An Emergent Design Framework for Accessible and Inclusive Future Mobility

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ABSTRACT

Future mobility will be highly automated, multimodal, and ubiquitous and thus have the potential to address a broader range of users. Yet non-average users with special needs are often underrepresented or simply not thought of in design processes of vehicles and mobility services, leading to exclusion from standard transportation. In consequence, it is crucial for designers of such vehicles and services to consider the needs of non-average users from the begin on. In this paper, we present a design framework that helps designers taking the perspective and thinking of the needs of non-average users. We present a set of exemplary applications from the literature and interviews and show how they fit into the framework, indicating room for further developments. We further demonstrate how the framework supports in designing a mobility service in a fictional design process. Overall, our work contributes to universal design of future mobility.

CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models**; *Interaction design theory, concepts and paradigms*; *Systems and tools for interaction design*; *Mobile computing*; **Accessibility theory, concepts and paradigms**.

KEYWORDS

Future Mobility, Automated Driving, Autonomous Driving, Inclusion, Accessibility, Assistive Technology, Universal Design

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1 INTRODUCTION

Commuting to work or visiting friends: mobility is fundamental for individuals and society. Future mobility technologies and services for land transport on which we focus in this paper will be highly or even fully automated (cf. SAE level 4 and 5 [49]) and highly connected (e.g., through 5G). Future mobility has the potential to include a broader range of users than ever before. People without a driver's license could use the system. This could enable, for example, people with cognitive or physical impairments to overcome mobility access barriers and better participate in social life, work, and education. Further, caregivers or individuals who provide assistance can spend time for care work instead of driving during journeys. However, one should consider these potentials in design processes from early on – retrofitting accessibility features into mobility services can be complicated and require much effort. Thus, automotive designers should take the perspective of all potential users for their services to make future mobility inclusive.

We see a raised interest in research for the design of inclusive future mobility over the last few years. Recent works looked into the design requirements of vehicles services like shared rides from the perspective of particularly older adults [22], women [52], and people with impaired vision [7]. Others looked into the communication between vehicles and other road users [16]. At the same time, workshop initiatives started in the last two years that address the topic of inclusive mobility over diverse venues, e.g., at MobileHCI [34], AutoUI [18, 55], or Automated Vehicles Symposium [43]. Reflecting the increasing efforts, in both 2021 and 2022 AutomotiveUI organizers designated *accessibility & variety of users*[1] as a key topic for the conference. The field of inclusive mobility research in HCI is just emerging and spans a broad range of users, services, and settings. A structured design framework for the inclusive design of future mobility services is still missing, yet such frameworks (often referred to as *design spaces*) are a valuable tool in other contexts

[1] https://www.auto-ui.org/22/authors/papers/

like mobile computing [2, 51], AR-googles [26], external HMIs [15], and automotive AR-displays [23, 59]. One typically builds design spaces in HCI around a large set of existing artifacts and possible use cases. Because highly connected and fully automated mobility is not available yet, there are comparably sparse examples of appropriate design solutions for inclusive design. Furthermore, automotive designers and researchers lack experience in designing these systems. Nevertheless, especially in the early stage of development, it is crucial to consider the design dimension and options that lead to inclusive mobility services. Consequently, this paper poses an emergent design framework that helps researchers and designers explore the design possibilities and dimensions of future mobility means and services for non-average users.

In the sense of Universal Design, we consider the framework to complement existing automotive design processes to foster the inclusion perspective. Designers can use the framework to facilitate thinking about essential dimensions of inclusiveness for mobility services, communicate requirements in a structured and standardized way, or compare existing services' properties. To build our design framework, we did a literature survey ($N = 138$) on current assistive technologies from research and industry to support users' mobility. Further, we interviewed caregivers and disability representatives ($N = 8$) to get insights into their everyday routines and collect other possible use cases for automated and connected mobility services. From the literature review and the interviews, we collected examples of inclusive mobility concepts and clustered them into application categories (cf. Table 1). We fit these application examples into our design framework, revealing future research directions. Additionally, we demonstrate the practical use of the design framework in a fictional usage scenario.

Contribution Statement. Overall, our work contributes to better communication, understanding, and design of highly connected and automated mobility services for persons with current accessibility barriers to personal mobility, like physical and cognitive impairments, and their helpers. Specifically, we provide (1) a set of potential use cases for inclusive future mobility, (2) a first design framework for inclusive future mobility, and (3) demonstrate the use of the design framework.Because the design framework aims at a comparatively new area of research, we do not claim it to be exhaustive but see it as a tool that should evolve as the field develops.

2 BACKGROUND & RELATED WORK

In this section, we first look at terms and definitions related to inclusive mobility and design before providing an overview of design frameworks and spaces in HCI in general and mobility in particular.

2.1 (Dis-)Ability, Technology, Inclusion: General Terms and Definitions

Throughout this paper, we use the definitions of the World Health Organization [62] (WHO) when referring to the terms impairment and disability. The WHO defines an *impairment* as "any loss or abnormality of a psychological, physiological, or anatomical structure or function." An impairment could be temporary, like a headache, or relatively permanent, like a migraine. A *disability* is "any restriction or lack (resulting from an impairment) of ability to perform an activity in the manner or within the range considered normal for a human being." Accordingly, the limitation in executing specific actions leads to environmental barriers of cultural, social, or physical nature. Barriers can lead to disadvantages (*handicap* or *exclusion*) in terms of social life or occupation. Thus, we, as technology designers and researchers, need to think about potential barriers that users encounter and how to resolve them to ensure equity and participation in mobility for all (*inclusion*).

