicle and with other devices inspired by current literature that is also exploring these challenges (e.g. [9,35,45]). We believe that there are further possibilities for collaborative interaction in driving situations that can assist drivers, such as passengers helping the driver or even drivers helping other drivers. Furthermore, we see a possibility for enhancing the experience of more novel technologies, such as autonomous vehicles in situations that does not require full driver attention.

Managing Changing Functionality

Our study revealed that Tesla owners had a high awareness towards updates and had experienced it several times. It also revealed that sometimes they would get updates, that altered the behavior slightly. For example, one of our Tesla owners had experienced unexpected behavior from the autopilot so that functionality also had to be slightly relearned. However, the car is an advanced piece of technology, where the functionality of its components is often considered critical to reducing crashes. Studies in HCI has already addressed this area, arguing that changing software without informing the user challenges their mental model (e.g. [3,15,27]). This presents a challenge because altering software to do something different could increase the driver's mental workload, and therefore could pose a safety risk. Another dimension is how much change users are willing to accept, which is also indicated by Lyrra and Koskinen [27]. Research into this area could investigate how updating the car could have an effect on the user, possible restriction, ways to inform the user about system changes, and if specific contexts are relevant to this.

It seems that visibility of updates was important to our participants. For example, Tesla owners would look forward to updating wirelessly and knew that they would receive additional functionality. Some of our non-Tesla driving households knew of updates but were unsure how got them and what functionality had changed. The only way for them to get an update was at the repair shop to get an official manufacturer upgrade. Surprisingly, most participants only thought about updates as getting functionality. Thinking straightly in functionality can be a problem because updates are also important for getting the latest safety and security features [32,43]. A simple solution to this problem is to install updates automatically. However, research has shown that this is not always the proper solution for every user, for example, the ones that want control [43]. Research into how to distribute software and which interfaces and information should present updates presents a challenge that we believe will need exploration.

Facilitating Security

Many of our participants didn't think of their car as something that could be compromised or hacked. Surprisingly, they could reflect on it after they showed us how smartphones and computers were a part of their interaction with the car. To some of the participants, the idea of a compromised car was very real, and it would seem like it was most apparent to the owners of car models with more advanced features. While it hadn't happened directly to any of the households, they had heard of incidents where phone apps were exploited, which made it possible to hack cars. Awareness towards digital security is not a new phenomenon in HCI (e.g. security on the Internet), it is important to consider how to create a secure environment for novices or users with less technical knowledge.

With an increasing amount of data is transferred, it is perhaps also important to consider needed data for the manufacturer which is not only important in relation to more technical aspects such as bandwidth and storage but also trust from the users. One of our participants was quite skeptical about the data he could see and knew that there must be more data than he could get from the various displays, which frustrated him to overcome such issues. Further research is needed in this area, however, as a starting point researchers could look at the car and compare it to HCI research of other connected mobile devices, such as smartphones.

We found that households were aware of manufacturers actively collecting data and using it for various purposes, such as making new updates. The general tendency was that manufacturers collecting data were acceptable. However, many of the households were unsure exactly what data was collected, and to some this caused frustration. While many of the households trusted manufacturers not misusing data, some of them agreed that some types of data, if leaked, would be harmful. Similar concerns from users are also represented in the literature concerning other devices (e.g. [4,20,28]) where users sometimes want to hide data such as location. The solution, however, as suggested by one of our participants, could be to simply have options, like occasionally hiding their location, which is also supported by Mancini et al. [28]. We propose that researchers look further into such issues, and more importantly, what needs to be controlled by the user and what can be collected automatically. However, to achieve this, a deeper understanding is needed of issues such as trust, and how different contexts are sensitive to people and collecting data from the car.

CONCLUSIONS

We have presented an empirical study of 13 households with connected electric vehicles. We explored the car from the perspective of it being a connected, mobile digital device. We conducted interviews with participants, and through thematic analysis we identified three themes of *interaction through connectivity, updating and upgrading car software,* and *security and privacy*, which described the use and importance of different devices in relation to connectivity and the car. We found that owners would often interact with their car through other devices, such as smartphone apps. Further our findings described how the car could get new functionality through updating and upgrading its software. Finally, our participants were sometimes frustrated by safety and privacy issues, such as which data sent to the manufacturer. To inspire and inform further research in mobile HCI with the connected car, we have discussed our findings under the three headings of *supporting continuous and collaborative interaction, managing changing functionality,* and *facilitating security*. We have discussed that mobile HCI research could consider research into how continuous and collaborative interactions can be supported in different contexts. Further, we discussed implications of changing functionality through updates and how research could consider mental load and trust to explore it. Finally, we discussed research into security and privacy and how mobile HCI research could begin to explore cars for inspiration in other mobile device research.

Our study has some limitations. Firstly, while all recruited households had at least two persons that lived in their own houses, we acknowledge that other types of compositions or housing, for example, singles or living in apartments, might have had an impact on the results of our study. Secondly, the recruited participants were early adopters of car technology and emerging technology in general. Again, this might influence how the perceive and use both their cars and the related devices when interacting with the car. Finally, we realize that many modern non-electric vehicles are also connected. Studies of these vehicles are therefore needed to reveal more domain specific areas.

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REFERENCES

1. Apple Inc. Apple CarPlay. Retrieved February 8, 2017 from http://www.apple.com/ios/carplay/
2. Apple Inc. macOS - Continuity. Retrieved February 8, 2017 from http://www.apple.com/macos/continuity/
3. Kenneth Majlund Ba h, Mads Gregers Jæger, Mikael B. Skov, and Nils Gram Thomassen. 2008. You can touch, but you can't look. In *Proceeding of the twenty-sixth annual CHI conference on Human factors in computing systems* (CHI '08), 1139. https://doi.org/10.1145/1357054.1357233
4. Louise Barkuus, Anind Dey, and Louise Barkhuus. 2003. Location-Based Services for Mobile Telephony : a Study of Users ' Privacy Concerns Location-Based Services for Mobile Telephony : a study of users ' privacy concerns. In *Proceedings of the INTERACT 2003, 9TH IFIP TC13 International Conference on Human-Computer Interaction* (INTERACT '03), 702--712.
5. Hugh Beyer and Karen Holtzblatt. 1999. Contextual Design. *Interactions*, January + February: 32–42. https://doi.org/10.1145/291224.291229
6. Mark Blythe, Andrew Monk, and Jisoo Park. 2002. Technology biogarphies. In *CHI '02 extended abstracts on Human factors in computing systems - CHI '02* (CHI '02), 658. https://doi.org/10.1145/506443.506532
7. Barry Brown and Eric Laurier. 2012. The normal natural troubles of driving with GPS. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems* (CHI '12), 1621. https://doi.org/10.1145/2207676.2208285
8. Stephen M. Casner, Edwin L. Hutchins, and Don Norman. 2016. The Challenges of Partially Automated Driving. *Communications of the ACM* 59, 5: 70–77. https://doi.org/10.1145/2830565
9. Mario Chiesa, Riccardo Toppan, Alessandro Branciforti, and Francesco Posca. 2014. Social parking. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (AutomotiveUI '14), 1–6. https://doi.org/10.1145/2667239.2667283
10. Riccardo Coppola, Maurizio Morisio, and Politecnico Torino. 2016. Connected Car : Technologies , Issues , Future Trends. *ACM Computing Surveys* 49, 3: 1–36. https://doi.org/http://dx.doi.org/10.1145/2971482
11. Cyriel Diels and Jelte E. Bos. 2015. User Interface Considerations to Prevent Self-Driving Carsickness. *7th International Conference on Automotive User Interface and Interactive Vehicular Applications*: 14–19. https://doi.org/10.1145/2809730.2809754

12. Ronald Ecker, Verena Broy, Andreas Butz, and Alexander De Luca. 2009. pieTouch. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services* (MobileHCI '10), 1. https://doi.org/10.1145/1613858.1613887

13. Google Inc. Android Auto. Retrieved February 8, 2017 from https://www.android.com/auto/

14. Nikhil Gowda, Kirstin Kohler, and Wendy Ju. 2014. Dashboard Design for an Autonomous Car. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (AutomotiveUI '14), 1–4. https://doi.org/10.1145/2667239.2667313

15. Brit Susan Jensen, Mikael B. Skov, and Nissan Thiruravichandran. 2010. Studying driver attention and behaviour for three configurations of GPS navigation in real traffic driving. In *Proceedings of the 28th international conference on Human factors in computing systems* (CHI '10), 1271. https://doi.org/10.1145/1753326.1753517

16. Ing-Marie Jonsson, Helen Harris, and Clifford Nass. 2008. How accurate must an in-car information system be? In *Proceeding of the twenty-sixth annual CHI conference on Human factors in computing systems* (CHI '08), 1665. https://doi.org/10.1145/1357054.1357315

17. Malte F. Jung, David Sirkin, Turgut M. Gür, and Martin Steinert. 2015. Displayed Uncertainty Improves Driving Experience and Behavior. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (CHI '15), 2201–2210. https://doi.org/10.1145/2702123.2702479

18. Dagmar Kern, Albrecht Schmidt, Jonas Arnsmann, Thorsten Appelmann, Nillakshi Pararasasegaran, and Benjamin Piepiera. 2009. Writing to your car. In *Proceedings of the 27th international conference extended abstracts on Human factors in computing systems* (CHI EA '09), 4705. https://doi.org/10.1145/1520340.1520724

19. Pierre Kleberger, Tomas Olovsson, and Erland Jonsson. 2011. Security aspects of the in-vehicle network in the connected car. *IEEE Intelligent Vehicles Symposium, Proceedings*, Iv: 528–533. https://doi.org/10.1109/IVS.2011.5940525

20. Robin Kravets, Güliz Seray Tuncay, and Hari Sundaram. 2015. For Your Eyes Only. In *Proceedings of the 6th International Workshop on Mobile Cloud Computing and Services* (MCS '15), 28–35. https://doi.org/10.1145/2802130.2802137

21. Steinar Kvale. 1996. InterViews: An introduction to qualitative research interviewing. *Sage Publications*: 129–140. https://doi.org/10.1016/S0149-7189(97)89858-8

22. Marc Landau, Sebastian Loehmann, and Moritz Koerber. 2014. Energy Flow. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (AutomotiveUI '14), 1–6. https://doi.org/10.1145/2667239.2667301

23. Key Jung Lee, Yeon Kyoung Joo, and Clifford Nass. 2014. Partially intelligent automobiles and driving experience at the moment of system transition. *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14*: 3631–3634. https://doi.org/10.1145/2556288.2557370

24. Gilly Leshed, Theresa Velden, Oya Rieger, Blazej Kot, and Phoebe Sengers. 2008. In-car gps navigation. In *Proceeding of the twenty-sixth annual CHI conference on Human factors in computing systems* (CHI '08), 1675. https://doi.org/10.1145/1357054.1357316

25. Sebastian Loehmann, Marc Landau, Moritz Koerber, and Andreas Butz. 2014. Heartbeat. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (AutomotiveUI '14), 1–10. https://doi.org/10.1145/2667317.2667331

26. Anders Lundström, Cristian Bogdan, Filip Kis, Ingvar Olsson, and Lennart Fahlén. 2012. Enough power to move. In *Proceedings of the 14th international conference on Human-computer interaction with mobile devices and services* (MobileHCI '12), 201. https://doi.org/10.1145/2371574.2371605

27. Antti K. Lyyra and Kari M. Koskinen. 2016. The Ambivalent Characteristics of Connected, Digitised Products: Case Tesla Model S. . Springer International Publishing, 57–69. https://doi.org/10.1007/978-3-319-43597-8_5

28. Clara Mancini, Yvonne Rogers, Keerthi Thomas, Adam Joinson, Blaine Price, Arosha Bandara, Lukasz Jedrzejczyk, and Bashar Nuseibeh. 2011. In the best families: tracking and relationships. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*: 2419–2428. https://doi.org/10.1145/1978942.1979296

29. Vince Mancuso. 2009. Take me home. In *Proceedings of the 27th international conference extended abstracts on Human factors in computing systems* (CHI EA '09), 4591. https://doi.org/10.1145/1520340.1520705

30. Andrii Matviienko, Andreas Löcken, Abdallah El Ali, Wilko Heuten, and Susanne Boll. 2016. NaviLight. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services* (MobileHCI '16), 283–294. https://doi.org/10.1145/2935334.2935359

31. Hidde van der Meulen, Andrew L Kun, and Christian P Janssen. 2016. Switching Back to Manual Driving. In *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Automotive'UI 16), 229–236. https://doi.org/10.1145/3003715.3005452

32. New York Times. 2016. Elon Musk Says Pending Tesla Updates Could Have Prevented Fatal Crash - The New York Times. Retrieved September 19, 2016 from http://www.nytimes.com/2016/09/12/business/elon-musk-says-pending-tesla-updates-could-have-prevented-fatal-crash.html

33. Nissan Motor. Nissan CARWINGS®. Retrieved February 8, 2017 from https://www.nissanusa.com/blog/carwings-app

34. Changhoon Oh, Jeongsoo Park, and Bongwon Suh. 2014. Gravity. In *Proceedings of the 16th international conference on Human-computer interaction with mobile devices & services* (MobileHCI '14), 519–524. https://doi.org/10.1145/2628363.2634226

35. Mattias Östergren. 2004. Sound Pryer: Adding Value to Traffic Encounters with Streaming Audio. In *Entertainment Computing - Icec 2004*. 541–552. https://doi.org/10.1007/978-3-540-28643-1_71

36. Dimitrios Raptis, Jesper Kjeldskov, and Mikael B Skov. 2016. Continuity in Multi-Device Interaction. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction* (NordiCHI '16), 1–10. https://doi.org/10.1145/2971485.2971533

37. Bryan Reimer, Anthony Pettinato, Lex Fridman, Joonbum Lee, Bruce Mehler, Bobbie Seppelt, Junghee Park, and Karl Iagnemma. 2016. Behavioral Impact of Drivers' Roles in Automated Driving. In *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Automotive'UI 16), 217–224. https://doi.org/10.1145/3003715.3005411

38. Alireza Sahami Shirazi, Thomas Kubitza, Florian Alt, Bastian Pfleging, and Albrecht Schmidt. 2010. WEtransport. In *Proceedings of the 12th ACM international conference adjunct papers on Ubiquitous computing* (Ubicomp '10), 425. https://doi.org/10.1145/1864431.1864469

39. Henrik Sørensen, Dimitrios Raptis, Jesper Kjeldskov, and Mikael B. Skov. 2014. The 4C framework. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '14), 87–97. https://doi.org/10.1145/2632048.2636089

40. Helena Strömberg, Pontus Andersson, Susanne Almgren, Johan Ericsson, MariAnne Karlsson, and Arne Nåbo. 2011. Driver interfaces for electric vehicles. In *Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (AutomotiveUI '11), 177. https://doi.org/10.1145/2381416.2381445

41. Johannes Tulusan, Thorsten Staake, and Elgar Fleisch. 2012. Providing eco-driving feedback to corporate car drivers. In *Proceedings of the 2012 ACM Conference on Ubiquitous Computing* (UbiComp '12), 212. https://doi.org/10.1145/2370216.2370250

42. United States Department of Transportation. Intelligent Transportation Systems - Connected Vehicle Basics. Retrieved February 7, 2017 from http://www.its.dot.gov/cv_basics/cv_basics_20qs.htm

43. Kami Vaniea and Yasmeen Rashidi. 2016. Tales of Software Updates : The process of updating software. *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*: 3215–3226. https://doi.org/10.1145/2858036.2858303

44. Volkswagen Group. VW Car-Net Connect. Retrieved February 8, 2017 from http://www.vwcarnetconnect.com/

45. Chao Wang, Jacques Terken, Jun Hu, and Matthias Rauterberg. 2016. Improving Connectedness between Drivers by Digital Augmentation. In *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct* (Automotive'UI 16), 135–140. https://doi.org/10.1145/3004323.3004339

46. Chao Wang, Jacques Terken, Bin Yu, and Jun Hu. 2015. Reducing driving violations by receiving feedback from other drivers. In *Adjunct Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (AutomotiveUI Adjunct '15), 62–67. https://doi.org/10.1145/2809730.2809736

47. Robert YIN. 2013. *Case Study Research: Design and Methods*. Sage publications.

6.4 Passenger Trip Planning using Ride-Sharing Services

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Abstract: Ride-sharing can potentially address transportation challenges such as traffic congestion and air pollution by letting drivers share their cars unused capacity with a number of passengers. However, even though multiple ride-sharing services exist and HCI research has investigated various aspects of their use, we still have limited knowledge on how passengers use ride-sharing services to plan their trips. In this paper, we study how passengers use existing services to support the activity of planning a trip. We report from a qualitative study where we participated in 5 rides and conducted interviews with 19 passengers about their use and opinions towards ride-sharing services. We found that planning a ride involves comparing individual preferences across a number of services which enabled participants to support finding a trip and handle challenges such as privacy and trust. Further, we discuss these findings and their implications for future HCI research in ride-sharing.

