Acceptability and Acceptance of Autonomous Mobility on Demand: The Impact of an Immersive Experience

Verena Distler
University of Luxembourg
ECCS Research Unit
Esch-sur-Alzette, Luxembourg
verena.distler@uni.lu

Carine Lallemand
University of Luxembourg
ECCS Research Unit
Esch-sur-Alzette, Luxembourg
carine.lallemand@uni.lu

Thierry Bellet
The French Institute of Science and Technology for Transport, Development and Networks
Bron, France
thierry.bellet@ifsttar.fr

ABSTRACT
Autonomous vehicles have the potential to fundamentally change existing transportation systems. Beyond legal concerns, these societal evolutions will critically depend on user acceptance. As an emerging mode of public transportation, Autonomous mobility on demand (AMoD) is of particular interest in this context [7]. The aim of the present study is to identify the main components of acceptability (before first use) and acceptance (after first use) of AMoD, following a user experience (UX) framework. To address this goal, we conducted three workshops (N=14) involving open discussions and a ride in an experimental autonomous shuttle. Using a mixed-methods approach, we measured pre-immersion acceptability before immersing the participants in an on-demand transport scenario, and eventually measured post-immersion acceptance of AMoD. Results show that participants were reassured about safety concerns, however they perceived the AMoD experience as ineffective. Our findings highlight key factors to be taken into account when designing AMoD experiences.

Author Keywords
Autonomous driving; user experience; acceptance; acceptability; human needs; mobility on demand.

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

INTRODUCTION
The last decade has seen an increasing interest in automated transport systems [22]. With the rapid development of autonomous vehicles, the way we travel could undergo fundamental changes. The deployment of autonomous vehicles facilitates the development of new mobility models such as Autonomous Mobility on Demand (AMoD) [28, 35]. AMoD is a transformative mode of transportation where robotic, self-driving vehicles transport customers in a given environment based on their mobility demands [28]. If first and last mile transportation is coupled with other means of public transport, it can provide cost-effective and sustainable door-to-door transportation [5]. However, will users accept using an automated vehicle on demand?

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In this exploratory study, we investigated the differences between acceptability (before use) and acceptance (after use, as defined by [31]) of a first experience on an AMoD using a mixed-methods approach. It is crucial that AMoD experiences be perceived positively by users, as a positive user experience can foster acceptance of AMoD. Therefore, we decided to complement existing technology acceptance models with a UX framework in order to gain a holistic understanding of the principal components of user experience and acceptance of AMoD.

We will first introduce the concepts of acceptability, acceptance, and underlying technology acceptance models. We will also focus on User Experience (UX) through the pragmatic and hedonic quality of products, as well as human needs theories. We will then describe the methodology used to address our research question, before presenting and discussing the results.

DISTINCTION BETWEEN ACCEPTABILITY AND ACCEPTANCE
Research [24] has shown that there is a difference between the prospective judgement of a product before having used it and after first use. On the one hand, acceptability refers to a prospective judgement toward a technology or measures to be introduced in the future. The target group will not yet have experienced the new measures, or the new technology [31]. On the other hand, acceptance refers to the judgement, attitude and behavioural reactions toward a product after use [31, 32]. Somat et al. [34] introduce the continuum acceptability-acceptance-appropriation, describing the change in the subjective evaluation of a product before using it (acceptability), after having used it (acceptance) and once the product has been introduced into the user's daily life (appropriation).

In the present study, we investigated the influence of an immersive influence on the acceptability, using Auvray and al.'s [2] definition of immersion as "being involved in a world of action and new perception, made possible by a technical device".

LINKS BETWEEN TECHNOLOGY ACCEPTANCE MODELS AND USER EXPERIENCE

Few research exists on the acceptance of autonomous vehicles [e.g., 1]. Existing studies mostly used adaptations of technology acceptance models such as the Technology Acceptance Model (TAM [6]), the Unified Theory of Acceptance and Use of Technology (UTAUT [36]) and the Car Technology Acceptance Model (CTAM, [26]). While TAM and UTAUT have been developed to assess acceptance in the context of computer use, CTAM is an adaptation of the UTAUT for the context of cars (Figure 1).