One solution is *assistive technology* that helps overcome barriers and creates *access*, e.g., a ticketing app with a screen reader that provides access to mobility services for persons with vision impairments. Assistive technology typically aims at supporting users' independence by bridging a perceived access gap between an impaired person and the environment designed for the non-impaired [3]. Nevertheless, independence is subjective and often misses the social environment, and thus, Bennett et al. suggests broadening the notion of independence to *interdependence*. Interdependence is a perspective that emphasizes the complex co-creation of access through people and sometimes unreliable assistive technology. Overall, to take an inclusive perspective on mobility services, it is crucial to think about users' special needs, mobility patterns, and the social and technological environment they act in, including assisting persons and assistive technologies.

Inclusion is not optional. The *UN Convention on the Rights of Persons with Disabilities* (CRPD) recognizes personal mobility as a fundamental human right [58]. The CRPD requires accessible, self-determined, and affordable mobility services for persons with disabilities and training in mobility skills as inclusion measures for every committed party. Further, the CRPD explicitly mentions the responsibility of producers/designers of mobility services:

> "Encouraging entities that produce mobility aids, devices and assistive technologies to take into account all aspects of mobility for persons with disabilities." [58]

This raises the question of what designers and researchers can do to foster inclusive mobility.

2.2 Inclusive Mobility Design

To ensure inclusiveness in the design process of a mobility service and the product's accessibility, designers can stick to the principles of *Universal Design* (UD). The goal of the UD framework is the "design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design. Characteristics of any UD product or environment are that it is accessible, usable, and inclusive." [11]. Ability-based design [60] or user-sensitive design [41] emphasize a similar design philosophy. However, responding to every user need is not goal-directed (cf. [19]) and might make products too complex, but thinking about potential users and their abilities increases the chance to identify synergies or handle design conflicts. For example, an auditory interface for vision-impaired users might also increase the experience for non-impaired users.

An example of the application of the UD framework is the World Wide Web Consortium's Accessibility initiative which resulted in the *Web Content Accessibility Guidelines* (WCAG) [63]. Many

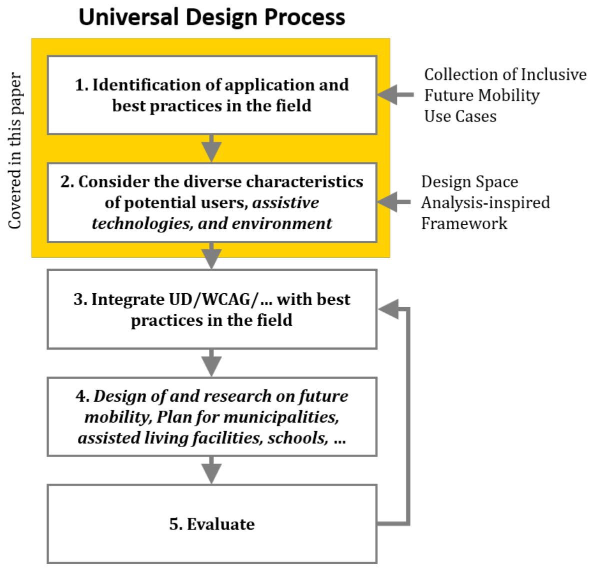

Figure 1: Universal Design process by Burgstahler – adapted (italic text) for future mobility services. Contributions of this paper (yellow) are towards the identification of best practices and applications and the systematic consideration of user characteristics, as well as the users' vehicles, tools and their (social) environment.

of the WCAG guidelines also apply in the mobility context since there is an overlap with the digital aspects of mobility services like smartphone apps for ticketing. However, as the WCAG guidelines do not cover non-digital aspects like the journey context or social situation during a ride, it is worth thinking about the mobility-specific UD. For this purpose, Burgstahler defines a five-stage UD process that one can adapt to any domain – Figure 1 shows the adaptation we made for future mobility service design. In this paper, we focus on the first and the second step of the UD process: We collect 1) experiences, applications, and use cases for inclusive future mobility, and then 2) we utilize design space analysis to create a design frame for systematic inspection of design requirements for non-average users. Regarding the second step, we extend the UD-step by not only looking at user characteristics. Instead, we additionally look into relevant contextual factors that influence the design for users with special needs, e.g., social or technological context. To better structure different aspects of the users' mobility context, design space analysis can be a useful tool.

2.3 Design Frameworks and Spaces for Mobile HCI

The design space analysis or exploration for a particular artifact, a mobility service in our case, aims at finding a systematic description of design alternatives. MacLean et al. [35] describe essential elements of such explorations within their Question-Option-Criteria (abbr.: QOC) scheme. The QOC representation contains a set of design-relevant *questions*, the range of possible answers or *options* (e.g., *How to display a scroll bar?* ⟶ {*Permanent*, *Appearing*}) and the impact of an option when selected or its *criteria* (*Permanent* ⟶ {*Low effort*, *Continuous feedback*}). The QOC scheme can support knowledge representation for design rationale [47] (focus on criteria) and Design Space Analysis (focus on questions and options). Within the Design Space Analysis (abbr.: DSA) questions are commonly referred to as *dimensions* and options as *parameters*.