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Passenger Trip Planning using Ride-Sharing Services

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ABSTRACT

Ride-sharing can potentially address transportation challenges such as traffic congestion and air pollution by letting drivers share their cars unused capacity with a number of passengers. However, even though multiple ride-sharing services exist and HCI research has investigated various aspects of their use, we still have limited knowledge on how passengers use ride-sharing services to plan their trips. In this paper, we study how passengers use existing services to support the activity of planning a trip. We report from a qualitative study where we participated in 5 rides and conducted interviews with 19 passengers about their use and opinions towards ride-sharing services. We found that planning a ride involves comparing individual preferences across a number of services which enabled participants to support finding a trip and handle challenges such as privacy and trust. Further, we discuss these findings and their implications for future HCI research in ride-sharing.

Author Keywords

Ride-sharing; transportation; mobility;

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

INTRODUCTION

Ride-sharing is often suggested as an immediate minimal cost solution to address challenges such as increased air pollution or traffic congestion by tapping into the significant amount of unused capacity in transportation networks [5,17,44]. From a personal perspective, ride-sharing provides passengers and drivers with the opportunity to split travel costs such as gas, toll, or parking fees [15], but despite such benefits, ride-sharers still face a number of challenges. For passengers, one of these challenges is planning rides, especially if ride-sharing is only part of their full trip and other types of transportation has to be considered [15].

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Several online services have emerged over the last years supporting trip planning and ride-sharing, for example, UberPool [42], GoMore [16], and BlaBlaCar [2]. These services provide new opportunities such as ride-matching through the use of platforms such as the web, smart phone applications, and social networking, thus making it more accessible and attractive for individual travelers.

HCI research has studied different aspects of ride-sharing, such as, technical solutions supporting efficient ride matching or passenger-transfer algorithms (e.g., [9,10]), but also studies that investigate the value ride-sharing bring to different groups of people such as the elderly [30,39] or low resource populations [14]. Also, research into subjective meanings and use have exposed reasons why people do not use ride-sharing such as data privacy problems and lack of trust between drivers and passengers (e.g., [7,11,23]). However, even though several services exist and HCI research has provided valuable insights into how and why people ride-share through them, we still have a limited understanding how ride-sharing services are used, with respect to, how passengers exactly plan rides, which rides they consider using, if efficiency is important, and if other services and devices support ride-share planning.

In this paper, we extend previous work with an empirical understanding of how passengers use existing ride-sharing services and technologies to support planning of their trips. We are studying the use of existing services (e.g., social platforms and dedicated ride-sharing services) and why and how they use them. We present our results from a mixed methods study, where we participated in 5 rides and interviewed a total of 19 passengers. One of our primary findings of this study was that participants did not only use ride-sharing services to plan their rides. Surprisingly, they planned their rides across a number of services (e.g., multiple ride-sharing and transportation services) which enabled them to handle some of the challenges mentioned in the literature such as ride coordination, trust, and privacy. We present our findings in six themes that describe passengers' considerations towards planning a ride and the use of services to support it. Furthermore, we discuss these findings under three headings of facilitating partial and detour ride-sharing, passenger trust and privacy, and finally, facilitating interaction with multiple services. We discuss the implications of our research and how we can use them to inform and inspire HCI research and design of systems and services that support ride-sharing.

RELATED WORK

In the following sub-sections, we will unfold literature focusing on ride-sharing with cars. First, we explain the overall concept of ride-sharing and secondly, we describe HCI literature with ride-sharing focusing on passenger planning of trips.

Ride-Sharing History and Characteristics

As part of the growing "sharing-economy", ride-sharing refer to a mode of transportation in which individual travelers share a vehicle for a trip and split travel costs such as gas, toll, and parking fees with each other [15]. While several terms or concepts exist for this sharing of rides, such as car-pooling, hitchhiking, or peer-to-peer shared rides, we will in this paper use ride-sharing as concept to describe this. We will also like to emphasize that ride-sharing services are different from taxi-like services, such as Uber or Lyft, that likewise offer to transport people for a fee [9]. Despite this difference, we found that the word ride-sharing is often used for systems that have a more taxi-like nature.

Ride-sharing can be categorized in terms of two organizing strategies namely unorganized and organized ride-sharing [15]. Unorganized ride-sharing is ad-hoc (e.g., hitchhiking) and does often not scale well [15]. Organized ride-sharing, on the other hand, relies on agencies that provide ride-matching opportunities for participants. While unorganized ride-sharing has existed for many years, the more organized forms of ride-sharing were introduced by the U.S. government with the purpose to conserve fuel during WWII. However, ride-sharing became quite popular in the 70's [28], where people organized rides through communities using slip-boxes and bill-boards to exchange offers or requests [15,18]. However, for many years, ride-sharing was static in the sense that is, rides had to be arranged some time in advance beforehand, which wasn't very flexible or easy compared to private car usage [1].

Furuhata et al. [15] identified four types of ride-sharing patterns; i) identical (driver and passenger origin and destination is the same), ii) inclusive (passenger origin and destination is on the drivers route), iii) partial (the offered ride is only part of the passengers trip), and iv) detour (the driver has to take a detour in order to pick up the passenger). However, as Furuhata et al. further argue that many existing ride-sharing services fail to take into account that these ride-patterns exist and thus, matching drivers as if they are identical.

A key characteristic of contemporary organized ride-sharing is the widespread utilization of Internet-based digital services and platforms that allows ad-hoc planning and booking of rides [1,15]. With the latest breakthroughs in digital technology, we are seeing more and more services, that allows for a more dynamic way of organizing rides with very short notice or en-route, through common mobile technologies such as smart phones [1]. Several commercial examples of ride-sharing applications or services exist. For example, the services UBERPool [42], LyftCarpool [26] and BlaBlaCar [2].

Ride-Matching Optimization

Arguing that effective and efficient technology optimization is needed for people to adopt ride-sharing, a substantial amount of research addresses how to improve planning of ride-sharing from a technical perspective. Here we find several suggestions for algorithms that attempt to provide real-time sharing of rides. There have been suggestions for algorithms and systems where passengers can be matched with short notice or even en route (e.g., [9,10,43,44,46]). For example, Zhang et al. [46] present their service coRide, based on an algorithm which intends to reduce total mileage and gas consumption by matching passengers en-route and Cici et al. [9] presents a scalable online ride-sharing system for short notice booking. Further, Coltlin et al. [10] proposed a multi-hop heuristics that allows passengers plan transfers to match several rides in order to cover their full trip.

Ride-Sharing Experiences and Attitudes

Several papers argue that subjective meanings are important in mobility, e.g. Kaizer [20], or Steg [38], or Ziegler et al. [47]. As a result, HCI research has also focused on challenges and opportunities when creating future ride-sharing services. A number of HCI studies has investigated how various groups of people use ride-sharing services and the associated benefits and challenges [14,27,29,30,33,39].

Research shows that ride-sharing especially can benefit disadvantaged populations such as unemployed people, low resource people, or people from low socioeconomic status neighborhoods [13]. As examples, Dillahunt et al. [14] investigated how people with low income living in transportation scarce environments could benefit from using ride-sharing. They found that people with low income benefited from rich social interaction with drivers and other passengers. Likewise, Meurer et al. explored ride-sharing opportunities and obstacles for elderly and found that for this particular group of people, independence of mobility and decisional autonomy was considered important [29].

As technology has become an integrated part of ride-sharing and people use it to support arranging their rides, several studies have found challenges towards the adoption of it. For example, several studies indicate that trust in the driver and fellow passengers are important in the ride-sharing process but can be obscured through technology (e.g., [4,7,11,32,41]). For example, Morse et al. found that users were reluctant towards carpooling involving unknown drivers or passengers. They suggest a CarLoop interface that matches passengers and drivers that lives close together [32]. Other challenges towards ride-sharing that has been highlighted is sufficient users [24,34], monetary transaction concerns [13,21], privacy protection [23,40], and safety [8,41]. As an example, Dillahunt and Malone [13] found that even though there are social and monetary benefits for the users, the use of technology to achieve it (e.g., using mobile phones to pay) make people reluctant due to the fear of misuse of their personal information.

Even though several challenges exist towards ride-sharing, some research points in the direction of the opportunity to overcome them by integrating systems, such as social platforms, together with ride-sharing (e.g., [4,6,35]). As an example, Brereton et al. [6] suggests that integrating social platforms could also have a positive impact on trust between drivers and passengers along with the ability to support more agile ride-sharing.

STUDY

HCI studies on ride-sharing have revealed challenges that make passengers hesitate to ride with others such as trust and privacy. Despite these challenges, we know that ride-sharing services are being used by people to support planning of trips. However, we lack empirical studies that reveal how passengers are using these existing services to plan their trips and how it relates to the challenges and opportunities mentioned in the literature.

We have investigated the activity of planning trips through a mixed-methods study consisting of three phases. In the first phase, we participated in 5 rides and informally interviewed passengers about their experiences and use of ride-sharing services. In the second phase, we observed and conducted explorative in-situ interviews with 5 participants centered around planning a ride. In the last phase, we conducted semi-structured interviews with 10 passengers where we asked participants specific questions informed about the prior two parts.

Phase 1: Ride Participation and Interviews

We initiated our study with participation in five rides to get a feeling of the planning and booking but also to get an understanding of the ride itself – both seen from driver and passenger perspectives. The lead researcher of this paper participated in these rides.

We booked the rides through two popular services used in Denmark; GoMore [16] and Facebook. GoMore provides a fully integrated service [15] that allows users to manage rides (e.g., searching, different preferences for rides, and ratings) along with handling payments that are paid up front before a ride begins. The service is available as a web page and as a smartphone app (iOS and Android). GoMore charges a percentage (12,5%) of the passenger price to facilitate the service. Facebook is a social network with millions of users and several FB groups deals with ride-sharing and actively advertises ride opportunities. Facebook as a ride-sharing service is community driven [15] and organized through different groups where users post available rides. No ride management is offered and payment is negotiated individually, and usually handled after the ride is completed.

The lead researcher of this paper participated in all five rides where three were organized through the ride-sharing service GoMore and two rides through Facebook (see Table 1). We booked rides of one to three hours duration where the ride would have at least one other passenger (besides the lead researcher) and one driver. The driver and passengers were notified of the purpose of our participation beforehand for ethical reasons, but also practical reasons such as, avoiding that they would refuse participation. During the rides, the researcher engaged in conversation with the other passengers (and occasionally the driver) about ride-sharing, how they found this particular ride, how often they would ride-share etc. The rides and interviews were exploratory by nature and no specific interview guide was used. Rides were documented through researcher notes.

ID	Ride duration	Service	Passengers Gender (age)	Driver Gender (age)
R1	1h	GoMore	F (32)	M (39)
R2	2h30m	GoMore	F (28), M (32)	M (28)
R3	1h30m	Facebook	F (30), M (29)	M (35)
R4	1h	Facebook	F (18), F (19), M (27)	M (42)
R5	3h	GoMore	F (24)	F (31)

Table 1: Ride participation overview

Phase 2: Ride Planning Sessions

In order to achieve an in-depth and direct understanding of the ride-sharing planning and booking process, we asked each of the passengers from the previous ride participation if it would be possible for us to observe and interview them the next time they booked a shared ride. Five of them, R1:F(32), R2:(M32), R3:(F30), R4:(F18), and R4:(F19), agreed to participate. Each of them contacted us by email a number of days before they were to book their next shared ride, and we arranged for us to come and observe this booking. These observations were held at the homes of the five participants, and the observations and interviews took between 30 minutes to 1 hour and were arranged as informal conversational technology tours [3] for two reasons. Firstly, we wanted the participants to speak and reflect more openly on how they planned their trips and thereby also revealing any tacit knowledge. Secondly, we wanted to be able to get a richer and concrete understanding of which considerations they had when planning a shared ride and we observed the actual planning and booking and asked questions during this process. We audio recorded the conversations and interviews and also took notes for later analysis.

Phase 3: Semi-structured Interviews with Passengers

As a final approach to collect data and knowledge about the planning of ride-sharing, we recruited ten participants (six females) independent of the two prior parts for elaborating semi-structured interviews [22]. We selected participants from the following inclusion criteria: 1) gender, 2) ride frequency, and 3) occupation. Participants were recruited by contacting them directly on Facebook groups on ride-sharing and from GoMore communities. An overview of the participants can be found in Table 2.

We constructed an interview-guide based on the knowledge that we gained from the first two interviews of this study. Because we wanted to investigate ride-sharing in its real-life context, we based our interview guides on Yins [45] question forms (*how, what, where, why*). As an example, we included questions about "what" services were used, and "how" and "where" they were used. Additionally, we added questions about "why" a specific service was used for a purpose. Six interviews were held at the participants' homes or at their workplaces, while the rest of them were conducted through Skype as a video call [31]. The interviews lasted between 30 minutes and 1.5 hours.