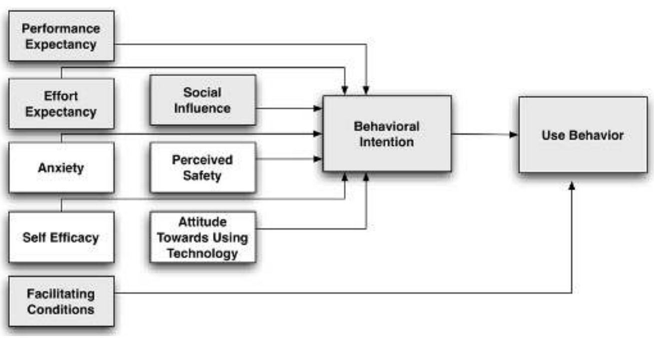

Figure 1. Car Technology Acceptance Model (CTAM, [26])

Studies [37] suggest that hedonic motivation might be a critical factor influencing behavioral intention in consumer-based contexts. The perceived hedonic quality of a product is an important factor in UX research, where it is considered a driver of positive experiences [12].

In the field of UX, it is important to differentiate between the pragmatic quality and the hedonic quality of products and how they are linked to need fulfilment. According to recent works in UX [10, 11, 12, 19], the pragmatic quality describes "a product's perceived ability to support the achievement of "do-goals" (i.e. tasks). Pragmatic quality relates to the functionality and utility of the product, while the hedonic quality refers to a product's perceived ability to support the achievement of "be goals", such as "being competent" or "being special" for instance. Hassenzahl [12] argues that the fulfilment of be-goals is the driver of experience: the hedonic quality therefore contributes directly to the core of positive experiences. Mahlke's framework includes three user experience components [23]: (1) perception of instrumental qualities (2) emotional user reactions (3) perception of non-instrumental qualities. The model also includes system properties, user characteristics and context parameters which are influencing factors for the interaction of the user with the product.

It is important to emphasize that there are similarities between UX models and acceptance models. For example, the CTAM factors *perceived safety*, *attitude towards using technology*, *anxiety* and *self-efficacy* are in accordance with the human need theories, which include the need for security, control and competence. The TAM [6] includes *perceived usefulness* (utility in Mahlke's framework [23]) and *perceived ease of use* (usability in Mahlke's framework). Acceptance models therefore do already partially cover UX aspects, whereas other UX constructs such as hedonic motivation are not yet addressed, even though consensus [10, 12, 13, 27] on their importance exists in the literature.

Studies have shown that it is essential to take into account psychological needs when designing experiences, as a positive UX is the result of fulfilling human needs [12, 33]. Based on these psychological need theories, a unifying model of human needs assessment has been created, retaining ten needs: autonomy, competence, relatedness, self-actualization-meaning, physical thriving, pleasure-stimulation, money-luxury, security, self-esteem and popularity-influence [33]. The needs described by [12] and [33] can be considered be-goals. These results have been used and adapted for several other studies [12, 26], proving the relation between need fulfilment and positive experiences. [15] and [13] narrowed the relevant needs down to autonomy, competence, relatedness, popularity, stimulation and security. But how are these needs related to technology acceptance? In the context of autonomous cars, studies linking UX need fulfillment to acceptance factors showed for instance the influence of autonomy levels on the acceptance of autonomous driving [30].

RESEARCH QUESTIONS

In the present paper, our goal is to gain an understanding of the principal components of UX and acceptance in the context of AMoD. Combining acceptance models with a psychological needs-driven approach, the present study has two purposes. First, by creating an immersive experience on an AMoD, we strive to understand how the level of acceptability before the experience and the level of acceptance after the immersive experience on an AMoD differ. Second, we want to understand which underlying psychological needs were at play, and how they influenced the experience participants had.

METHODOLOGY

We conducted 3 workshops with a total of 14 participants. Each workshop took approximately 4 hours with 3 scheduled breaks to avoid participant fatigue and included a combination of methods. The workshops were split up into three main phases: a pre-immersion evaluation of acceptability, an immersive journey on an autonomous shuttle and a post-immersion evaluation of acceptance.