In HCI, researches use DSA for a variety of technologies, applications, and interaction, e.g., computer input devices [12], interactive public displays [40], gaze-interaction in head-mounted displays [26], or 3D-printing [2]. Similar, in the automotive context, there are design spaces for driver HMIs concerning the external communication with other road users [14, 15], the internal HMI [31], and more specific taxonomies, e.g., for AR and virtual windshields [23, 59] or infotainment [6]. Finally, in the domain of digital data analysis, Kim et al. [32] present a design space for the creation of accessible visualizations. Overall, design space analysis helps to structure and think about an artifact. Nevertheless, given the variety of the design spaces' nature (visualizations, virtual windshields, mobile computers, ...), their construction (bottom-up vs. top-down) varies as well. Thus, there is no one-fits-all approach for design space exploration.

MacLean et al. describe the main purposes of a DSA: (1) *Communication*, (2) *Management*, (3) *Creation*, and (4) *Reflection*. As design is a social process, DSA can facilitate *communication* and thus *management* between current and later team members, clients and other stakeholder, e.g., making it for example easier to discuss the impact of product changes by highlighting decisions, tradeoffs, and evaluations. Further, the discussions about design options, their impacts, and interrelations can also raise new the *creation* of new options, improving the current design practice. DSA also helps with structuring *reflections* of past projects. There are two major use cases for design spaces in HCI with that in mind. The first is the *ideation*: Through the creative combination of design dimensions and the discussions about the design options at hand, designers can be inspired to think about their products in new ways. The second is *classification*: With a design space, existing and future artifacts can be classified and compared along the design space dimensions and, e.g., reveal common and uncommon parameters. A common tool for that purpose is the so-called "Zwicky Box" [65] (cf. [2, 15, 26]).

3 USE CASES & CONSTRUCTION OF THE DESIGN FRAMEWORK

We applied multiple steps to build our design framework, i.e., to collect use cases and applications (UD step 1) of inclusive and accessible future mobility, we (1) looked into the literature, and (2) spoke with caregivers and disability representatives about current and future mobility. Using design space analysis, we simultaneously (3) extracted and refined design space dimensions for consideration of diverse users and context (UD step 2). In the following, we describe the individual steps in detail.

3.1 Identification of Application and Best Practices for Inclusive Future Mobility

Review of Future Inclusive Mobility. Since we target the design of predominantly future artifacts, we conducted a literature review of

Table 1: Inclusive future mobility – Use case collection grouped by category - with examples from related work (marked with reference) and/or interviews (marked with [I]).

Category	*Sub-Category*	*Use Case Examples*
Safety	Emergency Stop	Simple "panic"-button for emergency stop [I] Voice-controlled emergency stop [8]
	Breakdown Assistance	Automatic connection to emergency contact person [I] Auditory information of the problem and necessary steps to resolve it [8]
	Surveillance	Passenger camera [I] Warning if someone leaves geofenced area [I] Tracking of the vehicle [1]
	Remote Vehicle Control	Configuration of speed, seat belts, temperature, etc. [13, 44]
	External HMIs	Crossing message, representing intent and instruction [16] Engine sounds for vehicle detection [61]
	Anchoring	Automatic door locks that open regularly only at on-/offboarding points [I] Automatic seat belt aids [I] Automatically connecting safety anchors for wheelchairs [I]
	Reducing Emotional Triggers	AR Windows that block triggering views, e.g., MCDonalds on the route for a child [44]
Convenience	Interior Adjustment	Automatic seat adjustment [I]
	Vehicle Finder	Key chains designed to vibrate based on proximity to the vehicle [9]
Ride Configuration	Ordering	Pre-ride selection of multiple accessibility features [13], [I]
	Navigation	Conversational interface for destination input (Siri-like) [8, 9] Brain-controller to enter destination [4]
	Direct Vehicle Control	Steering wheel and pedals with assistance lateral or longitudinal as needed [64] Gesture-based control [37] Voice controlled take-over for car correction [8] Joystick to control the vehicle [28, 39]
Communication	Exchange with Remote Person	Ride assistance through other clients in facility control center (community support) [I] Video chat caregiver-passenger [1, 44]
Orientation	Vehicle Identification	Automatic detection and auditory transmission of available bus lines [30], [I] Visually simplified IDs of public transportation vehicles [I]
	Interior and HMI Sensing	Visual feedback of all buttons and action for deaf people [I] Auditory feedback of all buttons like a screen reader, "voiceover" feature [8, 9]
	Ride Status & Progress	Tactile compass that informs about travel direction [8] Conversational interface for current GPS location [8] Location verification backup system during offboarding [9]
	Training	User training of interaction procedures, locations, switches, etc. [I]
	Environment Sensing	Refreshable braille display for environmental information [8] Object-indicating vibrating steering wheel [8] Vehicle attached "stick" to detect potholes [8] Accessibility information through virtual twin [33] Walking aids that detect and warn about potholes [29] Sonar-like environmental sensing with walking stick (hold in direction) [8]
Productivity & Entertainment	Gaming	Child games [1]
	Work	Homework assistance [1] Joint appointment preparation and sheduling [I]
		Going to work and traineeships [I] Storage for medication [I]
Connection Aids	On-/Offboarding Aids	App guide to fixed stopping positions of on-demand vehicles [I] Ramp system [I]
	Personal Mobility Aids	Autonomous tricyle at bicyle station [I] Autonomous scooter [42] Autonomous wheelchair [36]