ID	Gender (Age)	Average monthly rides	Preferred service	Occupation
P1	F (27)	2-3	Facebook	Sales ass.
P2	F (24)	5	Facebook	Student
P3	F (19)	8	Facebook	Student
P4	M (30)	1	GoMore	Physician
P5	F (26)	1	Facebook	Student
P6	F (26)	3	Facebook	Designer
P7	F (25)	3	GoMore	Student
P8	M (27)	1	GoMore	Consultant
P9	M (25)	1	GoMore	Game developer
P10	M (29)	2	GoMore	Student

Table 2: Overview of interview participants

Data Collection and Analysis

Data collection during the three phases was done using an approach where one phase would inform the next. In the first phase, the participating researcher took notes. The second and third phase was recorded on audio and documented through researcher notes. In the three phases, a total of fourteen hours of audio and several researcher notes was collected and further transcribed and coded separately for thematic analysis by two of the authors.

The data from the three phases were transcribed and processed in a similar manner. Firstly, we familiarized ourselves with the data by reading the transcriptions several times and identifying suggestions for codes (e.g., "driver negotiation"). Secondly, we added specific codes to interview quotes (e.g., the code "driver negotiation" for this quote *"I usually ask the driver if he can drive me to or close to my destination"*). Thirdly, we created themes using affinity diagramming [5], where quotes were put on a large whiteboard and organized into themes over several iterations. After analyzing the data from the first phase, an initial set of themes emerged which served as a point of reference for the second phase. The analysis of the second phase resulted in a set of six themes (similar to those in our findings section) describing how ride-sharing services are part of passenger's trip planning. Finally, the outcome of the third phase was a richer understanding, however, it didn't raise new themes.

FINDINGS

In the following sections, we will describe passengers' considerations towards planning a ride. We present our findings in 6 themes: i) *finding rides based on price, time, and place,* ii) *ride pick-up and drop-off negotiation,* iii) using public transportation to reduce uncertainty, iv) *Ad-hoc Handling of the Unforeseen,* v) *using social media to plan conversation topics,* and vi) *driver reliability and privacy.* All date presented have been anonymized. We distinguish between quotes belonging to the participation in rides and planning sessions (R) and semi-structured interviews (P). We further refer to them by index, for example, P1 means the semi-structured interview with passenger 1. Occasionally, we refer to the number of participants or observations, for example, (3/10) refers to three of ten interviews and (2/5) refers to two of five rides.

Finding Rides Based on Price, Time, and Place

All participants planned shared rides based on preferences on price, time, and place, and in fact in that particular order of importance. Most important during the planning of a future shared ride was the price. Some participants were university students and inexpensive rides were highly important to them as argued by one participant *"I'm a student and I don't have a lot of money, so finding an inexpensive ride is important to me"* **(P3)**. Other participants perceived alternative public transportation (particularly train rides) as unnecessarily expensive, but also complicated in terms of economical cost *"I never travel by train, I hate it. You can never figure out how much your trip will cost"* **(P4)**.

But planning a shared ride for our participants was a rather complicated process and involved using different and sometimes more digital online services. Several of them (8/10) liked the type of administration free service that Facebook provided. When booking through Facebook, they often found that prices would be cheaper, e.g. due to the fact that no administration fee would be charged as when booking a ride with GoMore. One participant expressed that even though the administration fee was negligible (12.5% of the total price), she would still use Facebook: "*I usually choose a ride on Facebook because it's cheaper due to the extra fee on GoMore. I know it's not a lot cheaper but the more you save the more you earn"* **(P3)**. Others didn't express a clear preference, and they did not mind the administration fee on GoMore, as it provided them with extra benefits such as advanced search functionality that would make them find a specific ride faster: *"Facebook might be cheaper at first glance. However, it might be easier to find a ride on GoMore, because the service saves me time and you know, time is money"* **(P6)**.

During our participation in the ride planning sessions, we observed an interesting degree of internalization of price knowledge. We found two approaches to judging fair prices. Firstly, we found an element of routine price judgment. A few participants (4/10) had an expertise from frequent ride-sharing and had over time learned the prices of familiar rides and they would use this knowledge in the planning process and in the selection of a ride. Several times, we had to ask them to clarify, why they exactly chose one ride over the other. This was clearer with the regular users of the ride-sharing services: *"I know roughly, usually within US $1, how much the price of the ride will cost, I've learned that on GoMore, so if I see an overly expensive ride in either service*

I'm not going to take that" (**P2**). Secondly, we found an approach where participants would compare prices across services every time (6/10). For most, comparing price was interesting and finding the cheapest price was a game. However, in one case (P6) we found that difference in trips would impact price judgement. P6 compared prices every time she planned a ride because she would often take rides to different parts of the country: *"I don't travel to a lot of different places and therefore it makes sense to me to compare prices on both ride-sharing and public transportation. For example, if I'm going to somewhere far away, it might be cheaper to take ride-sharing, but if I'm just going to the airport, with available public transportation it's sometimes cheaper to take the bus. However, you never know, because it'll also depend on the time of the day and the number of people traveling"* **(P6)**.

Price was not the only factor when planning a shared ride and choosing a particular ride. Unsurprisingly, it was quite clear that finding rides that fitted with their point of origin and their destination was crucial: *"Planning a ride is always connected with some effort because I have to compare each individual ride to my actual start and end point"* **(P10)**. As a consequence, we found that price was being perceived in different ways. For example, while everyone could talk about price as money, some of our participants also mentioned that the time and place for a ride also would have an impact on the total cost of the trip, especially when considering further transportation. Most participants (7/10) said that leveraging time and place against price was an important consideration to them for the total cost of their trip: *"Time and place is definitely important to me, if I can see that I can get closer to my destination on a ride that's a little more expensive, I'll choose it, that's a no-brainer, then I don't have to use public transportation for getting there"* **(P2)**.

Occasionally our participants were unable to find a suitable candidate for a shared trip, e.g. because it was too expensive or no trips for a particular destination, and to compensate for missing rides on one service, we found that participants would combine more services. But perhaps more significant, participants did not see the individual online services as distinct, because rides would occasionally be shared across several services. Interestingly, we noticed that one of our participants as a deliberate strategy, would combine the services and use the search functionality on GoMore to find a ride and then book it through Facebook avoiding the fee: *"I don't see it as two services. I combine them. I check for a ride on GoMore because it has better search functionality. Then I go book it on Facebook if it is available there also"* **(P7)**. However, we found that occasionally participants would be forced to compromise on the price, time or place of the ride if none were available: *"Sometimes a cheap ride just isn't available on a particular service, that sucks, then I have the choice of waiting for the right one to come up or to choose a more expensive, I usually end up taking the latter, but I don't like it"* **(P4)**.

Ride Pick-Up and Drop-Off Negotiation

Surprisingly, some participants (7/10) was using the ride-sharing services to negotiate with drivers about taking detours. As the ride-sharing services would sometimes lack available rides in certain areas (e.g., rural areas or suburbs). We found two strategies for coping with this which involved drivers to take detours; passenger ride requests and ride-negotiations.

As the first approach, we found that in contrast to drivers posting available rides online, for our participants, a strategy was to take the initiative and use the community features of Facebook to request rides. One participant explained: *"If no rides can be found, you can also put in a request for a ride on Facebook, like 'Hi, I'm seeking a ride for Aarhus on Friday, can anyone pick me up at a specific place'. Sometimes it works but you cannot count on it."* **(P4)**. This strategy would sometimes have a positive effect and drivers would contact them with available rides.

A second approach was to negotiate pick-up and drop-off locations with drivers when a ride was booked. Even though we did not see it during the observations, interestingly, in the interviews, we found that as another strategy to get around the lack of rides, some participants would actively try to negotiate with the driver to take a detour after booking a ride: *"Usually you cannot get to the suburbs of a city or to rural areas unless you're extremely lucky. However, sometimes you can negotiate it with the driver"* **(P8)** and "*I usually ask the driver if he can drive me to or close to my destination. I'm paying for it, why shouldn't I try to make it a little easier for myself*" **(P1)**.

To support negotiating with the driver, participants (6/10) explained that they preferred to use Facebook rather than GoMore for negotiating detours. To them, Facebook was perceived as an easier service to convince the driver to drop off or pick up participants at certain locations due to its messaging system. One participant had experiences trying to negotiate through GoMore:

"Sometimes I use the Facebook messaging system to negotiate with drivers about where I can get dropped off, I think it is way easier and faster than GoMore. I have tried writing to a driver on GoMore once about another drop-off point, but I never received an answer. When I got in the car with him, he told me that he didn't want to drop me off there. That was a complete waste of time. **(P10)**

Interestingly, some of the negotiating participants (3/10) avoided GoMore for negotiating the ride even though the service implements a messaging system. We found that it was perceived as being less attractive because it was perceived as a stricter or more official service: "*I don't negotiate with the driver through GoMore, it is not because you cannot do it, it has a messenger system, but I don't know if they are recording the conversation or anything, then I prefer Facebook, just writing them or sending an SMS*" **(P4)**.

It wasn't all participants who wanted to negotiate detours (3/10). Even though some of the participants would use Facebook for negotiating about drop off-points we also found that three of our interviewed participants perceived negotiating as a violation against traditional ride-sharing practices: *"I don't feel comfortable asking the driver to drive me somewhere, it's his car and after all he is doing me a favor of providing me a ride"* **(P9)**. However, all of the interviewed participants had experienced the driver asking them during the ride if they wanted to be dropped off somewhere specific which was perceived as alright, for instance: *"I have been asked several times about if I wanted to be driven home. The drivers are usually really sweet, but it depends on the situation and the number of passengers. It is really nice if it is night time to be dropped off somewhere safe rather than walking or taking the bus"* **(P2)**. We also experienced being asked if we wanted to get dropped off by two of the drivers in the rides that we participated in.

Using Public Transportation to Reduce Uncertainty

To most participants (9/10), a ride was only covered a partial amount of their trip and was sometimes connected with some uncertainty. During the ride participations, we asked passengers where they were heading. In all ride participations, we were heading to the same town, however with different destinations. We asked how they would get there when they were dropped off. Some were picked up by relatives, some walked, but the majority would use public transportation to continue their trip. This also seemed to agree with our following interviews and almost all participants (9/10) agreed that unless they could get a detour, they would normally use public transportation as a mean to cover the last distance of their trip. We noticed that planning the full trip (both ride and additional transportation) was a task, that required taking into account different services, ride options and preferences:

"Planning a ride is always connected with some effort, because I have to compare my preferences to the different ride opportunities" **(P10)**

*"It can be difficult to plan a ride. So yeah, you have to compare the different transportation services. You have to leverage the different rides to your own preferences and if the ride doesn't cover the full ride you also have to find a bus or another ride without waiting ages" (***R4***)*

Some participants (6/10) expressed that planning a full trip was connected with some uncertainty because of the availability of rides. However, this wasn't concerned with one-way rides, but rather return rides that couldn't be booked because there weren't any available: "*Normally I take a ride with the same driver (to work), then I know that I can return home. However, sometimes when going on a longer trip I have to wait with booking a return ride because rides are usually not available before at the last minute"* **(P3)**. While some would wait and book at the last minute (2/10), others preferred to have a plan (4/10), handled this by using public transportation services to complement the ride-sharing when booking the complete trip instead of only one way: *"Sometimes, while I'm booking a GoMore ride, I book a bus home right away through the public transportation portal, because then I don't have to go through the hassle of finding a last-minute ride later"* **(P4)**.

In contrast to longer trips, we found shorter common trips such as commuting was easier to plan. One participant used ride-sharing for commuting every week **(P3)**, she said that she used the same driver and that was easy to plan because work is usually within a fixed time frame (e.g., 8 hours a day). However, in some cases we found some shorter trips were still a problem, especially when the time frame was unknown. We found that participants would be reluctant towards planning a ride in the last minute because they were uncertain if rides were available: *"Normally on shorter trips I can book a ride home right away, but it depends on the purpose of the trip. For example, if I'm going to a concert that I don't know when will end, it's difficult to plan a ride beforehand. Then I'll just take a bus with frequent departures. I don't want to book a ride in the last minute because you never know if something is available in your area"* **(P7).**

To solve this uncertainty one participant argued that ride-sharing services should have a proactive recommendation service:

"Last week we visited this small theatre just outside of town. We ended up taking a bus back home because we didn't want to go through the overhead of booking a ride. It annoys me because I could see a lot of cars outside the theatre and I thought to myself, my smartphone can remind me to do things and know where I am and what I am up to through Googles services. Why can't GoMore then match me up with a driver automatically. I mean, I can't be that hard to figure out that I'm about to go home" **(P9)**.

Ad-hoc Handling of the Unforeseen

All participants (10/10) preferred to plan a trip beforehand, however, we also found that some planning was better handled ad-hoc as ride-sharing sometimes had unforeseen elements. Most planning could and was preferred to be done beforehand (e.g., booking a ride, choosing public transportation): "*I'm the kind of person that needs to know exactly how I will get there. It just makes me feel more relaxed"* **(P5)**. However, we also found that ad-hoc arrangements had to be considered, especially because ride-sharing isn't scheduled like with public transportation (e.g., no scheduled arrival times). This meant that if participants needed to take a bus when their ride was over, finding an exact departure time was done ad-hoc (i.e., finding departure times) by using their mobile phones:

"*I always plan my trip from home, and I know which bus to take when I arrive. However, I can't decide on a specific departure because you never know how long the ride will be. For example, you can be stuck in a traffic jam or the driver needs to go to a gas station. Therefore, I always plan a time-*

buffer and check public transportation services as the last thing before I get out of the car" **(P8)**

We found that participants had different devices to support them using the ride-sharing or public transportation services. We observed that passengers would often bring their mobile phone on the rides and we could see that some of them browsed available rides for their way home, while others would use their computer for booking rides, likewise some would use different apps for checking available rides or public transportation. Using different devices for planning a ride was more a matter of context to users. For example, to gain an overview and comparing different ride options participants would often use their laptop: *"I booked on the computer. I'm very conscious about it because I think it gives a better overview on a browser with more tabs open when you need to compare public transportation to GoMore and perhaps also Google Maps" (***R3***)*. On the other hand, smartphones were often used in an ad-hoc manner for last minute bookings outside or when in need of a ride:

"Often, I end up using the mobile phone (the GoMore application) to know how to get home while I'm on the way to my destination or for last minute bookings when public transportation isn't an option. The app is more convenient for me, it doesn't give me the same overview and I cannot compare prices as easily, but normally I am just interested in finding a further ride quickly" **(P2)**

Using Social Media to Plan Conversation Topics

All participants liked to engage in conversation during the rides and some (6/10) tried to support this by planning conversation topics beforehand. In the rides we participated in, we found it interesting that most of the people in the car were engaged in conversation and it seemed like they had spent time prior to the ride finding new topics to talk about. We followed up on these observations in the following interviews and most interviewed participants agreed that having a conversation in the car was more pleasant than silence: "*I think conversation is important when you ride-share, it makes the whole situation of you getting into a stranger's car a little more pleasant*" **(P4)**. While GoMore gave passengers the opportunity to choose a silent ride, people not talking or working was perceived as unnatural and more appropriate on a bus or train where there was a more natural atmosphere:

"I have experienced that people get into the car and put on their headphones which effectively excludes them from all conversation. If it was me, I would just take public transportation. That is just not natural to me. You wouldn't get into your friends' car and do that. You have the option to select it on GoMore and that's fine, then I can use it to avoid it" **(P6)**.