Both the pre- and the post-immersion evaluation of acceptance were split up into an acceptance questionnaire and a focus group. The questionnaires allowed us to measure the influence of the immersive experience on acceptance levels, while participants also explained their thoughts and concerns during the discussion stage. This approach helped us gain a broad understanding of the pre- and post-immersion acceptance.

Participants

14 participants took part in the workshops (9 male, 5 female). Participants were target users of autonomous shuttles, i.e. public transport users and likely to need first and last mile transportation means. To study acceptability, they should not have prior experience with autonomous vehicles. Participants knew each other beforehand, as pre-existing groups support an enriched group dynamics and reduce the influence of social desirability biases [20]. As people often use public transport with acquaintances, our group composition hence maximizes the ecological validity of the research. The average age was 26.8 years (Min=22, Max=48, SD=6.27). 11 (79%) participants had a driver's licence, while three (21%) participants did not. Participants declared that they hardly used cars for their trips, public transport was predominantly used. Six participants never used a car, while seven participants used a car between zero and two times a week. Public transport is a common mean of transport with 11 participants stating they used public transport at least three times per week. Four participants reported that they are usually among the first to adopt a new technology (early adopters), while 10 stated they were "in the average" when it comes to adopting new technologies. Eleven participants stated they used on demand means of transport such as Uber © "from time to time" (at least once a month).

Pre-immersion Evaluation of Acceptability

In order to be able to compare acceptability and acceptance, we started by measuring (1) the acceptability of autonomous cars as well as (2) the acceptability of AMoD (pre-immersion). The questionnaires were based on existing technology acceptance questionnaires, namely UTAUT [36] and CTAM [26]. We adapted the wording to fit the context of autonomous mobility and removed items which were not considered suitable to the context of mobility. We measured the level of agreement with these items on a continuous scale between 0 (do not agree at all) and 100 (completely agree), for example "If I had the opportunity, I would like to try an autonomous car." This is an adaptation of the FoG-CoQS method [4]. Complementary to these acceptability questionnaires, we also assessed human needs which were perceived as relevant in the context of autonomous mobility on demand, using the UX Cards method [18].

Questionnaire (1): Acceptability of autonomous cars

First, participants filled in a questionnaire with general questions concerning their gender, age, driver's license, existing mobility habits and adoption of new technologies. We then showed a video presenting autonomous individual cars to the participants. We created the video specially for the workshop by using excerpts of different informational videos on autonomous vehicles. The participants could see persons travelling on autonomous cars in regular traffic, leaving all control to the vehicle. Our goal was to create a common vision of what autonomous cars are able to do, in a quick and interesting way. After having seen the video, participants individually filled out the 16-item questionnaire on acceptability as described above.

Questionnaire (2): Pre-immersion acceptability of AMoD

Again, we used video support, this time to demonstrate the functioning of AMoD. The video showed autonomous shuttles circulating in an AMoD scenario and in a real traffic situation. Autonomous shuttles on demand were defined as vehicles which flexibly respond to the mobility needs of users. After having watched the video, participants individually filled out the same questionnaire with 16 items evaluating acceptability factors, this time concerning autonomous shuttles. Again, we measured agreement on a continuous scale between 0 and 100.

Pre-immersion focus group: Human needs assessment in the context of autonomous mobility on demand

The third activity before the immersion on the autonomous shuttle was the exploration of human needs in the context of AMoD, which was based on the UX Cards by Lallemand [18]. During this phase, participants explained the reasons for their ratings in the questionnaires in a structured way. Seven cards represent fundamental needs which humans strive to fulfill (security-control, competence-effectiveness, pleasure-stimulation, relatedness-belongingness, influence-popularity, autonomy-independence, self-actualizing-meaning). Depending on the context, people subjectively consider some needs as more important than others. The participants took a couple of minutes to read the cards. Then, they ranked the cards between 1 (most important need) and 7 (least important need) according to their perceived importance in the context of AMoD. They created their ranking individually and gave a short written reasoning for the 3 needs which they considered most important. This was followed by a global ranking for the group, where the facilitator collected the rankings of all participants and wrote them down, visible to all participants. The global ranking was used as a discussion base for the focus group where we asked participants to give more in-depth reasoning for their rankings and discuss examples.