future mobility services focusing on artifacts that enable personal mobility for people. For the review, we used the term *autonomous driving* and variations and combined it with a variation of terms we expect to be associated with inclusive mobility: *{ { autonomous OR automated } AND { driving OR transport* OR ride* OR bus* OR mobility OR vehicle* OR car* } } AND { inclusive OR assist* OR access* OR impair* OR disab* OR child* }*. The * stands for variations of the word, e.g., *vehicle** includes *vehicles*. For the search, we used Google Scholar and ScienceDirect. The search resulted in a total of 153 papers. As an inclusion criterion, the papers had to present a use case for assistive technology in inclusive future mobility, e.g., through prototypes, scenarios or interview studies. We excluded driving task assistance technologies because the machine will perform the driving task. In addition, we scanned the references and the google scholar profiles of the authors of the included papers to include possibly missed papers. Overall, we collected a 33 use cases for inclusive future mobility from 23 included papers (cf. Table 1).

Expert Interviews. In a next step, we did an interview study with care givers in assisted living and disability representatives in communities (f=6, m=2, M=41.6yrs, SD=15.11yrs; labeled as P1-P8, see Table 2). Thereby, we want to understand the pains and gains associated with their work, the mobility of their clients, and autonomous systems to understand the potential impact and identify potential scenarios of future automated mobility services. These insights added real-life examples to the use case scenarios and helped collect new use cases regarding future transportation and understanding how to archive autonomy, leading to a total of 49 use cases.

Table 2: Expert Interviews – Overview of the participants.

ID	Gender	Age *years*	Duration *min*	Facility	Background & Occupation	Experience *years*
P1	f	28	23.6	Sheltered workshop in a city	HCI background, working in research management (assisted workplace)	7
P2	f	47	18.2	Larger city	Social pedagogue, working as municipal disability and inclusion officer and	1
P3	f	62	18.0	Assisted living and work in a village	Occupational therapist, working as caregiver in a residential group	15
P4	m	35	17.5	Assisted living and work in a village	Social pedagogue, managing the social service in a residential area	10
P5	f	66	16.1	Larger city	Retired teacher, working in the municipal advisory board for inclusion	35
P6	f	35	15.6	Sheltered workshop in a city	Social pedagogue, working in the pedagogical management of caregivers	15
P7	m	33	21.6	School in a larger city	Special pedagogue, working as class teacher inclusive primary school	15
P8	f	27	30.4	School in a larger city	Special pedagogue, working as trainee teacher	4

3.2 Consider Diverse Users, Technologies, and Environments

Review of Related Work. We started with a literature review of related design spaces ($N = 6$, cf. Section 2.3) to identify useful taxonomy dimensions, focusing on those related to HCI in automotive [6, 15, 23, 31, 59] and accessibility [32] domains. Further, we looked into taxonomies ($N = 2$, cf. Section 4.1) of different mobility services' user types with special needs [5, 27].

Building the Framework. In a parallel step, using the outcome of all previous activities (literature reviews and interviews), we went through all collected user cases and types and derived a design framework for inclusive future mobility from discussing the outcomes. We collected additional use cases, reflected on related design space taxonomies, and complemented missing dimensions and parameters for future inclusive mobility. We describe the final framework in the following.

4 DESIGN FRAMEWORK

We pose five framing questions for future mobility designers. These five questions help to think about the design process and aid in starting a discussion on how to make it inclusive. Next, we go step-by-step through the questions and possible answers that influence the design decisions. Figure 2 shows the framework summary.

4.1 Users

Each user brings specific needs, goals, and abilities for a trip so that challenges she or he experiences occur at different levels (cf. Figure 3). To support inclusive mobility, designers should consider potential users and their special needs. Hence, our first question for designers is: *What are the users' needs and capabilities?*

User Mode. A mobility service can either be used by a *single user* or by *multiple users*. E.g., a trip within an inclusive school class not only includes the pupil but typically also the assistant person(s).

> "At our school, individual students have integration assistants with them. Either one-to-one support or two-to-one support. However, some students are cognitively and mobility-wise able to cope independently with our support." [P5]

User Type. Users bring different conditions for interaction with mobility services to consider. We used the LUDI-classfication[5] to describe the diverse user types: *Intellectual Disorder*, *Hearing Impairment*, *Visual Impairment*, *Physical Impairment*, *Communication Disorder*, and *Autism Spectrum Disorder*. An impairment is a cognitive, physical, or sensory (vision, hearing) condition that prevents users from accessing the mobility service. A user with a cognitive impairment like dyslexia needs an interface that does not rely on written text. The vulnerable road users (VRUs) taxonomy (layer 5, especially VRU) of Holländer et al. [27] describes similar sub-categories (layer 6 and 7) for impairment. Nevertheless, they add an essential category that considers age (child, elderly) as a factor for the "vulnerability" of a road user. In consequence, we added the category *development state*. Some human development states differ in abilities and skills and are still developing to full function or are already beyond full function (e.g., presbyopia, natural vision-impairment of elderly). For example, young children are not able to read and lack the correct perception of speed over 20mph [53]. They have a high risk of making wrong decisions, e.g., tend to make dangerous road crossing decisions [21]. Thus, it is vital to consider *universal* design guidelines for internal and external HMI design.