While participants agreed that conversation in the car felt natural, we also found that conversations could become shallow: "It's mostly questions such as 'where are you heading?' or 'what do you do for a living?', you know, the same questions, sometimes they can be a little shallow" **(R4).**

To support conversation, some of our fellow passengers admitted that they sometimes used the information available on Facebook as conversation starters. This was also the case for the participants that we interviewed:

"I've experienced several times, that people use social platforms to find conversation starters before they participate in a ride, for instance, this one time during a ride, a girl that had prepared questions from looking me up on Facebook. She asked me about my job as a furniture designer before I had told her about it, which was made the conversation more interesting" **(P6)**

Complementing ride-sharing services could benefit both passengers and drivers. In some cases, drivers had a hard time knowing which passengers to pick up and vice versa because pick-ups would often happen in crowded places. We found the solution to be quite simple. Passengers would cluster before a pick-up and sometimes drivers would have some prior knowledge about the passengers and how they looked. In our ride participation, we experienced that fellow passengers would approach us before a ride and know our identity. We found that this information was obtained on Facebook as an addition to what GoMore could provide them with: *"I sometimes experience that other passengers approach me while waiting on a lift. They have checked out my profile picture on Facebook even though I have booked through GoMore. That is sort of nice because I feel that by clustering we are doing the driver a favor"* **(P7)**. In a similar manner, some drivers would check out how the passengers looked so they would know who to pick up: *"Sometimes the drivers have checked out our pictures on Facebook because the one on GoMore isn't really useful. It's practical, then he doesn't have to drive around public places looking for strangers"* **(P6)**. We also found this to be true through our observations even though we didn't interview any drivers. We noted that in two of the rides that we participated in the drivers had information such as how we looked and our occupancy.

Driver Reliability and Privacy

We found that most (8/10) of the participants had trust issues towards drivers which were materialized as concerns about reliability and privacy. In the interviews, the participants initially expressed that they had no challenges towards trusting both drivers and passengers: *"I have no problem with riding with strangers, I assume they are here for the same reason as I am"* **(P2)**. However, our observations indicated that they would use some time looking at driver profiles and ratings. When confronted with these observations our participants were able to articulate the reason for them and interestingly, it turned out that our participants had learned to use the ride-sharing services as a mean to help them make this choice: *"I actually end up using a lot of time looking at driver profiles matching the different options. It creates a feeling of trust. Things like number of passengers in the car and ratings of the driver is important to me"* **(P6).**

One thing we found very important to our participants was that they wanted to have a prior knowledge about who the driver and the car before choosing a ride. This was to ensure that the driver could be trusted (e.g., if the driver was actually the person on the profile pictures). Several of them mentioned that this was especially important to them because they had prior negative experiences. We found that both Facebook and GoMore was used for gaining knowledge about the driver. We found that GoMore seemed to be the preferred service for choosing a ride with respect to the driver and car. GoMore would be used to get information about driver ratings, car type and the number of additional passengers, which was important to our participants especially if they needed to book a long ride. To one participant, booking a ride in a large car was especially important, because she had experienced several times that the car would be filled with people: *"I need to know the car type and the number of other passengers. I've been in a small, filled car several times, that's fine if you are going on short trips, however, I frequently go on longer rides and a fully booked car is just not comfortable enough and there's no room for luggage"* **(P5).**

Even though ride-sharing was considered as a mean for social interaction to many of our participants we found that there were certain data or information that was perceived private. Somewhat more interested in keeping the arrangements of fixed destination because they wanted to keep some privacy. However, it seemed that this was mainly a matter of judging the situation and the driver's intentions: *"Some time ago I was riding with this male driver. After he dropped off the other passengers he started asking me all of these creepy questions. When he asked me where I wanted to be dropped off I just found a place. I didn't want him to know where I lived. He even texted me afterwards, but it is easy to decline someone over the phone, it's more real if they know where you live"* **(P7).**

To our participants, there was a clear distinction between driver information on Facebook and GoMore. We found that verifying the driver was real could be a challenge on Facebook: "*You only know the driver from his profile picture(s). You don't know which car he drives in. You don't have the extra security that the GoMore service offers you*" **(P9)**. GoMore, on the other hand, had detailed information such as driver reviews, car, and passenger information. Interestingly we found that some participants (7/10) were using multiple services together to complement each other. For example, sometimes rides offered on Gomore were shared on Facebook. One participant said that when she found a ride on Facebook, checking it would always involve checking GoMore: *"I very much like the fact that you can see information about people on GoMore., You can find their profile. It gives me a sense of safety. I can see that they are 'real' people and I can kind of see who they are by looking at their Facebook pictures"* **(P6)**.

We found that options or statistics such as driver reviews, type of car, number of passengers was considered when choosing a ride. For instance, if the driver looked suspicious, picking a ride that had more than one passenger would make them feel safer: *"This is going to sound discriminating, but besides looking at ratings I usually look at a person's profile picture. If there are no other passengers and if the guy looks creepy, he's out!"* **(P1)**. To some of the participants (7/10) the choice of a reliable driver was important. We found that they had actually tried to book a ride through Facebook and then have the driver cancel at the last minute. It turned out that Facebook was perceived less reliable when choosing a ride because of the lack of information about driver statistics and information about the car. Especially the lack of ratings on Facebook was experienced as a problem: *"You don't have the same security on Facebook that you have on GoMore, because they don't offer any ratings. So, in the end, you don't know if the driver will actually show up"* **(P1)**.

DISCUSSION

Our study indicated many of the same challenges found in the literature (e.g., price [14] and trust [32]). However, we didn't see any particular signs of reluctance for engaging in ride-sharing. A significant finding towards this, was the fact that participants wasn't confined to single services or devices, but used many of them interchangeable or to complement each other, which indicate a interesting synergy. We believe that the findings from our study constitute a contribution to HCI. However, in extension, we will in the following sub-sections outline considerations that might inform and inspire further HCI research on ride-sharing.

Facilitating Detour and Partial Rides

Our findings indicated that ride-sharing services had support for planning rides. However, our observations and interviews also indicated that a ride often cannot be seen in isolation. For all participants, identical ride-sharing was the most uncommon type of ride-sharing. Instead we found two other types of ride-sharing; partial (the passenger must arrange additional transportation before or/and after the ride) and detour (the driver has to take a detour to pick up the passenger). As a consequence, we found an additional complexity where the participants used resources to support plan their full ride. For example, some used resources on finding additional transportation or by negotiating with drivers. This is also backed up by Furuhata et al. [15] who argues that most services today only support identical ride-sharing.

Previous work on ride-sharing has had a strong focus on the creation of new and more efficient systems. An obvious question is which type of ride-sharing service is better in supporting the users. We argue that both services that we studied have their values. Facebook groups were valuable for informal ride-sharing with no fees and for negotiating with drivers. In contrast, GoMore more advanced search features supports quickly finding rides that matches passenger preferences such as driver and car type, which was perceived as contributing to a greater feeling of trust. In the case of both services, we also found drawbacks and reasons to not using them. However, even though there are arguments for and against each system, the real value to our participants could be found in the combination of them to support the activity of planning. It seems like supporting the users in different types of ride-sharing can be a valuable addition to most services and further, to get more people to ride-share.

Supporting Passenger Trust and Privacy

Research on technology use in ride-sharing have found that the passenger's trust becomes an issue when they don't know the driver or passengers beforehand (e.g., [14,40]). We also found that our participants were reluctant to give too much information about themselves while participating in rides, but on the other hand, they liked to have some prior knowledge about the other passengers and drivers. In a study by Tahmasseby et al. [40] where they implemented and studied a carpooling service, they found reluctance to participate in ride-sharing from drivers that didn't want to share too much information about themselves to find passengers. Interestingly, we found the opposite thing, passengers did not want to share information about themselves with drivers which compared to our findings seems like a paradox. However, research have suggested that the use of social media could overcome this barrier and ensure trust amongst ride-sharers [4]. We partially agree as we found that social media alone wasn't enough to ensure trust (e.g., is the driver profile fake). We therefore suggest that social media could be used to complement existing ride-sharing services with driver verification.

As we found, our participants often had concerns about the reliability of the ride-sharing services, such as availability of rides and if drivers would show up. Reliability of ride-sharing and ensuring that rides are available is also indicated as an issue in a number of papers (e.g., [1,15]). However, even though at first glance, this might seem as a challenge related to the users of the services (e.g., that there are not enough drivers), we found that our participants solved these issues by looking at the availability of rides across services (not only ride-sharing but also public transportation). Further, our findings indicated that it wasn't just providers of rides that could announce rides, but passengers could actively request rides or negotiate with drivers. Considering this, is seems that reliable ride-sharing could be considered in a larger context where planning a ride relies on passenger initiatives along with the use of several different types of services, complementing each other.

Interaction with Multiple Services

Studies have indicated a positive impact of combining multiple services in ride-sharing (e.g. social platforms [4,6]). Our study similarly indicated that social platforms such as Facebook can complement dedicated ride-sharing services and vice versa. However, our study also revealed that booking a ride was seen by participants as rather complex because it involved interaction with multiple different services and different contexts. For example, some used several services (e.g. ride-sharing, social platforms, and public transportation) to complement each other for cost matching and others moved between the service and device that fitted a particular context best, such as the laptop running at home for better overview and a smart phone while on the road. We believe that multi-device interaction is an important opportunity for the propagation of ride-sharing services and should be approached with the focus on users and contexts rather than specific applications, which is also discussed by Dearman and Pierce [12]. Moreover, we believe that such interactions can be approached from a designers' perspective by, for example, exploring different possibilities for interaction with an outset in the literature multi-device interaction literature.

Multi-device interaction in HCI is an area that has seen a lot of interest in recent years. For example, Lucero et al. [25] show how multiple mobile phones can be used in collaboration, and Nielsen et al. [33] shows how the screens of smart phones and tablets can be stitched together to make up a larger screen. We think that such examples can be used to explore new interaction possibilities. We have also seen suggestions for frameworks that explains different types of multi-device interaction. Such research can provide an opportunity to systematically explore how different types of multi-device interaction can support ride-sharing (e.g. [19,36]). For example, the "4C framework" [37] that illustrates 4 types of interaction with multiple devices. Using the 4C framework to explain our work, we have already seen examples of continuous interaction (where users move from one system or device to another). However, more importantly, we can also use the framework in future research to explain and explore new opportunities such as complementary or collaborative interaction. In a ride-sharing context, it becomes especially relevant when we do not only consider ride-sharing services but also the integration with public transportation services distributed over several services, devices, and contexts.

CONCLUSIONS

In this paper, we presented an empirical study of 19 passengers of ride-sharing and their use of ride-sharing services to plan their trips. Through analysis of a mixed-methods study with 5 ride participations, 5 planning observations and 10 semi-structured interviews we identified six themes that describe how ride-sharing passengers are planning their trips and which preferences they have for a specific ride. Our findings describe how our participants didn't only use individual services to plan their rides. Surprisingly, they planned their rides across a number of ride-sharing services which enabled them to handle some of the challenges they had in planning their rides such as finding a ride with the right price and with a trusted driver. To inspire further research in HCI with ride-sharing, we have discussed our findings under three headings of facilitating detour and partial rides, supporting passenger trust and privacy, and interaction with multiple services. We have discussed the implications of our findings and suggested that HCI research consider multi-device interaction as an important addition to ride-sharing services.

While we believe that our study provides insights into how passengers use ride-sharing platforms, we also acknowledge that driver experiences would be valuable to provide different perspectives on topics such as multi-device interaction. We therefore suggest further work investigating these dynamics, for example, how drivers and passengers engage in collaborative ride-sharing.

REFERENCES

1. Niels Agatz, Alan Erera, Martin Savelsbergh, and Xing Wang. 2012. Optimization for dynamic ride-sharing: A review. *European Journal of Operational Research 223*, 295–303. https://doi.org/10.1016/j.ejor.2012.05.028
2. BlaBlaCar. BlaBlaCar - Trusted carpooling. Retrieved September 12, 2017 from https://www.blablacar.com/
3. Mark Blythe, Andrew Monk, and Jisoo Park. 2002. Technology biogarphies. In *Proceedings of CHI '02 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '02), 658. https://doi.org/10.1145/506443.506532
4. John M. Booher, Balakrishna Chennupati, Nina S. Onesti, and David P. Royer. 2007. Facebook ride connect. In *Proceedings of CHI '07 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '07), 2043. https://doi.org/10.1145/1240866.1240947
5. Rachel Botsman and Roo Rogers. 2010. *What's mine is yours: How Collaborative Consumption is changing the way we live*.
6. Margot Brereton, Paul Roe, Marcus Foth, Jonathan M. Bunker, and Laurie Buys. 2009. Designing participation in agile ridesharing with mobile social software. In *proceedings of the 21st Annual Conference of the Australian Computer-Human Interaction Special Interest Group on Design: Open 24/7* (OZCHI '09), 257. https://doi.org/10.1145/1738826.1738868
7. Vineeta Chaube, Andrea L. Kavanaugh, and Manuel A. Perez-Quinones. 2010. Leveraging Social Networks to Embed Trust in Rideshare Programs. In *Proceedings of the 43rd Hawaii International Conference on System Sciences* (HICSS '10), 1–8. https://doi.org/10.1109/HICSS.2010.255
8. Blerim Cici, Athina Markopoulou, Enrique Frias-Martinez, and Nikolaos Laoutaris. 2014. Assessing the potential of ride-sharing using mobile and social data. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '14 Adjunct), 201–211. https://doi.org/10.1145/2632048.2632055
9. Blerim Cici, Athina Markopoulou, and Nikolaos Laoutaris. 2016. SORS. In *Proceedings of the 9th ACM SIGSPATIAL International Workshop on Computational Transportation Science* (IWCTS '16), 13–18. https://doi.org/10.1145/3003965.3003971
10. Brian Coltin. 2013. Towards Ridesharing with Passenger Transfers. In *Proceedings of the 2013 international conference on Autonomous agents and multi-agent systems* (AAMAS '13), 1299–1300.
11. Lisa Créno and Béatrice Cahour. 2014. Chronicles of Lived Experiences for studying the process of trust building in carpooling. In *Proceedings of the 2014 European Conference on Cognitive Ergonomics* (ECCE '14), 1–8. https://doi.org/10.1145/2637248.2637255
12. David Dearman and Jeffery S. Pierce. 2008. It's on my other computer! In *Proceeding of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '08), 767. https://doi.org/10.1145/1357054.1357177
13. Tawanna R. Dillahunt and Amelia R. Malone. 2015. The Promise of the Sharing Economy among Disadvantaged Communities. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (CHI '15), 2285–2294. https://doi.org/10.1145/2702123.2702189
14. Tawanna R Dillahunt, Vaishnav Kameswaran, Linfeng Li, and Tanya Rosenblat. 2017. Uncovering the Values and Constraints of Real-time Ridesharing for Low-resource Populations. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (CHI '17), 2757–2769. https://doi.org/10.1145/3025453.3025470
15. Masabumi Furuhata, Maged Dessouky, Fernando Ordóñez, Marc Etienne Brunet, Xiaoqing Wang, and Sven Koenig. 2013. Ridesharing: The state-of-the-art and future directions. *Transportation Research Part B: Methodological* 57: 28–46. https://doi.org/10.1016/j.trb.2013.08.012
16. GoMore. GoMore. Retrieved September 17, 2017 from https://gomore.dk/
17. Lisa Gransky. 2014. *The mesh - why the future of business is sharing*. Portfolio Penguin. https://doi.org/10.1007/s13398-014-0173-7.2
18. Volker Handke and Helga Jonuschat. 2012. *Flexible Ridesharing: New Opportunities and Service Concepts for Sustainable Mobility*. Springer Science & Business Media.
19. Heekyoung Jung, Erik Stolterman, Will Ryan, Tonya Thompson, and Marty Siegel. 2008. Toward a framework for ecologies of artifacts. In *Proceedings of the 5th Nordic conference on Human-computer interaction building bridges - NordiCHI '08*, 201. https://doi.org/10.1145/1463160.1463182
20. H. J. Kaiser. 2009. Mobility in Old Age: Beyond the Transportation Perspective. *Journal of Applied Gerontology* 28, 4: 411–418. https://doi.org/10.1177/0733464808329121

21. Esther Keymolen. 2013. Trust and technology in collaborative consumption. Why it is not just about you and me. *Bridging distances in technology and regulation*: 135–150.