Immersive Experience: the On-Demand Autonomous Shuttle

The goal of the second stage of our methodology was to design a high-fidelity simulation of an on-demand shuttle service using a smartphone application prototype. The shuttle's autonomy level is 4 out of 5 on the US National Highway Traffic Safety Administration (NHTSA) scale [see 30]. As for the majority of shuttles, the one we used here has a speed limit of 20km/h (actual speed 10-15 km/h). It is open to public users, driving on a public road with pedestrians, bicycles and cars in an uncontrolled environment. We gave the participants the mission to go to a specific place where they had to take a picture. They had to use our mobile prototype (Figure 2) to plan their itinerary. The itinerary included a ride on the experimental autonomous public shuttle which circulates in the French city where the experience took place. The prototype allowed them to book the shuttle for their journey, giving a realistic impression of an autonomous vehicle on-demand to the participants. The ride on the shuttle took around 15 minutes, which is realistic for public transportation.

The facilitator of the focus group sent a text message to the operator of the shuttle prior to arrival. The operator had the role of a safety controller with no or minimal interaction with users. This safety controller presses a button for the shuttle to start its journey. Remaining tasks are completed by the shuttle in a completely autonomous way.

When the participants arrived at the stop, the shuttle was waiting for them. Using this Wizard of Oz approach [9], we could give the participants the impression that they had reserved the shuttle via the application. The participants and the facilitator took the shuttle for three stops, the group took a picture at their destination and then returned with the shuttle. During the ride, the facilitator took the role of a participating observer, noting verbalizations of participants and their interactions with the human operator who, at this experimental stage, is still on board.

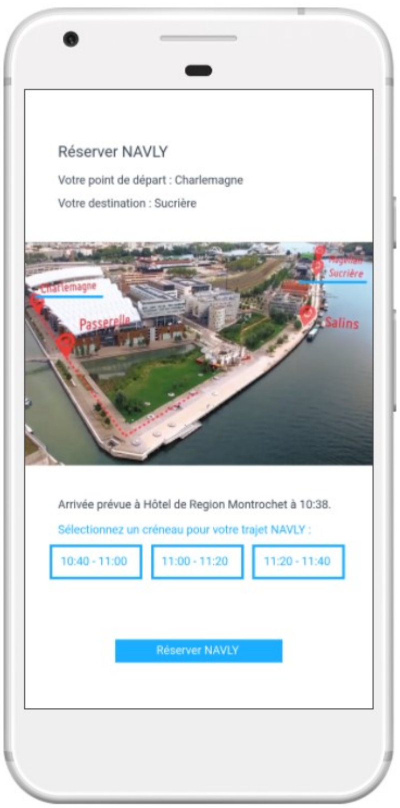

Figure 2. A screenshot of the application allowing users to select their itinerary, pick up time and number of passengers

Post-immersion evaluation of acceptance

Back in the meeting room, the participants filled out the same acceptance questionnaire, now assessing their acceptance after their first experience on an autonomous vehicle. The second post-immersion activity was the assessment of UX needs, this time in direct relation to the experience on the autonomous shuttle. Again, the participants ranked the UX cards from the need they felt was most important to them to the need they perceived as least important during the ride on the autonomous shuttle. As before, they wrote down a brief rationale for their individual rankings on the three most important needs. After the facilitator had created the global ranking, visible for all, the discussion phase started, this time concentrating on the actual experience participants had lived. This discussion phase provided us with rich insights into the experience participants had had, thereby substantiating the results from the questionnaires.

RESULTS

Acceptability and Acceptance Questionnaires

The acceptability questionnaires measured participants' agreement with 17 statements on a scale from 0 (do not agree at all) to 100 (completely agree). Table 1 sums up the results, a higher number corresponding with a higher acceptability/acceptance level.

Measured through the pre-immersion questionnaire, the acceptability of autonomous cars was highest for the dimension effort expectancy (Mean=81, SD=18), meaning that participants thought that it would be easy to understand and learn to use an autonomous car. On the other hand, performance expectancy (Mean=59, SD=27) and perceived usefulness (Mean=63, SD=37) had the lowest assigned ratings, corresponding to a certain skepticism concerning the performance (e.g., comfort, effectiveness, safety) of autonomous cars and their usefulness in the daily transport habits of the individuals.