Accompaniment. While some impairments allow to travel *alone* under certain conditions, e.g., having a reliable infrastructure, other users need different forms of assistance either direct *on-site support* or technology-mediated *remote support*. For physically impaired persons, it is already a hurdle today:

> "A physical impairment, for example, hemiplegia, and I can't get into this thing, into this bus, or into this self-driving car. That is, of course, another kind of hurdle that you have to consider, how is this means of transport designed so that I can simply get in and out. Because it is already sometimes with the buses with the entrances, there are indeed the low-floor buses, but for someone who is all alone with a gait problem and has no accompaniment, it is difficult perhaps." [P4]

These accompaniment requirements can change over time when users get familiar with taking a specific route. In assisted living facilities, it is the goal to move to the autonomy-side of the spectrum:

`Users`

1. What are the users' needs and capabilities?

User Mode	Single User ↔ Multiple Users
Special User State/Trait	Intellectual Disorder, Hearing Impairment, Visual Impairment, Physical Impairment, Communication Disorder, Autism Spectrum Disorder, Development State
Accompaniment	Alone ↔ with support (remote) ↔ with support (on-site)
Needs & Goals	Autonomy, Competence, Relatedness, Meaning, Stimulation, Safety & Control

`Journey`

2. What is the journey's context?

Travel Phases	Planning, Ordering, Onboarding, Riding, Offboarding
Emotional Impact	Positive Connotation ↔ Negative Connotation
Route Familiarity	Known Route ↔ Unknown Route
Road Conditions	Perfect ↔ Poor
Traffic Density	Sparse ↔ Dense
Travel Duration	Short ↔ Long

`Mobility Service`

3. How does the transportation service look like?

Means of Transport	Train, Tram, (Shuttle-)Bus, Car, Pod, Bike, By Foot
Privacy	Private, Shared - Selected , Shared - Public
Availability	Constant, On-Demand, Scheduled
Connection	One Transport Mode ↔ Many Transport Modes

`Assitive Technology Interaction`

4. How to interact with the service?

Application Context	Safety, Convenience, Communication, Productivity & Entertainment, Accessibility
Location	Internal HMI, External HMI, User Device, Public Device
Initiative	User ↔ System

`Training`

5. How to train for the journey?

Environment	Real-World ↔ Mixed Reality ↔ Virtual Reality
Trainer	Assistant Person ↔ Virtual Avatar ↔ Self-Training

Figure 2: Framework summary.

> "And the goal is not only to take over but, above all, to empower people so that they can actually do it themselves." [P4]

Needs & Goals. Understanding motivation is essential for adequately describing the psychosocial role of assistive technology for people. As pointed out by Scherer et al. [50], besides an efficient, effective, and satisfying experience, the psychosocial function and the well-being effects of assistive technology play an essential role in the short- and long-term use of technology. The *self-determination theory* (abbr.: SDT) [17] is a prominent paradigm for describing human motivation and related well-being. According to the self-determination theory, there are three essential human needs: 1) *autonomy*, 2) *competence*, and 3) *relatedness*. *Relatedness* refers to the desire of what people think of you and also what you think of others. *Competence* is the desire to be able to successfully impact the factors that are deemed significant within a particular situation and that situation's outcome. *Autonomy* refers to the need to have one's experience self-organized and in line with our "integrated mission" [48], our intrinsic motivation. The DAUX framework of Frison and Riener [20] highlights the importance of the needs for autonomy and competence, among others, i.e., *meaning* (personal significance of a product) and *stimulation* (enjoyment during an activity). For an overview of UX-relevant needs, we refer to Hassenzahl et al. [24]. In addition to the DAUX and SDT frameworks, we argue that the need for *safety & control* is a motivational factor in future mobility services. Motivational not for the passenger (we

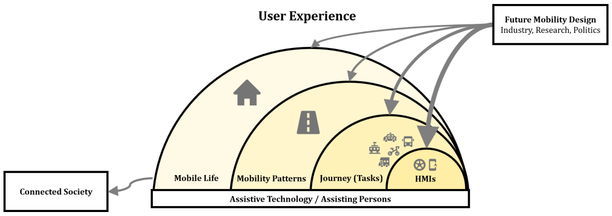

Figure 3: User Experience for future mobility – The METUX [46] framework applied for future mobility. Mobility designers' decisions can influence the users' experience of a mobility artifact in different spheres, e.g., experiencing a great HMI, task support, and behavior support, that might change an aspect of the user's life. Within each sphere, motivation can be built or taken – based on fulfilling the users' needs. Taking the inclusion perspective, these future mobility experiences are not only based on the artifact itself but are influenced through the interdependence with assisting persons and assistive technologies. In the best case, future mobility will contribute to inclusion on an individual level and thus contribute to a better-connected society.

assume future mobility to be safe and safety as a "hygenic" factor [25]) but rather for a remotely assisting person in multi-user settings, e.g., caregivers connected to their clients or parents to their children. Nevertheless, constant deprivation of any basic need has adverse health and well-being [17]. Thus, it is reasonable to design assistive technology in a way that supports these human needs in order to promote well-being (cf. Motivation, Engagement, Thriving in UX, METUX framework [46], Figure 3). For guidelines for need-based design, we refer to Peters [45].