22. Steinar Kvale. 1996. InterViews: An introduction to qualitative research interviewing. *Sage Publications*: 129–140. https://doi.org/10.1016/S0149-7189(97)89858-8

23. Airi Lampinen, Kai Huotari, and Coye Cheshire. 2015. Challenges to participation in the sharing economy: The Case of Local Online Peer-to-Peer Exchange in a Single Parents' Network. *Interaction Design and Architecture(s) special issue on peer-to-peer exchange and the sharing economy* 24, 1: 16–32.

24. Alan Lee and Martin Savelsbergh. 2015. Dynamic ridesharing: Is there a role for dedicated drivers? *Transportation Research Part B: Methodological* 81: 483–497. https://doi.org/10.1016/j.trb.2015.02.013

25. Andrés Lucero, Jussi Holopainen, and Tero Jokela. 2011. Pass-them-around. In *Proceedings of the 2011 annual conference on Human factors in computing systems* (CHI '11), 1787. https://doi.org/10.1145/1978942.1979201

26. Lyft. A ride whenever you need one. Retrieved September 12, 2017 from https://www.lyft.com/

27. Johanna Meurer, Dennis Lawo, Lukas Janßen, and Volker Wulf. 2016. Designing Mobility Eco-Feedback for Elderly Users. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (CHI EA '16), 921–926. https://doi.org/10.1145/2851581.2851599

28. Johanna Meurer, Martin Stein, David Randall, Markus Rohde, and Volker Wulf. 2014. Social dependency and mobile autonomy. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems* (CHI '14), 1923–1932. https://doi.org/10.1145/2556288.2557300

29. Johanna Meurer, Martin Stein, David Randall, Markus Rohde, and Volker Wulf. 2014. Social dependency and mobile autonomy. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems* (CHI '14), 1923–1932. https://doi.org/10.1145/2556288.2557300

30. Johanna Meurer, Martin Stein, and Volker Wulf. 2014. Designing Cooperation for Sustainable Mobility: Mobile Methods in Ridesharing Contexts. In *Proceedings of the 11th International Conference on the Design of Cooperative Systems (COOP '14), 27-30 May 2014, Nice (France)*. Springer International Publishing, Cham, 345–359. https://doi.org/10.1007/978-3-319-06498-7_21

31. Microsoft inc. Skype. Retrieved September 15, 2017 from https://www.skype.com/da/

32. Joshua Morse, Joshua Palay, Yarun Luon, and Satyendra Nainwal. 2007. CarLoop. In *Proceedings of CHI '07 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '07), 2073. https://doi.org/10.1145/1240866.1240952

33. Will Odom, Scott Jensen, and Meng Li. 2007. Senior travel buddies. In *Proceedings of CHI '07 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '07), 2079. https://doi.org/10.1145/1240866.1240953

34. Sungkyu Park, Jaram Park, Suyeon Cho, and Jaeyeon Won. 2017. Approaches to Successful Entry of the Ride-sharing Service for Startups. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (CHI EA '17), 1161–1169. https://doi.org/10.1145/3027063.3053340

35. Kenneth Radke, Margot Brereton, Seyed Mirisaee, Sunil Ghelawat, Colin Boyd, and Juan Gonzalez Nieto. 2011. Tensions in Developing a Secure Collective Information Practice - The Case of Agile Ridesharing. In *Interact'11*. 524–532. https://doi.org/10.1007/978-3-642-23771-3_39

36. Henrik Sørensen, Dimitrios Raptis, Jesper Kjeldskov, and Mikael Skov. 2014. The 4C Framework The 4C Framework: Principles of Interaction in Digital Ecosystems. 87–97. https://doi.org/10.1145/2632048.2636089

37. Henrik Sørensen, Dimitrios Raptis, Jesper Kjeldskov, and Mikael B. Skov. 2014. The 4C framework. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '14), 87–97. https://doi.org/10.1145/2632048.2636089

38. Linda Steg. 2005. Car use: Lust and must. Instrumental, symbolic and affective motives for car use. *Transportation Research Part A: Policy and Practice* 39, 2–3 SPEC. ISS.: 147–162. https://doi.org/10.1016/j.tra.2004.07.001

39. Martin Stein, Johanna Meurer, Alexander Boden, and Volker Wulf. 2017. Mobility in Later Life. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (CHI '17), 5716–5729. https://doi.org/10.1145/3025453.3025672

40. Shahram Tahmasseby, Lina Kattan, and Brian Barbour. 2016. Propensity to participate in a peer-to-peer social-network-based carpooling system. *Journal of Advanced Transportation* 50, 2: 240–254. https://doi.org/10.1002/atr.1326

41. Iis P. Tussyadiah and Juho Pesonen. 2016. Drivers and barriers of peer-to-peer accommodation stay – an exploratory study with American and Finnish travellers.

Current Issues in Tourism: 1–18. https://doi.org/10.1080/13683500.2016.1141180

42. Uber. UberCommute. Retrieved September 12, 2017 from https://www.uber.com/info/commute/
43. Xin Xing, Tobias Warden, Tom Nicolai, and Otthein Herzog. 2009. SMIZE: A spontaneous ride-sharing system for individual urban transit. In *Lecture Notes in Computer Science*, 165–176. https://doi.org/10.1007/978-3-642-04143-3_15
44. Huayu Xu, Fernando Ordóñez, and Maged Dessouky. 2015. A traffic assignment model for a ridesharing transportation market. *Journal of Advanced Transportation* 49, 7: 793–816. https://doi.org/10.1002/atr.1300
45. Robert K (Robert Kuo-Zuir) Yin. 2014. *Case study research: design and methods, 5th ed.* Sage publications. https://doi.org/10.1080/09500790.2011.582317
46. Desheng Zhang, Tian He, F A N Zhang, Mingming Lu, Yunhuai Liu, Haengju Lee, and Sang H Son. 2016. *Carpooling Service for Large-Scale Taxicab Networks*. https://doi.org/10.1145/2897517
47. Friederike Ziegler and Tim Schwanen. 2011. "I like to go out to be energised by different people": an exploratory analysis of mobility and wellbeing in later life. *Ageing and Society* 31, 5: 758–781. https://doi.org/10.1017/S0144686X10000498

6.5 Investigating the Use of an Online Peer-to-Peer Car S haring Service

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Abstract. Online peer-to-peer car sharing services are increasingly being used for enabling people to share cars between them. However, our body of knowledge about peer-to-peer car sharing is still limited in terms of understanding actual use and which opportunities and challenges present for those who use them. In this paper, we investigate peer-to-peer car sharing between car-owners and car-borrowers as facilitated by the Australian car sharing service Car Next Door. We conducted a study with 6 car-owners and 10 car-borrowers. Our findings, outlined in four themes, suggest that P2P car sharing fuels different goals for both borrowers and owners. While it is complementing traditional means of transportation car sharing is also in itself a mean of mobility, for example, for recreational purposes. Further, the sharing service plays a central role in supporting the users to make it more convenient to share cars, for example, by letting borrowers find and book cars instantly reducing resources needed to borrow a car. We further discuss our findings and relate it to existing literature providing opportunities and challenges for future research and design on car sharing in HCI.

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Investigating the Use of an Online Peer-to-Peer Car Sharing Service

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Abstract. Online peer-to-peer car sharing services are increasingly being used for enabling people to share cars between them. However, our body of knowledge about peer-to-peer car sharing is still limited in terms of understanding actual use and which opportunities and challenges present for those who use them. In this paper, we investigate peer-to-peer car sharing between car-owners and car-borrowers as facilitated by the Australian car sharing service Car Next Door. We conducted a study with 6 car-owners and 10 car-borrowers. Our findings, outlined in four themes, suggest that P2P car sharing fuels different goals for both borrowers and owners. While it is complementing traditional means of transportation car sharing is also in itself a mean of mobility, for example, for recreational purposes. Further, the sharing service plays a central role in supporting the users to make it more convenient to share cars, for example, by letting borrowers find and book cars instantly reducing resources needed to borrow a car. We further discuss our findings and relate it to existing literature providing opportunities and challenges for future research and design on car sharing in HCI. AQ1

Keywords: Car sharing · Sharing economy · Mobility

1 Introduction

Car sharing services enable new and promising ways for car-owners to share their cars with drivers who do not own one [21]. At the individual level car sharing offers the car-owners an opportunity to make money on their car and car-borrowers can get a car at a cheaper price than owning one. On a societal level car sharing offer to reduce the number of privately owned cars on the road [21, 34, 43]. Car sharing, which is a part of the sharing economy, has in the recent decade become increasingly popular [1]. Observers argue that this development is largely a result of the mediation or digitalization of sharing marketplaces [4, 20, 24, 39].

In HCI research, the sharing economy has sparked an interest in recent years [12]. A number of mobility-related studies focus on applications such as sharing rides and carpooling, modes of transportation where people can ride together (e.g., [11, 33, 46]). These studies highlight important aspects such as motivational factors towards making

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people participate in the sharing economy but also challenges such as the lack of trust in fellow sharers (e.g., [12, 36, 45]). Within HCI, car sharing has received little attention. Although areas such as social sciences have provided valuable insights into the use of car sharing, such as highlighting differences between owning and sharing cars (e.g., [9, 15, 32]), we still lack HCI insights into how emerging services are actually used.

Inspired by similar studies on other sharing economy platforms such as ride-sharing and accommodation, in this paper, we extend previous work in HCI on the sharing economy with an empirical understanding of a specific type of car sharing where cars are shared between car-owners and car-borrowers (P2P car sharing). As such, we investigate how and why people share cars, in which situations they share it, how they reflect on their own mobility, and what role the sharing services have. The research presented in this paper is based on a qualitative study with 6 car-owners and 10 car-borrowers that use the Australian peer-to-peer car sharing service Car Next Door [8]. Our findings, presented in four themes, suggest that car sharing services provide opportunities for both borrowers and owners of cars. On one hand, specific characteristics of these systems provide important support to create efficiency for example by reducing time spent when booking cars. As a result, car sharing is seen as a viable option to many other means of transportation and not just for shorter trips. On the other hand, our findings also suggest challenges exist such as the feeling of alienation for borrowers and owners when face-to-face communication is reduced. This led to a decrease in trust and as a consequence, coping strategies were used such as leaving personal objects to make borrowers take better care of the cars. Finally, we discuss our findings and implications that our findings have for future HCI research and design on car sharing and how it scales up in sharing economy in general.

2 Related Work

Although the sharing economy in general has gained an increased interest in the HCI community in the last 5 years [12], there is still a lack of research on car sharing. In the following two sections, we firstly unfold sharing economy in HCI, and secondly give an overview of the literature on car sharing.

2.1 The Sharing Economy

The sharing economy (with common synonyms such as collaborative consumption [4] and peer economy [3]) that focus on access to goods rather than ownership is becoming an increasingly larger part of our daily lives with an estimated global revenue of approximately 18.6 billion dollars in 2017 [38]. Sharing economy can potentially address the problem of finite resources or shared commons also described by [22] and [5]. Although sharing is not a new concept, observers tend to agree that recent development is largely a result of the mediation of the traditional sharing marketplaces to reach a wider population [4, 24]. As the sharing economy has evolved it now includes many different markets a definition has become a matter of interpretation and is not only restricted to sharing between people. As pointed out by Huurne et al. [24], the sharing economy today remains an umbrella term because it does not refer to a specific market but to different ones which include B2B, B2C and, P2P.

2.2 The Sharing Economy in HCI Research

An increasing amount of research in HCI involving sharing economy that focuses on the digitalization of marketplaces used for sharing. Towards this end, HCI studies focus on finding reasons for the participation in sharing like motivational factors such as sustainability concerns [30, 37], belief in the commons [11, 37], and social relationships between participants [11, 33, 46]. On the other hand, some HCI studies raise concerns and report on issues such as privacy and the lack of trust between strangers online (e.g., [10, 11, 30, 46]). Towards this end, some studies also report on challenges such as discrimination and exclusion (e.g., [10, 25, 33]).

A number of studies focus on existing applications within the sharing economy. Dillahunt and Malone [10] studied how sharing economy applications (e.g., Lyft, Airbnb, and TaskRabbit) can benefit unemployed or financially constrained people. They found a large potential in the disadvantaged communities, although digital literacy, privacy and security were seen as major concerns [10]. A number of papers investigate more specific applications in sharing economy. Towards this end, several papers exist on ride-sharing and car-pooling (e.g., [7, 11, 18, 33, 46]). Towards this end, Svangren et al. [46], provides empirical understandings of ride-sharing through GoMore and Facebook. They find that searching for and booking rides can be a complex task that involves leveraging several preferences and combining transportation options. A number of papers also exist on accommodation (e.g., [25, 26, 30, 36]). As an example, Qiu et al. [36] studied the role of how reviews impact trust in Airbnb and find that people's accommodation choices are highly subjective to information such as user reviews.

2.3 Car Sharing

Many years of HCI research have provided insightful knowledge about different aspects of the car, however surprisingly, car sharing in HCI, has received little attention. In this section, we will include literature from other areas to illustrate important findings on car sharing.

Car Sharing Overview. Car sharing refers to the concept of sharing cars between groups of people. In the literature, the term "car sharing" is often mistakenly used to describe a number of other sharing concepts [14]. However, in car sharing, it is the car itself is shared and is therefore different from other sharing schemes like ride-sharing or carpooling where it is a ride that is shared [14]. The first historical examples of car sharing describe informal and unorganized groups, typically in small communities such as between friends and family [35]. According to Shaheen et al. [43], one of the first attempts of a more organized form of car sharing was a small scale initiative started in Switzerland in 1948, by individuals that could not afford to purchase a car. Organized car sharing has evolved since then, especially since the introduction of the internet, which has sparked many different digital cars sharing services that today serves more than 7 million users worldwide [1]. Car sharing can seem similar to other businesses like car renting, however, although similarities exist, there are differences such as car sharing typically grants access to cars independent of the time of the day (e.g., users does not rely on office hours to get the keys) [43].