The acceptability of AMoD before the immersive experience was even higher on average than the one of autonomous cars on all dimensions. Both means of transportation trigger curiosity, with very high ratings attributed to the statement "If I had the opportunity, I would like to try an autonomous car" (M=95, SD=11) or "AMoD" (M=97, SD=8). Participants reported an overall positive attitude towards AMoD (M=82, SD=25) and a high level of perceived usefulness (M=83, SD=22). The differences between the perception of AMoD before and after the immersive experience are presented in the next section.

Impact of the Immersive Experience on Acceptance Ratings

This section describes the impact of the immersive experience on the acceptability of our participants. We conducted a Wilcoxon signed-rank test in order to compare the values of the pre- and post-immersion questionnaires. Our results showed a significant change (Z=-1.984, p=.047) on the Performance Expectancy dimension after the immersive experience, decreasing from a mean of 67 (SD=29) to a mean of 58 (SD=26). This observation suggests that the immersive experience led participants to lower their expectations towards the performance of AMoD. The immersion did also elicit a significant change in Perceived Usefulness (Z=-2.005, p=.045), which dropped from M=83 (SD=22) to M=61 (SD=34). After having experienced it, participants felt like AMoD would be less useful for them than expected.

Dimension	Autonomous Cars				AMoD pre-immersion				AMoD post-immersion				Evolu-tion
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	
Would like to try (1 item)	95	11	70	100	97	8	70	100	-	-	-	-	-
Perceived usefulness (1 item)	63	37	0	100	83	22	25	100	61	34	0	100	-22
Performance expectancy (4 items)	59	27	0	100	67	29	0	100	58	26	0	100	-9
Effort Expectancy (2 items)	81	18	50	100	88	17	30	100	92	12	60	100	+4
Social Influence (2 items)	71	27	0	100	79	28	0	100	76	28	0	100	-3
Behavioral intention to use the system (3 items)	72	26	0	100	80	27	10	100	69	31	0	100	-11
Attitude towards using the system (4 items)	73	26	0	100	82	25	10	100	75	26	10	100	-7

Table 1. Comparison of the questionnaires (1) acceptability of autonomous cars (2) pre-immersion acceptability of AMoD and (3) post-immersion acceptability of AMoD

Other dimensions did not show significant changes according to the Wilcoxon test, however one can note changes in the average ratings before and after the immersion. For example, after the immersive experience, the mean for Effort Expectancy was slightly higher (pre-immersion: mean=88, SD= 17, post-immersion: mean=92, SD=12). Even though the change is not significant, participants stated during the discussion stage that the experience gave participants the impression that AMoD was even easier to use than imagined. The dimensions Social Influence, Behavioral intention to use the system and Attitude towards using the system were all rated as slightly lower after the experience (cf. Table 1).

Pre- and Post-Immersion Focus Groups

The UX Cards and discussion phase activity explains the reasons behind the changes we observed pre- to post-immersion. The participants created individual rankings of the cards representing human needs between 1 (the most important need) and 7 (the least important need). We did this both before and after the immersive experience. Table 2 presents the accumulated rankings for all three workshops.

Before the immersive experience, security and autonomy were considered the most important needs (average score 2.4), followed by pleasure and competence. Relatedness, self-actualizing and influence were considered less important. While participants felt that machines were less prone to errors than humans, they also expressed a certain apprehension related to safety. Before the experience, autonomy and competence were perceived as major advantages brought by AMoD. Participants expected such a system to address their mobility needs by improving the efficiency of public transportation and supporting customized needs.

When comparing pre- and post-immersion rankings of the UX Cards, security, competence and relatedness were considered more important after the experience. On the other hand, the values assigned to the needs autonomy, influence, pleasure and self-actualizing lowered as a result of the experience.