4.2 Journey Context

The context of a journey is complex. For users with special needs, the emotional context like the past experiences, the expectation that users connect with a journey, the progress of the journey, or the traffic environment plays a prominent role. Designers should think of these contextual factors when designing future mobility services, and, thus, our second question for designers is: *What is the journey's context?*

Travel Phases. There are five subsequent phases during a trip that are proceeded: 1) *Planning*, 2) *Ordering*, 3) *Onboarding*, 4) *Riding*, and 5) *Offboarding*. Because requirements change for these phases, it is essential to think about in which phase a user needs what kind of assistance: A trip has to be *planned*, alone or together with a caregiver. Assistive technology can, e.g., support learning critical aspects of the route (cf. familiarity, see next section). Then, if not individually owned, the ride has to be *ordered*. Ordering the ride might be through an app or an on-site terminal of a mobility station. If these interfaces are not accessible, it might already be a frustration point for individual autonomy. The following transportation with a vehicle contains adaption to the special needs of impaired users:

> "It should be possible to enter the disability before the start of the journey, but then not only the mobility restrictions but also the restriction in communication, so that it is then clear: 'Hello, here is someone who needs support'." [P5]

Onboarding and *Offboarding* phases bring a lot of challenges for persons with impairments. The physically impaired need an entry/exit ramp, and low-vision requires infrastructural support like alerting sounds before the exit and other wayfinding aids. Here, again, familiarity is a key to autonomy:

> "Then the next problem is getting out, i.e., the person must be spatially oriented in such a way that he also finds the place where he wants to go. There are many people with intellectual disabilities who travel by bus without any problems and have if they always make the same routes..." [P5]

While *riding*, a challenge is when something unforeseen happens: a detour, a missing stop, or an accident requires backup mechanisms for impaired users. Cognitively impaired persons might require an assisting person that guides them through the unknown situation.

> "So that in an emergency [she/he] can actually press a button and there a person is switched on, maybe even somehow by video chat that I can imagine that can be calming, if the persons unsettled, what is happening right now or where it goes, that is really again a person who listens and then somehow maybe trained and communicates in easy language with him and can somehow find out what the problem is right now." [P8]

Emotional Impact. The purpose of a journey can have a *positive* or *negative connotation* for the user. While the way to a good friend elicits positive emotions, the way to the dentist might be negatively connotated for some and thus evoke unwanted responses like anxiety or even panic attacks. Additionally, certain situations evoke emotional responses, like an McDonald's restaurant at the sight of a hungry child. Designers can influence (un)wanted emotional triggers by, e.g., augmenting the view through an AR-Windshield display [44].

Route Familiarity. The journey can either be on a known or an unknown route – or something in between. Whereas the known routes are doable for most impaired persons, the challenge lies in the unknown: How long will the trip take? Will the user have the patience? Is there one stop or multiple stops on the way? Users with physical impairments need to know, e.g., if there is a wheelchair-friendly station if they reach their goal, and users with cognitive impairments feel insecure and thus can not make a journey on an unknown route on their own. A low-vision user might need to remember the exact number of stops until the destination. Overall, the need for assistance is higher on unknown trips. Training can be an option to make routes more familiar and move the spectrum of "known", making the trips predictable for users, leading to more security and autonomy for users.

Road Conditions. During a journey, the direct road conditions influence the journey experience for some users. Whereas a *perfect* road is not a challenge, *poor* road conditions like gravel roads become an obstacle for touch interaction with assistant systems. They are also problematic for physically impaired users, e.g., wheelchair users need the possibility to attach their wheelchair during the ride:

> "Wheelchair users have anchors in the buses, for example, in the buses we use at the school, so that the wheelchair cannot slip away during the journey." [P7]

Traffic Density. The traffic density might be *sparse* or *dense*. Similar to the road conditions, this parameter influences the interaction quality with assistant systems: A high traffic volume is often noisy and thus might influence the interaction with voice assistants. In addition, dense traffic further influences the emotional annotation of the ride because it can be perceived as stressful by users compared to a free road. Door exits in areas with high traffic volume are practical examples of the traffic's implications:

> "Well, if I now look at people with mobility impairments, then it is, of course, the case that they would like to park, provided they have their vehicles, preferably in front of their doctor's office, meaning to find there also a sufficiently dimensioned parking space, which is wider, which allows the exit in preferably not the flowing traffic, but at a distance from the flowing traffic..." [P2]

Travel Duration. The travel duration might be *short* or *long*. The longer a trip lasts, the more patience users need, and other trip-related consequences like resting times or entertainment become prevalent.