Car sharing as a concept is broad and covers several types of businesses [40], for example, while peer-to-peer (P2P) businesses facilitates sharing between car-owners and car-borrowers (e.g., the company Car Next Door [8]) other businesses fall into the category of business-to-consumer (B2C) where car-borrowers are borrowing cars directly from companies (e.g., the companies GoGet [19] or Zipcar [48]). Opportunities and challenges exist for each business. The P2P business potentially allows for a much greater spatial distribution of cars which potentially is anywhere car-owners live [42]. However, because people own the cars, they must also be returned to their original location after they have been borrowed, a model usually referred to as the traditional or round-trip car sharing which does not always fit into the travel patterns of the borrowers [27]. The B2C business relies on companies managing cars, however, to do this, the cars are often confined to fixed parking spaces or hubs spread across the city. The B2C business allows for different car sharing models such as free-floating car sharing where cars can be returned to any available spot owned by the car-sharing company [16]. The free-floating model has been adopted by several car sharing companies, however, although it is considered more flexible for borrowers it presents more organization overhead for the facilitating company, such as keeping track of cars [2, 31].

Car Sharing. Much of the existing research on car sharing focus on the ways it confronts the use of the private car [28]. Investigating the viability and usage of car sharing Duncan [15] finds that sharing cars requires a conscious decision and is often planned in advance. Further, the decision to car share depends on how the fixed cost of ownership is leveraged against the variable cost of sharing and because of this shared cars are used more consciously, for example, instead of a second car for the household [43]. Studies also reveal that car sharing is only part of an ecosystem of transportation options used by sharers. Small-distance trips that are not mundane are often in favor when choosing car sharing over other options [9, 32]. Motivation towards car sharing has also drawn interest. On one hand, instrumental or practical reasons such as saving money weigh heavily on the choice to car share rather than owning a car [15, 34]. However, on the other hand, some studies show that people who car share are also focused on more intrinsic reasons such as environmental consciousness and value initiatives such as carbon offsetting [9]. Most of the studies conducted focus on B2C car sharing with fewer studies specifically focusing on P2P car sharing. However, while the B2C car sharing has potentials such as cost reduction and efficiency, P2P has other qualities. Conducting expert interviews with experts on P2P car sharing, Shaheen et al. [42] found that besides monetary and environmental motivation to engage in car sharing, providing others with mobility was seen as important to P2P sharers and face-to-face communication in P2P car sharing was seen as important to create trust amongst participants. Studies also find that P2P car sharing has the potential to support wider car accessibility over traditional car sharing [21, 41, 42] and further improve interconnectivity between other modes of transportation [41].

Research within the computing literature tends to focus on more technical aspects of car sharing. For example, suggestions to improve access control systems [13] or demand modelling [23] for free floating car sharing. However, although car sharing is represented in the computing literature, there is still a lack of HCI studies on car sharing focusing on real-world applications and use of systems which have already been investigated in a number of other contexts within sharing economy (e.g., ride sharing and accommodation).

3 Empirical Study

Although research in many areas has focused on different aspects of car sharing, there is still a lack of HCI research that studies actual applications and provide insights about actual use. Responding to this gap, we have investigated digital car sharing services through a study of people using the service Car Next Door. In this section, we first describe the context of Car Next Door. Secondly, we describe our study method consisting of a three-step approach (gathering initial experiences, conducting interviews and walk through, and participant observations). Lastly, we describe data integration and analysis.

3.1 Study Context

Extending previous work on the sharing economy, in this paper, we present a study of how people from Brisbane, Australia use the P2P sharing service Car Next Door (CND) [8], and how they experience sharing cars. CND was chosen based on their status as one of the few P2P car sharing services in Australia and at the same time have a significant number of users and rentals.

CND is represented in many of the larger cities in Australia, although still a young company with a five-year-old history. The service started in Sydney in 2013, with 20 cars and 60 borrowers. In 2014, they expanded and included Melbourne and in 2017 Brisbane. By 2018 they count over 60.000 members, 1550 cars, and 2000 trips weekly across Australia. CND offers their service through an application for desktop and on smartphone on the mobile platforms IOS and Android. CND facilitates sharing between car-owners and car-borrowers. Cars are spread across town often near the owner's addresses. CND uses a traditional car sharing model where cars need to be returned to the place where they were picked up.

In addition to rational incentives such as offering low borrowing fees and a guaranteed income for owners, CND also promotes themselves on more intrinsic values. For example, they provide a social aspect as they are facilitators of car sharing between people (P2P), and they provide a sustainable aspect as they are investing in carbon emission offsetting through reforestation projects throughout Australia. CND has made a number of choices regarding their platform and includes technological features for both car-owners and car-borrowers. For example, they make sharing more convenient by providing instant bookings that requiring less time to get a car. Every car contains a lockbox for key handover, a GPS for tracking, a toll tag for automatic toll handling, and a fuel card.

When borrowing out cars, the service does not require interaction from an owner such as accepting bookings as these are automatically accepted. Further key handover is handled via the lockbox which is usually attached to the door of the car. As an extra security measure, the owner can follow the car's location through the app, however, only if the car is returned late. For borrowers, the CND platform offers transparency regarding user ratings and vehicle type, that is, the borrowed car and its ratings will be exactly the same as the one described when they book the car. In addition to regular car borrowing, CND also offers instant borrowing of cars which makes it possible to get a car with short notice. At the pick-up time, the car can be located through the CND mobile application where the GPS module provides an exact location of the car. When the borrower picks up a car, the car keys can be acquired by entering a provided pin code from the mobile application into the lockbox without face-to-face communication. Before and after the trip, borrowers are asked to take pictures of the car using the CND mobile app to document damages made before and after borrowing the car.

3.2 Study Method

In this section, we describe our study approach consisting of three methods. Firstly, we gathered initial experiences. Secondly, we conducted interviews and walk-throughs with car-owners and finally, we observed and conducted interviews with car-borrowers.

Gathering Initial Experiences. Initially, we conducted an exploratory investigation with the purpose of creating interview guides for owners and borrowers for later interviews. The first author booked and borrowed three cars through the CND mobile app. Different makes and types of cars located in different places in Brisbane were selected. For the first booking we borrowed a small size Holden Barina located in the center of the city, the second was a mid-size Toyota Camry located in the suburbs, whereas in the last booking we borrowed a large size Mitsubishi Outlander also located in the suburbs. We borrowed the cars for different periods of time. We borrowed the first car for two hours to go grocery shopping, the second car for a day to go to the nearby mountains, and the last car for a five-day period to go on a road trip. The experiences were documented in researcher notes and images. Most of the documentation was created at the time of the booking, pick-up, and drop-off point as most interaction occurs at this time. The first author shared his knowledge and notes with the remaining authors which lead to the creation of two interview guides used for semi-structured interviews [29] with owners and borrowers. Interview guides were based on Yins [47] four question forms (*how, what, where, why*).

Owner Interviews and Recalling Bookings. We explored car sharing from an owner's perspective by conducting semi-structured interviews with 6 owners. Through cooperation with CND we had access to their user email list that contained all users in and in the near vicinity of Brisbane, Australia. We deployed a questionnaire to all owners in the area asking if they were willing to participate in interviews. For sampling purposes, the questionnaire included questions about age, gender, address, number of cars in the household, number of cars on CND, and the number of times their car(s) had been borrowed out in the last three months. The questionnaire resulted in 7 candidates that were sampled based on an even distribution between questionnaire questions.

Candidates was emailed asking to participate of which 6 participants replied and were recruited. The six owners were between 26 and 69 years of age (M = 44.3) and equally distributed between male and females. Three owners lived alone, and three lived in families consisting of three, four, and six members. Four lived in houses and two in apartments. Owners had borrowed out their car between three and thirty times in the last three months and had been members of CND between four and fourteen months. Three had an additional car and three only had one car. To get a more in-depth understanding of the booking process from the owners' perspective, before the interviews, we instructed them to write down a short description of their specific actions and thoughts when receiving a booking such as checking out borrower information, rescheduling bookings, and checking payments. The owners were then instructed to bring these descriptions with them to the interviews. If no bookings were received before the interviews, we asked them to recall the last booking that they received. Interviews lasted between 45 min and 1 h and were recorded on audio. In addition, researcher notes were also taken. This resulted in a total of 4,5 h of audio and 8 pages of researcher notes.

Borrower Interviews and Observation. We explored borrower's perspectives by conducting semi-structured interviews with 10 borrowers. With an email list supplied by CND, we recruited borrowers through a questionnaire deployed to all borrowers in and in the near vicinity of Brisbane, Australia. The questionnaire was targeted borrowers who had borrowed a car at least once. For sampling purposes, we included questions about the number of cars borrowed in the last three months, if they owned another vehicle, and how many times a month they drove a car. The questionnaire yielded 21 answers from borrowers of which we selected 10 participants based on a distribution from questionnaire questions. The recruited borrowers (five female) were between 22 and 59 years of age (M = 40), and all lived in urban areas (e.g., city centers and suburbs). They had borrowed a car between one and six times within the last three months and had been a member of the CND service between five and eighteen months. Seven borrowers lived alone, three lived with their partner or families. Six borrowers were living in houses and four in apartments.

We asked the borrowers to give a short description of their last booking. We instructed them to give a short description of actions and thoughts such as looking up car and owner information, important booking criteria and reasons for borrowing. We further asked borrowers to bring their mobile phone for the interviews so that they could show us examples of how they booked a car. Owner interviews lasted between 45 min and 1,5 h and were recorded on audio and in addition researcher notes were taken. This resulted in 10.5 h of audio recorded and 20 pages of researcher notes.

3.3 Data Integration and Analysis

A total of 15 h of audio and 28 pages of researcher notes was transcribed, anonymized and coded separately for thematic analysis [6] by two of the authors. Firstly, we familiarized ourselves with the data by reading the transcriptions several times and specifically looking for use of the sharing services. We then identified suggestions for codes (e.g., "*convenience*"). Secondly, we generated codes to interview quotes (e.g., the code “*mundane car sharing*” for the quote “*Often I just borrow the same car down at the corner, I know all its quirks and I know the price. Besides I’m just getting the groceries and there’s a limit towards how much time I’m willing to put into it*”). Thirdly, we generated and reviewed themes using affinity diagramming, where quotes were put on a bulletin board and reorganized into themes over several iterations. As a final result of this, a set of four themes emerged.

4 Findings

We found that the car sharing service investigated in this paper (CND) was a significant contributor towards car sharing for both owners and borrowers of cars in a number of ways. In the following sections, we outline our findings in four themes describing opportunities and challenges associated using P2P car sharing. The four themes are; *Fueling Individual Motivation, Supporting Daily Mobility, Facilitating Car Sharing Purposes,* and *Socializing P2P Car Sharing Services.*

All data presented have been anonymized. We distinguish between owners (**O**) and borrowers (**B**) and refer to each participant by an index like **O1** as owner one and **B5** as borrower five. Occasionally we refer to the number of participants behind a finding, for example, (8/10) is eight out of ten borrowers and (4/6) is four out of six owners.

4.1 Fueling Individual Motivation

To some participants, rational motivation such as earning money of their assets was a motivation for car sharing, and to others. To others, ideological motivation such as reducing their carbon footprint was in focus. In the following sections, we describe the individual goals achieved through the platform for both borrowers and owners.

Utilizing Unused Assets and Environmental Awareness. For most owners (5/6) the primary motivation for car sharing was bound in rational motivation such as utilizing unused cars, while one owner’s primary motivation was more intrinsic as he felt like he was helping others. All six of them had at least one car that they used rarely and many of them found that sharing this car through CND would justify their ownership. Although owners were annoyed with own an unused asset, the car was generally perceived as necessary because of flexible mobility needs where alternative (public) transportation means didn’t always suffice. As such, several of the owners (5/6) were initially attracted to having an extra income from using CND. Some of them (3/6) had considered alternative solutions like selling their car, however the perceived extra value of owning a car along with the possibility of losing money kept them from doing selling it, for example, one owner mentioned that after having purchased a new car, altered personal living arrangements made the car less needed and used, as he argued this way:

> *“I moved here recently from Sydney. And so, because I live and work in the city my car is basically in my carport just carrying rust. And because it is quite new, I was looking at different options because I didn’t want to lose money by selling it”* **(O3)**

Most owners (5/6) also articulated a strong environmental awareness and car sharing made them reflect upon their own behavior and driving needs, for example one owner that had started cycling instead of taking the car every day: *"I mean now that I don't use my car I have started to cycle again, which has made me less depressed about the world and the problems that cars impose on the environment"* **(O4)**. Seven of the ten borrowers also mentioned environmental concerns was something that motivated them to car share. Further, almost all borrowers (9/10) mentioned, like some of the owners, that they felt more comfortable giving money to a company that they perceive as being facilitators of relationships amongst people, which they perceived CND to be, and not just in it for the business:

> *"It's partly price, and partly ethos. I would much rather borrow from a company that I trust is not just taking my money, and that is very good at one thing and is based on a relationship with people versus a bigger company that is a business of sharing or renting cars"* **(B4)**

Convenience and Helping Others. Mentioned by both owners and borrowers were the convenience that CND handled issues that otherwise would add complexity to car sharing (e.g., finding cars, insurance, communication, and payment). Convenience was a major motivational factor for the borrowers in relation to car sharing. All ten borrowers articulated that they could not completely live their lives without the use of cars, because alternative transportation forms such as buses or bikes could only satisfy some of their needs. Many of them (7/10) lived in the inner city with limited needs for daily car transportation. Here they had access to many public transportation options and bike lanes, and as a result, these seven borrowers did not own a car. The three remaining borrowers were living outside the inner city, however, still near their workplaces and did therefore not need a car on a daily basis. However, sometimes a car was needed for going out of the city or driving a long distances where other transportation types were insufficient. All ten borrowers found car renting using CND convenient as an easy alternative to get a car when they needed one especially because of cars being distributed across town, for example:

> *"... opposed to rental companies where you have to go to a place to pick up the car and do a lot of paperwork ... with this service, in less than 5 min, I can in most cases, find a car, book it, and pick it up"* **(B3)**

Community building was also found important for both owners and borrowers when using car sharing, and many of them felt that they, in fact, helped others from their community when either renting or renting out a car. In fact, one of the primary reasons for using a peer-to-peer car sharing service like CND was that sharing was between people rather than companies owning the cars. Owners stressed a personal feeling associated with the sentiment of helping those in need, i.e. people without a car. For example, **O2**, who were the one with the most borrowing of his car, explained that he started to car share to help others: *"I think that a lot of people is in a financial position where they can't afford a car and we are in a position where we can supply one, that just makes me feel good"* **(O2)**. Complementing this perspective, five borrowers mentioned that contributing to a community and the feeling of helping other people were reasons why they sometimes maintained borrowing a car:

"In my own imagination, I felt good about the fact that I'm contributing, that's why I keep doing it, I think. I know that he or she might be an oversee student and probably have the need for her car at the weekend, but it helped me feel good about myself. I felt in that case that I was helping this person because they were going to get some of my dollars" **(B6)**

4.2 Supporting Daily Mobility

Both borrowers and owners expressed the need to use many different modes of mobility to support their daily trips and that it required some degree of flexibility in order to be able to car share. The following sections we describe the reasons for choosing car sharing and some of the requirements for being a car sharer.

Transportation Types. We found that borrowers had a number of transportation types that they mentioned as being available to them and that they had to consider actively when going on a trip. Often public transportation, biking, or walking would fulfill their commuting needs for going to work or on smaller trips. However, these transportation forms were also perceived as impractical when carrying physical items like groceries. In such situations, the borrowers would consider renting or borrowing a car. As an alternative, some participants (5/10) mentioned that they had used taxi and ridesharing services. Although these services were perceived as convenient - the car would come to them and not vice versa – the borrowers also stressed that this depended on the specific trip, for example, it wasn't very well suitable for transporting larger or more personal pieces of goods:

"It's a choice depending on the trip. Sometimes I take a taxi or an Uber if I'm in a hurry and just have to go and see my friends in town. I don't think it's very suitable if you want to go shopping or want to just move some stuff. It's really only suitable for one-way stuff. For example, I don't want to be stuck outside the store, waiting for a cab. Then it's much more convenient to get a car" **(B10)**

Public transportation and taxi services were not seen as a viable alternative for trips like freighting larger goods, driving long distances, or going doing something extraordinary. For such purpose borrowers would, therefore, prefer to rent or borrow a car. In contrast to car sharing, car renting was seen as an expensive alternative even though some participants would use it from time to time. Most borrowers agreed that car sharing in some case were more practical over rentals because of price and distribution of cars instead of having to go to an office. Alternatively, if borrowers needed to borrow a car and it was beyond walking distance some borrowers (4/10) articulated that they would combine different transportation types which also meant planning and comparing them separately on each individual service:

"Sometimes, if you really want a specific car and you need to travel a bit to get it you need to find other means of transportation to get it. One time I had to take a train and then a bus to get a car, it was quite tedious because I had to compare departure times manually on each service. That would have been easier if CND would provide me an overview of the different transportation options instead" **(B1)**

Flexible Car Ownership. Occasionally owners would need to use their own car which they all believed required a degree of flexibility. Some (3/6) would book their own car and block out times on the service well in advance, while others wouldn't block out times unless it was absolutely necessary as they wanted to get as many bookings as possible. Most owners (5/6) had previously experienced unavailability of their own car in a situation where they actually needed to use the car. In those situations, they were forced to arrange other transportation forms. Interestingly, in relation to this, car sharing actually triggered self-reflection towards own transportation needs. Several of them (4/6) commuted to work using public transportation, a bike, or walking. Many owners said that before they began to share their car, they had often taken the car to work because it was seen as easier or as a subconscious choice than having to deal with alternative transportation. Joining CND however made them reflect on their actual needs:

> *"Car sharing requires a degree of flexibility, that's just embedded into it. There have been a few times where we have let the car be rented and haven't thought about it, it's not until a few days before that we think oops, we've got this on and we need two cars, but then I just use a taxi, or we can just work around it. It's good because it makes you think about your options"* **(O3)**

Also sharing in the household was seen as requiring flexibility which was not always shared. Some owners (3/6) expressed that they were more interested in sharing their car than the rest of their household and were motivated by different things. Owners living with a spouse and children expressed that the other family members often didn't share their enthusiasm about car sharing The reason was that even though the rest of the household thought that sharing was a good idea, they were less interested in being flexible partly because of the requirement to find another mean of transportation if their car was unavailable: *"We have four cars and we could easily make do with only two, but my wife and I are very different in terms of sharing and flexibility. She wants a car she can access and drive all the time, whereas I am much more inclined to work it out, but CND doesn't help you with it"* **(O2)**.

4.3 Facilitating Car Sharing Purposes

We found that borrowers used car sharing for many different purposes which can be categorized as ad-hoc and planned car sharing. In the following sections describe the specific purposes that car sharing is used for and how it is facilitated by CND.

Ad-Hoc Car Sharing. Borrowers typically rented cars for mundane purposes to support typical day-to-day transportation needs, e.g., grocery shopping. We saw a clear preference for getting a cheaper, and also older car, for these purposes. Such trips could often only be planned ad-hoc and were last-minute bookings. None of these borrowers exclusively used car sharing for mundane purpose, however, choosing car sharing over alternative transportation options was mostly associated with convenience and what is right for the moment: *"Now and again I find the kids want to go and do something and it's a little bit of a stretch on the bike and the city is not well set up for cycling, and there are some roads that I won't take the kids to ... it's just sometimes easier to borrow a car"* (**B6**). Ad-hoc planning and easy access to cars were important in such situations, and in case no nearby cars were available, they would often consider other transportation options or means:

> "*I got called into the hospital one day at 2:30 am, no public transport. I checked Uber, but there were no Ubers around, so it would be like 30 min. We had patients and I had to get there*

very quickly. I checked Car Next Door and the car that I normally take was available for the couple of hours that I needed it and I booked it and within seven minutes I had a car and was on my way to work. I work with humans, they will always come first, and just having that nearby made a huge difference in my ability to provide care. I came back and dropped the car off and I just walked home. It was brilliant" (**B5**)

Interestingly, we found that borrowing cars for mundane purposes and smaller trips would often result in borrowers attempting to rent a previously rented car. Several borrowers (5/10) reported that they had borrowed the same car near to them several times to save them the time of finding a new one: "*Often I just borrow the same car down at the corner, I know all its quirks and I know the price. Besides I'm just getting the groceries and there's a limit towards how much time I'm willing to put into it*" (**B10**). We found that reasons such as it was close by, were important for choosing car sharing over other transportation options. However, also important was familiarity with the car such as its location and its condition, in particular when going for a quick or short ride. To support these trips, we found that instant bookings were appreciated and perceived as necessary by the borrowers.

Planned Car Sharing. While mundane mobility needs were prevailing, borrowers would occasionally rent cars for extraordinary or special experiences, like renting an exclusive car, going on holidays, or on weekend trips outside the city. Our interviews revealed that many of these trips were for longer periods of time which indicate more use of car sharing than borrowers using it primarily for day-to-day trips. Opposed day-to-day trips, these were often planned well ahead and borrowers would often use the car sharing service to browse cars because they liked the experience. Several borrowers (5/10) mentioned that they used car sharing as a way to achieve extraordinary driving experiences by borrowing a more exclusive car than their own or a car that could impress others. Interestingly, we found that especially transparency in the service, where borrowers could see exactly which car they would get, the associated expenses, and the location was perceived as important for choosing car sharing:

"Yeah, because on CND you always can see which car model you will get, whereas all the usual car companies will just say this or similar, so you never really know what you will get most of the time" (**B6**).

Compared to day-to-day car sharing, borrowers were willing to put more resources into getting a car for a longer trip and would accept higher prices or going further to pick it up: *"I mean realistically if someone had one of those for hire (a Smart convertible) I would probably go an hour to pick it up. And even if, I don't know, $250 a day of something"* (**B6**). Several borrowers (6/10) mentioned that they had or thought about borrowing a nicer car just for fun and for showing off for friends or family. We found no preference for car age, as this mode was mostly associated with getting experiences, which could be from an older car as well as a new one. For example, **B1** mentioned that she had arranged to borrow an older convertible with her sons and going for a trip along the coast. Experiencing cars could also be associated with easing into car ownership. We found that two of the borrowers (**B2**, **B10**) knew that they had to buy a car in the future and therefore was trying out car models to see which one they liked the most.

4.4 Socializing P2P Car Sharing Services

Both borrowers and owners expressed that they were engaged in car sharing and were considering it actively in their daily lives. For example, to borrowers, the ability to access a car instantly was important and for owners the ability to not have too much interaction to borrow out their cars were important. However, the choice from CND to reduce this overhead from users also resulted in challenges

Efficiency vs. Interacting with People. One reason for many borrowers and owners using CND was the reduced overhead of not having to think about bookings, who borrows the car, who borrowed it out, the handling of practical things as payment were mentioned as a contributor towards using a service. All participants agreed that these things were best handled through the service and many participants mentioned that the complexity of handling these issues was too much for them if they were to handle it themselves, and thus, outsourcing this complexity to the service made car sharing a viable option for them in their otherwise busy lives: *"I think the service is really important, because without that I would worry too much, for example, about who borrows my car and if he will damage it its simply too complex, with the CND I know there's insurance so there's no risk in it for me, so in a way you could say that I've outsourced that part*" **(O3).** We found that many owners believed that too much management would simply exclude some borrowers because they would worry them too much and start looking up borrowers on the internet. For example, one owner mentioned that getting to know the person who borrows their car would simply start too many thoughts and be too complex for him and he, therefore, relied on CND to take care of it:

> *"My mind is so analytical and if I had to manage every booking myself then I'm going to think about what will happen if this person crashes my car and this and that. I don't have time for that. So, in a way, I'm outsourcing the job to Car Next Door"* **(O3)**.

Most borrowers (7/10) shared the same opinion as owners. Part of them wanting to keep communication to a minimum with the owner was to avoid the feeling of guilt and owner's reactions, for example if they called about car damage: *"The service is critical, I wouldn't have started with borrowing if I didn't know that CND has my back if something happened. I always call them if there is a problem. Imagine calling the owner and telling him that his car is broken. I would avoid that conversation because it's probably not going to be very pleasant"* **(B4).** Interestingly, and quite opposite, not all borrowers thought this way. To them (3/10) not having any communication between owners and borrowers was expressed as alienating and that the only connection between them was the car and as expressed as somewhat odd because usually them wanting to put a face on the one they were borrowing from and not only a profile picture from the app:

> *"In a way, I would like more interaction with the people that I'm borrowing from. I have some information about the person, I can find that the app and that is fine, but it is a little bit alienating. For example, there is this one woman that I'm borrowing from quite a lot, but I have no connection with the person except via the car, I find that a little odd because I would like to thank her personally"* **(B6)**

Cars as Personal Items. To several borrowers (8/10) a borrowed car was a personal item, important to the people owning them, and therefore they took extra good care of it compared to rentals:

> *"It's interesting you know, I never take particularly good care of rentals, but I always take extra good care of the cars that I borrow. The fact that it belongs to people makes me want to take extra good care of it I suppose"* **(B7)**

Interestingly some owners (3/6) tried to facilitate this as they believed that they needed not only to provide a car but also provide a good experience to borrowers especially due to the lack of face-to-face communication. Towards the owners had started to personalize the experience by leaving small items of personal value in the car to make borrowers feel a little more at home and to make them feel less like a stranger in someone else's car. This was seen as a less resource demanding action however still adding to the borrowing experience. For example, **O1** who often left candy and her CD collection in the car and **O5,** who often left a personal note and mints from her to the borrower in the car. Further, personalizing the car was seen as a mechanism to prevent damage:

> "*I always leave a little note and some mints in the car and just say, you know, that I hope that they enjoy our car and have a great trip or whatever. Although CND offers me some security by offering me insurance for damage, I don't want the hassle of sorting that out after it's happened. They are borrowing something that is a value to our family and if you can humanize that experience for them you might catch it before by them taking a little bit better care of your car*" **(O5)**.

Borrowing a car containing a few personal items were a positive experience and that a car feels more personal if it contains the owner's items which could lead to affection towards the vehicle. For example, borrower mentioned that his son was so familiar with a particular car both because they had borrowed it several times and because it contained some personal items familiar to him that he had given it a name: *"We've borrowed the same car a couple of times, and you know what, my son gave it the name Bob, because previously we had this car named Bob, and the new one reminded him of it because we had some of the same items in the car. So, in a way, you could say it became a part of the family which also made us take better care of it"* **(B4)**.

5 Discussion

Our study highlights several interesting aspects of P2P car sharing enabled through the digital service Car Next Door. For example, individual motivation and synergies between car sharing and alternative transportation forms can be highlighted as important.

Adding to these finding, in the following sections, we discuss considerations that we hope may inform and inspire further HCI research and design on car sharing.

5.1 Beyond Individual Modes of Transportation

In itself, car sharing provided transportation for many of our participants in their everyday lives. However, there were also a plethora of situations where car sharing was not perceived as being practical, for example, travelling the inner city to go to work. Car sharing has the potential to improve interconnectivity between other modes of transportation [41] however, a clear challenge is to know how and when to combine it sequentially with other transportation in order to do so. With regards to this, we think it is important to consider car sharing as part of a larger transportation ecology used by people. Ecologies are also suggested by studies of other areas of transportation available in a larger ecology where users combine the different options to fit their needs (e.g., [9, 32, 46]). Therefore, when complementing other mobility types car sharing fits into the daily lives of users and not the other way around. We argue to study car sharing as part of an ecology further, for example by drawing on inspiration from the literature describing fundamental interactions in ecologies (e.g., [44]).

One way of designing transportation ecologies could be letting them make an informed choice from a number of transportation types (e.g., bus, train, and car sharing) and letting them know when it is opportune to choose car sharing over other types. Further, going beyond choosing one specific transportation type is the opportunity for continuous [44] transportation where users can combine different types of mobility to form a larger trip. The opportunity to not only integrate other transportation types, but also other modes of car sharing services. We must remember that car sharing, and especially the type of car sharing we investigate in this paper (round-trip P2P), only provides one of many alternatives for users. For example, although our participants had said that they didn't use any other sharing services, it wasn't an active choice and they were definitely open towards open for other types like one-way ride sharing. We argue that research and design along these lines could be beneficial for the sharing services to support mobility.

5.2 Supporting Ad-Hoc and Planned Car Sharing

Our insight provides a dimension towards P2P car sharing, that is, ad-hoc trips which can't be planned in advance and further for purposes like getting groceries or commuting to work. This is different from many studies that suggest that borrowing cars are associated with smaller trips planned in advance (e.g., [9, 15, 32]), Interestingly, this describes a new and different dimension than what the literature provides. Ironically this can seem counterintuitive, that borrowers can borrow a car from an owner with little planning ahead. We argue that finding can largely be ascribed to the choices made by CND to make their platform more effective by reducing the amount of coordination between parties involved in sharing a car. Features increasing efficiency, such as instant booking, not having to interact with an owner to get the keys, and the large distribution of cars around town, which the CND platform supports, is closely related to the purpose of getting a car ad-hoc. However, although we think that designers should consider these mechanisms if aiming to support ad-hoc P2P car sharing, we see a need for further research to understand its potential.

Another insight from our findings is that car sharing often is associated with booking a car for a short period of time (e.g., [21, 42]). However, our findings also suggest evidence for car sharing being used for longer trips, that are mostly related to experiences or recreation. Interestingly, efficiency and planning become less important for borrowers of cars for these types of purposes. Based on our findings, it seems like supporting getting a car for experience or recreation requires an amount of transparency where a borrower can browse cars and get exactly the one wanted. Further, the experience of browsing through a number of options matching many and diverse cars available through a P2P platform is equally a part of the experience which reflects in our participants' willingness to travel a further distance or pay more to get the car. Besides this seemingly unique aspect of the design of P2P car sharing over other service schemes, we argue that this also presents researchers with an opportunity to inquire such uniqueness of P2P services, one that potentially could be a challenge for other services (e.g., B2C) where a more uniform car park could be preferred.