4.3 Mobility Service

Future mobility offers different transportation modes and develops away from today's car-dominated transportation. Depending on the type of user, the ability to use these transportation services can differ and, of course, change over time (see also question 5). In consequence, our third question for designers is: *How does the transportation service look like?*

Means of Transport. For transportation users can take motorized services like a *train*, a *tram*, a *(shuttle-)bus*, or a *car*. For persons who feel not comfortable with taking these services, an alternative for shorter journeys is the *bike* or taking the way *by foot*. For physically impaired persons, these options are inappropriate. Yet, we included the *bike* and *by foot* options intentionally, as they do not fall into "traditional" mobility services. However, for persons with mild cognitive impairments, they are commonly the only option to be mobile today. As such, bikes are "practically comparable to cars for ordinary people, so the bike must also be stylish, be speedy, be good" [P3]. In the future, automated mobility services can be the bridge to longer self-determined trips and a well-anticipated autonomous personal mobility.

> "So basically, the cared-for people who can now ride a bike on their own, they could also, once you've practiced that a little bit, then ride autonomously." [P8]

Privacy. The ownership of a vehicle can be *private*, *shared - selected*, or *public - shared*. Shared transportation implies the co-use of a vehicle. Either with selected people or with anyone. It is desirable to have other people around in some instances, e.g., when a physically impaired person needs help with onboarding on a public bus. In other cases, more surrounding people equal unnecessary stress, e.g., for sensory or cognitive impaired persons.

Availability. The mobility service can have, depending on the ownership, different availability. While *constant* availability leads to the highest personal autonomy, *on-demand* concepts like shuttle buses include queue times, and *scheduled* concepts like public transportation are commonly tied to "regular" work and school times. Autonomous mobility services help to improve availability.

Connection. A mobility service can be directly connected from start to destination with one *mode of transportation* or have *many modes of transportation*, e.g., last-mile transportation from a central station to home. The latter means that users have to change. Physical impaired persons might prefer a longer route with fewer changes. Overall, it is crucial to consider the number of switches that a user needs for a trip, especially if this breaks routines for cognitively impaired persons.

4.4 Assistive Technology Interaction

It is common to interact with multiple HMIs that assist the user during diverse journey phases and for different activities, e.g., ordering a ticket via smartphone, watching a movie with the integrated in-car AR-display, or stopping the vehicle with a tactile button. We emphasize here *service* instead of *vehicle*, because a whole journey contains includes different interaction contexts (cf. question 3). Hence, our fourth question for designers is: *How to interact with the service?*

Application Context. We formed categories of different interaction purposes, i.e., *application contexts* from the literature review, related design spaces, and from the interviews. These are *safety*, *convenience*, *ride configuration*, *orientation*, *communication*, *productivity & entertainment*, and *connection aids*. Table 1 shows the use cases for interaction in context of inclusive mobility.

Location. The interaction during a journey can happen at a static location in the vehicle (*internal HMIs*) or outside of the used vehicle (*external HMIs*), on *user devices*, or on *public devices* like a ticket machine. External HMIs can be helpful for impaired users, e.g., for low-vision and blind people, it is beneficial to have external speakers on public busses that provide information about the line number and destination. On the other hand, these kinds of public auditory displays create interference for people with hearing impairments, yet they could read the same information from a visual display.

Initiative. The initiative of the interaction can be by a *user* or by the *system*. In most cases, interaction is user-initiated, but in some cases, assistive technology can support users who cannot express their intentions towards the system, particularly cognitively impaired persons. For example, a location-based security mechanism could help detect route anomalies:

> "We can see with GPS trackers when they leave the premises, then that would certainly be a possibility that you then get a warning." [P1]

On the other hand, these mechanisms have to preserve privacy [P6]. Thus, proactive assistive systems have to be designed transparently for users.

4.5 Training

Most users with impairments need to build a reliable routine. Knowing the infrastructural givens, the journey length, and other aspects like the stop frequency help gain security for self-determined mobility, especially for people with cognitive limitations:

> "Mobility training is clearly for people who are a bit fitter, who can orient themselves independently, at least if you've shown them a few times. That doesn't have to mean we have to be able to read the map, but it can also be an aid to help them find their way. And then we look at how we can teach them, some can only take one line at first, so they know that this is the stop where I get on the bus, and then I get off again." [P4]

Therefore, our fifth and last question for designers is: *How to train for the journey?*

Environment. A user can train the journey with a vehicle and all necessary interaction steps in different environments along the mixed reality continuum by Milgram et al. [38]: In *real-world* or *virtual reality* (VR) settings, or somewhere between these poles, in *mixed reality* (XR) environments (augmented reality or augmented virtuality) (AR). Real-world training needs a secure environment and constant supervision that comes with effort for the assistant persons. VR training [54, 56, 57] has proven effective in overcoming phobias by repeatedly exposing persons to an anxiety trigger and reframing emotional situations. Further, virtual training is physically safe for users, and traffic situations can be stopped, paused, and repeated. Thus, using virtual or augmented environments before trying a self-determined journey in real-world settings can be an efficient and safe addition to mobility training.

Trainer. The training environment provides the journey scenario or an excerpt of it. This virtual or real environment can be explored in *self-training* or with the assistance of a system, e.g., in the form of a *virtual avatar*, or in the form of a natural person, e.g., an *assistant person.*

5 APPLICATION OF THE DESIGN FRAMEWORK

Our framework helps mobility designers to think of essential design dimensions for inclusive design and discuss possible trade-offs, synergies/new options, or other impacts that a decision for a particular design option has. In this scenario, we showcase the use of the framework through a fictional design process.