5.3 Coping Strategies and Social Car Sharing Services

What happens to trust when face-to-face communication is removed from a service? We found that borrowers took particularly good care of the cars they borrowed, mainly because of the feeling that it was a personal item to another person. This was facilitated by some owners that placed small personal items in the car to ensure a more personal experience and thus making the borrower take better care of the car. This is interesting from a trust perspective as it seems that traditional coping strategies (e.g., insurance) is not quite enough as owners still recognizing that damages happen and wanting to avoid the whole scenario of having to deal with the insurance. Trust between people is especially important and is one of the pillars in the sharing economy [4]. Trust is especially important in car sharing, where the shared object is of high personal value to many people. Shaheen et al., amongst other mechanisms for ensuring trust in P2P car sharing and finds that face-to-face communication is perceived as increasing trust and helping borrowers not damage cars [41]. Towards this end, CND does not provide the feature of face-to-face communication and we do think that they were quite happy about this choice as it saved them time. However, this also meant that some owners employed their own coping strategy to ensure that their car would not get damaged. Alternative coping strategies towards ensuring trust that the P2P services does not provide needs further exploration as it could give inspiration for future designs.

Car sharing can be seen as a way of utilizing existing resources which might fuel motivational desires as a contrast to acquiring new resources. This also goes well in line with the idea of utilizing the commons [5, 22]. One aspect is peoples' individual goals that in our findings both revealed rational (e.g., earning an additional income) and intrinsic (helping others and socializing) motivation. Rational and intrinsic motivation has been investigated before in P2P car sharing. As such, Shaheen et al. [42] reports on borrowers and owners motivation and finds that earning money and convenience as a key motivational factor and further, although less important, helping others gain access to a vehicle. Although acknowledging this finding, interestingly, we also found that for some participants this relationship was flipped around by showing helping others as a key motivation. We think that this relationship highly reflects and can be attributed the nature of P2P sharing which seemingly is one reason why our participants chose CND as a service along with the fact that P2P car sharing was believed to be creating relations between people and was thus seen as "less evil" than other car sharing types. Our results indicate that while some aspects of optimizing a service are valued as a mean to actually share, other more intrinsic motivational aspects such as maintaining relationships between people. The aspect of social services can be an interesting dimension for designers and researchers to explore for reaching people that thinks that social values are also important. We think that car sharing is ideal to provide a clear and lucid setting [17] for such investigations, although it might scale up in all aspects of the sharing economy.

6 Conclusions

This paper has presented a study on the use of P2P car sharing services. Through a study with 6 owners and 10 borrowers using the service Car Next Door, we identified 4 themes that describe different aspects of car sharing. Our findings reveal that P2P car sharing is convenient for many participants by allowing them to utilize unused assets and helping each other out. The service explored is used for different purposes supporting ad-hoc and planned trips which allow users to complement existing transportation options at hand. Lastly, it was seen as convenient that Car Next Door provides an efficient way to car share by allowing instant bookings and getting the keys without interacting with an owner. However, the lack of face-to-face communication was in some cases perceived as alienating along with reducing trust in the people borrowing although coping strategies were identified.

To inspire HCI future research and design of sharing services we discussed three themes to serve as an inspiration to researchers and designers of car sharing services. Firstly, we have discussed that car sharing is part of an ecology of transportation options and how this perspective can be used in the design of new services. Secondly, we discuss how ad-hoc and planned car sharing can be supported and considering the uniqueness of the P2P systems. Thirdly, we argue that P2P services are social car sharing services where alternative coping strategies are developed to handle trust when face-to-face communication lacks.

Our study has some limitations. Firstly, we have only recruited participants living in cities that were already using Car Next Door. We acknowledge that other participants could have been interesting in our study, for example, those who had deselected the service or potential users such as disadvantaged populations. Secondly, we have chosen a peer-to-peer service, however, we do acknowledge that other services exist different from the one we studied. Thirdly, car use and opinions vary depending on location, and so, carrying out a similar study in a different location, such as in another country, could yield different results. Finally, our results provide qualitative insights which are not generalizable across a wider population. As such, we acknowledge that other methods are required to provide statistical generalizability.

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References

1. ACEA and Frost & Sullivan: Number of car sharing users worldwide from 2006 to 2025 (in millions). https://www.statista.com/statistics/415636/car-sharing-number-of-users-worldwide/. Accessed 5 Sept 2018
2. Ballús-Armet, I., Shaheen, S.A., Clonts, K., Weinzimmer, D.: Peer-to-peer carsharing. Transp. Res. Rec. J. Transp. Res. Board **2416**(1), 27–36 (2014). https://doi.org/10.3141/2416-04
3. Bellotti, V., Ambard, A., Turner, D., Gossmann, C., Demkova, K., Carroll, J.M.: A muddle of models of motivation for using peer-to-peer economy systems. In: Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI 2015, pp. 1085–1094 (2015). https://doi.org/10.1145/2702123.2702272
4. Botsman, R., Rogers, R.: What's Mine is Yours: How Collaborative Consumption Is Changing The Way We Live. Collaborative Consumption. Collins, London (2010)
5. Brady, G.L., Ostrom, E.: Governing the commons: the evolution of institutions for collective action. South. Econ. J. **60**(1), 249 (2006). https://doi.org/10.2307/1059950
6. Braun, V., Clarke, V.: Using thematic analysis in psychology. Qual. Res. Psychol. **3**(2), 77–101 (2006). https://doi.org/10.1191/1478088706qp063oa
7. Brereton, M., Roe, P., Foth, M., Bunker, J.M., Buys, L.: Designing participation in agile ridesharing with mobile social software. In: Proceedings of the 21st Annual Conference of the Australian Computer-Human Interaction Special Interest Group on Design: Open 24/7, OZCHI 2009, p. 257 (2009). https://doi.org/10.1145/1738826.1738868
8. CarNextDoor: Car Next Door. https://www.carnextdoor.com.au. Accessed 5 Sept 2018
9. Costain, C., Ardron, C., Habib, K.N.: Synopsis of users' behaviour of a carsharing program: a case study in Toronto. Transp. Res. Part A Policy Pract. **46**(3), 421–434 (2012). https://doi.org/10.1016/J.TRA.2011.11.005
10. Dillahunt, T.R., Malone, A.R.: The promise of the sharing economy among disadvantaged communities. In: Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI 2015, pp. 2285–2294 (2015). https://doi.org/10.1145/2702123.2702189
11. Dillahunt, T.R., Kameswaran, V., Li, L., Rosenblat, T.: Uncovering the values and constraints of real-time ridesharing for low-resource populations. In: Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, CHI 2017, pp. 2757–2769 (2017). https://doi.org/10.1145/3025453.3025470
12. Dillahunt, T.R., Wang, X., Wheeler, E., Cheng, H.F., Hecht, B., Zhu, H.: The sharing economy in computing: a systematic literature review. In: Proceedings of the ACM on Human-Computer Interaction Article, vol. 1, no. 26, pp. 1–26 (2017). https://doi.org/10.1145/3134673
13. Dmitrienko, A., Plappert, C.: Secure free-floating car sharing for offline cars. In: Proceedings of the Seventh ACM on Conference on Data and Application Security and Privacy - CODASPY 2017, pp. 349–360 (2017). https://doi.org/10.1145/3029806.3029807
14. Dowling, R., Kent, J.: Practice and public–private partnerships in sustainable transport governance: the case of car sharing in Sydney, Australia. Transp. Policy **40**, 58–64 (2015). https://doi.org/10.1016/J.TRANPOL.2015.02.007
15. Duncan, M.: The cost saving potential of carsharing in a US context. Transportation (AMST) **38**(2), 363–382 (2011). https://doi.org/10.1007/s11116-010-9304-y
16. Firnkorn, J., Müller, M.: What will be the environmental effects of new free-floating car-sharing systems? The case of car2go in Ulm. Ecol. Econ. **70**(8), 1519–1528 (2011). https://doi.org/10.1016/j.ecolecon.2011.03.014

17. Garfinkel, H.: Ethnomethodology's Program: Working Out Durkheim's Aphorism. Rowman & Littlefield Publishers, Lanham (2002)
18. Glöss, M., McGregor, M., Brown, B.: Designing for labour. In: Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI 2016, pp. 1632–1643 (2016). https://doi.org/10.1145/2858036.2858476
19. GoGet: GoGet. https://www.goget.com.au. Accessed 13 Sept 2018
20. Gransky, L.: The Mesh - Why the Future of Business is Sharing. Portfolio Penguin, Gurgaon (2014). https://doi.org/10.1007/s13398-014-0173-7.2
21. Hampshire, R.C., Gaites, C.: Peer-to-peer carsharing. Transp. Res. Rec. J. Transp. Res. Board **2217**(1), 119–126 (2011). https://doi.org/10.3141/2217-15
22. Hardin, G.: The tragedy of the commons. Science **162**, 1243–1248 (1968)
23. Heinrichs, M., Krajzewicz, D., Cyganski, R., Schmidt, A.: Introduction of car sharing into existing car fleets in microscopic travel demand modelling. https://doi.org/10.1007/s00779-017-1031-3
24. ter Huurne, M., Ronteltap, A., Corten, R., Busken, V.: Antecedents of trust in the sharing economy: a systematic review. J. Consum. Behav. **16**(6), 485–498 (2017). https://doi.org/10.1002/cb.1667
25. Ikkala, T., Lampinen, A.: Monetizing network hospitality: hospitality and sociability in the context of Airbnb. In: CSCW 2014, pp. 14–18 (2014). https://doi.org/10.1145/2675133.2675274
26. Jung, J., Lee, K.-P.: Curiosity or certainty? A qualitative, comparative analysis of Couchsurfing and Airbnb user behaviors. In: Proceedings of Conference on Human Factors in Computing Systems - Part F1276, pp. 1740–1747 (2017). https://doi.org/10.1145/3027063.3053162
27. Katzev, R.: Car sharing: a new approach to urban transportation problems. Anal. Soc. Issues Public Policy **3**(1), 65–86 (2003). https://doi.org/10.1111/j.1530-2415.2003.00015.x
28. Kent, J.L., Dowling, R.: Puncturing automobility? Carsharing practices. J. Transp. Geogr. **32** (2013), 86–92 (2013). https://doi.org/10.1016/j.jtrangeo.2013.08.014
29. Kvale, S.: InterViews: An Introduction to Qualitative Research Interviewing, pp. 129–140. Sage, Thousand Oaks (1996). https://doi.org/10.1016/S0149-7189(97)89858-8
30. Lampinen, A., Cheshire, C.: Hosting via Airbnb: motivations and financial assurances in monetized network hospitality. In: Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, pp. 1669–1680 (2016). https://doi.org/10.1145/2858036.2858092
31. Li, Q., Liao, F., Timmermans, H.J.P., Huang, H., Zhou, J.: Incorporating free-floating car-sharing into an activity-based dynamic user equilibrium model: a demand-side model. Transp. Res. Part B Methodol. **107**, 102–123 (2018). https://doi.org/10.1016/j.trb.2017.11.011
32. Martin, E., Shaheen, S.: The Impact of carsharing on public transit and non-motorized travel: an exploration of North American carsharing survey data. Energies **4**(11), 2094–2114 (2011). https://doi.org/10.3390/en4112094
33. Meurer, J., Stein, M., Randall, D., Rohde, M., Wulf, V.: Social dependency and mobile autonomy. In: Proceedings of the 32nd Annual ACM Conference on Human Factors in Computing Systems, CHI 2014, pp. 1923–1932 (2014). https://doi.org/10.1145/2556288.2557300
34. Millard-Ball, A.: Car-Sharing: Where and How It Succeeds. Transportation Research Board, Washington, D.C (2005). https://doi.org/10.17226/13559
35. Ornetzeder, M., Rohracher, H.: Of solar collectors, wind power, and car sharing: comparing and understanding successful cases of grassroots innovations. Glob. Environ. Change **23**(5), 856–867 (2013). https://doi.org/10.1016/j.gloenvcha.2012.12.007

36. Qiu, W., Parigi, P., Abrahao, B.: More stars or more reviews? Differential effects of reputation on trust in the sharing economy. In: CHI 2018, pp. 1–11 (2018). https://doi.org/10.1145/3173574.3173727
37. Quattrone, G., Proserpio, D., Quercia, D., Capra, L., Musolesi, M.: Who Benefits from the "Sharing" Economy of Airbnb? pp. 1385–1393 (2016). https://doi.org/10.1145/2872427.2874815
38. Juniper Research: Revenue of platform providers in the sharing economy worldwide in 2017 and 2022 (in billion U.S. dollars) (2017). https://www.statista.com/statistics/878844/global-sharing-economy-revenue-platform-providers/. Accessed 13 Sept 2018
39. Rifkin, J.: The Age of Access: The New Culture of Hypercapitalism Where All of Life Is a Paid for Experience. Penguin, New York (2000)
40. Shaheen, S.A., Cohen, A.P.: Carsharing and personal vehicle services: worldwide market developments and emerging trends. Int. J. Sustain. Transp. **7**(1), 5–34 (2013). https://doi.org/10.1080/15568318.2012.660103
41. Shaheen, S.A., Mallery, M.A., Kingsley, K.J.: Personal vehicle sharing services in North America. Res. Transp. Bus. Manag. **3**, 71–81 (2012). https://doi.org/10.1016/J.RTBM.2012.04.005
42. Shaheen, S.A., Martin, E., Bansal, A.: Peer-To-Peer (P2P) carsharing: understanding early markets, social dynamics, and behavioral impacts. UC Berkeley Research Reports (2018). https://doi.org/10.7922/G2FN14BD
43. Shaheen, S., Sperling, D., Wagner, C.: Carsharing in Europe and North American: Past, Present, and Future (1998). https://doi.org/10.1111/ina.12046
44. Sørensen, H., Raptis, D., Kjeldskov, J., Skov, M.B.: The 4C framework. In: Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing - UbiComp 2014 Adjunct, pp. 87–97 (2014). https://doi.org/10.1145/2632048.2636089
45. Svangren, M.K., Skov, M.B., Kjeldskov, J.: The connected car: an empirical study of electric cars as mobile digital devices. In: Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services - MobileHCI 2017, pp. 1–12 (2017). https://doi.org/10.1145/3098279.3098535
46. Svangren, M.K., Skov, M.B., Kjeldskov, J.: Passenger trip planning using ride-sharing services. In: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, CHI 2018, pp. 1–12 (2018). https://doi.org/10.1145/3173574.3174054
47. Yin, R.K.: Case Study Research: Design and Methods, 5th edn. Sage Publications, Thousand Oaks (2014). https://doi.org/10.1080/09500790.2011.582317
48. ZipCar: ZipCar. https://www.zipcar.com/. Accessed 13 Sept 2018

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