Use Case and Designers. A ridepooling company wants to implement a new reference selection mechanism for their app. They place a high priority on having an accessible and inclusive design. They hire two freelancers for the UX design and implementation of the feature. The designers have different backgrounds, skills, and interests. *Alice* is a 32-year-old computer scientist who has been working in the industry right after her Bachelor's thesis. She is practically oriented and specializes in web programming. Alice is responsible for the GUI implementation of the feature prototype. She gained some knowledge in UX design through implementing W3C accessibility and search engine optimization, but she lacks a theoretical background in UX. *Bob* is a 49-year-old UX designer who has been in the automotive industry for 15 years. Bob just completed a user-centered design course. He is most comfortable with conceptual design work and less so with implementation.

Using the framework. Alice and Bob are not usually involved in creating inclusive features for apps. Thus, to start them off, Bob prints the Design Framework for Accessible and Inclusive Future Mobility (Figure 2) and presents it to Alice. They begin going through the framing questions and dimensions.

They quickly agree that the preferences for the ridepooling service are entered *single user mode* and are matched before the ride starts. However, they are not sure about the selection of the particular *user state/traits*, as it is not entirely clear who the app users are. In order to implement the vision of inclusive design, Alice suggests that selecting the special needs is one of the first things users should do in the app and the choices could align with the Special User State/Trait. Alice offers to bring her experience with implementing the W3C guidelines to bear on the design of the app. She wants to keep the dialogs simple and self-explanatory, and use familiar shapes and symbols as much as possible, so that people with dyslexia or impaired vision have no problems using the GUI. Bob suggests that users who cannot work with the GUI should have a chatbot available. Alice asks Bob how they can include users with intellectual disabilities and children. Bob argues that this group will not use the ridepooling service *independently*, but they should keep these users in mind, as their companions might use the app and want adjacent seats. Bob looks at the options for *accompaniment* and finds an argument for all options. While most people travel *alone*, some users would need *on-site* or *remote assistance.* Regarding destination selection, Alice and Bob quickly conclude that the ridepooling app should help users with special needs to be *autonomous* and independently mobile. Bob also suggests that other goals are added to the interaction depending on the destination, *relatedness* when traveling to friends, *competence* when going to work, or *safety* for persons that provide assistance – Bob suggests creating personas for the user types with skills and goals to be reminded of the different profiles later in the design process.

Determining the *travel* and *service* dimensions is easier for Alice and Bob, as they expand on the existing ridepooling service here. The application clearly falls into the *ordering* phase of the journey. Bob notices that the *familiarity* and *emotional impact* of the route on users is unknown. However, Alice thinks that it should be possible to specify or avoid certain routes and waypoints, and to implement a filtering function for them later. Bob agrees. Conversely, he thinks one should also have the opportunity to intentionally use unknown, interesting routes. The ridepooling app is currently only available in the area of Modelcity, so they know that the *road* is largely in *good condition* and the *traffic situation* is rather *relaxed* (sparse) except during rush hours. The *routes* are mostly covered in the city area and tend to be *short.* The ridepooling service has specially converted limousines available as vehicles, and Bob selects *Car* as the *means of transport* options. The vehicles are shared and ordered by the user, thus they specify that *Ownership* is *shared* and *Availability* is *on-demand*, and connection is *one transport mode.*

The application falls into the category *ride configuration.* Users will enter preferences on a *user device.* Alice suggests that they could also install public displays at popular stops - this is a suggestion for the whole service. Alice and Bob agree that the *initiative* should come from the *user*, who enters their. However, since there are many preferences, Alice suggests to let the pre-fill set some preferences depending on the usage at a certain time or place. Bob is enthusiastic and adds to also suggest destinations in an automated way by observing the user's movements, but Alice counters: this would possibly make users feel observed and stop using the app. They agree to disable automated suggestions by default and make users aware of such additional features the first time they use the app.

Although *training* is not usually required to enter preferences, Alice and Bob find this aspect important as it is about familiarizing users with the journey. Bob thinks it could be helpful for users with mobility impairments to inspect the stopping points during the selection in a small VR preview area. They check *VR* for the *training environment* and *self-training* for the *trainer*. As a further add-on for the entire app, they include the item guided training.

With the generated personas, the list of add-ons for the ridepooling-service, the list of requirements for the preference-selection mechanism, and the thoughts of the discussion, Alice and Bob already discussed a lot of relevant questions for inclusion and start the further design process.

6 CONCLUSION & FUTURE WORK

It is fundamental for practitioners in the automotive industry and automotive researchers to understand that they are part of an inclusive design process. To make future mobility inclusive and accessible for all, they should establish procedures to include people with diverse backgrounds and special needs or their representatives in the design processes of future mobility services. In this paper, following the universal design process, we presented use cases of inclusive future mobility, a design framework for inclusive future mobility, and showed how to utilize the framework. We built our framework on previous work, similar taxonomies, and the mobility experiences of experts that work in inclusive facilities. It serves as a tool for automotive practitioners and researchers for communication, ideation, or reflection. It can be a starting point for designers to broaden their perspectives on accessibility and inclusion in future mobility. We invite automotive researchers to extend and refine the framework with further perspectives, e.g., from people with specific impairments, and tackle the next steps of universal and inclusive design, i.e., integrating the framework into design guidelines for mobility designers that help build and evaluate new mobility artifacts accessible for all.

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