	Autonomy		Competence		Influence		Pleasure		Self-actualizing		Relatedness		Security	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Total of all scores	34	41	49	40	82	90	46	48	73	80	72	62	33	31
Avg. score / participant	2.4	2.9 ↓	3.5	2.9 ↑	5.9	6.4 ↓	3.3	3.4 ↓	5.2	5.7 ↓	5.1	4.4 ↑	2.4	2.2 ↑

Table 2. Pre- and post-immersion ranking of UX cards according to their perceived importance in the context of AMoD. A low score means the need was considered important by the participants.

Security - Control	
Before	
1 - Machines make less mistakes than humans. Nevertheless, there is a certain apprehension.	"A computer does not drink, it is never tired. It is always attentive. There will be less human errors." " I would be confident in this type of shuttle." "I understand that it would be safer than humans, but I have a certain apprehension." "I feel safer in manual mode."
2 - Information gives participants a feeling of control.	"I need control, I need to know when the shuttle arrives, where it will drop me off and how much time it will take."
After	
1 - The experience has a reassuring effect with regards to the perceived security. 1a - Not everybody feels reassured after the experience in regards to security. 1b - Too many security measures can have a negative effect on the experience.	"The experience reassured me with regards to safety." "This shuttle drives better than I do." "Before having used the shuttle, it appeared to me that safety was essential. But the shuttle gave me a rather strong feeling of security." "I did not feel outstandingly safe. There are no seat belts, it might be difficult to hold on to something in case of a strong braking." "One gets lost in all of the security measures: slowness, emergency stops."
Autonomy - Independence	
Before	
1 - AMoD can make us independent from public transport and individualize our trips.	"On demand transport can help individualize travelers' needs."
2 - AMoD can improve the autonomy of certain population groups: the elderly, disabled, children or persons who do not have a car at their disposal.	"Autonomous shuttles can be a solution in case somebody is unable to drive, if you need to bring kids to school, for disabled persons, for the elderly…"
After	
1 - AMoD does bring certain advantages.	"It is good that one can take the shuttle anywhere and anytime."
2 - The autonomy of the autonomous shuttle is very incomplete.	"The autonomy of the shuttle was not flagrant compared to other means of public transportation."
Competence - Effectiveness	
Before	
1- The shuttle can allow us to be more efficient.	"It gives me a feeling of efficiency when a vehicle arrives exactly when I need it." "The autonomous shuttle needs to help me optimize my trips and make me win efficiency and time."
2 - The shuttle can improve the efficiency of public transport.	"The shuttle could help to go to areas which are currently not accessible by public transport, it would be a good complement to traditional public transport.
After	
In theory, the shuttle should help us gain effectiveness, but 1 - Its speed is not fast enough to evoke a feeling of effectiveness.	"We would have been faster walking." "If this would not have been an organized experience, we would not have waited for the shuttle. We would have walked to our destination."
2 - The shuttle was not always on time, which did have an impact on the experience the participants had.	"The shuttle is much less reliable than what I expected." "This was very inefficient."

Table 3. Main arguments expressed during the pre- and post-immersion focus groups, illustrated by participants' quotes.

These pre- and post-immersion rankings have a limited informative value on their own, however they support a deeper understanding of the entire experience when combined with the rationales and opinions expressed during the discussion phase. Table 3 sums the opinions expressed by the participants during the discussion phase of the workshop. Participants' quotes were analysed by the first author using the affinity diagram technique. Only the results related to the three most important needs (as perceived by participants), namely security, autonomy and competence, are presented. Regarding security, participants mainly expressed that the experience had a reassuring effect even though they noticed the absence of basic safety elements such as seat belts. On the other hand, the slowness of the shuttle and the frequent stops even had a negative impact on the experience. However, the factors that mostly influenced their perception were related to the perceived autonomy and effectiveness of the shuttle. What were seen before the experience as major advantages in favor of the development of AMoD were now the main elements of frustration, disappointment and eventually lack of acceptance. Quotes such as "this was very inefficient" or "we would have been faster walking" illustrate well the fact that participants' expectations regarding the effectiveness of the shuttle were not met. Interestingly, our observations suggest that the speed of an AMoD is a trade-off to be made in order to inspire a safety feeling on the one hand, while also giving the impression of effectiveness on the other hand.

DISCUSSION

AMoD is a particularly promising model of transportation which might provide a sustainable transport system, reduce private car ownership and minimize excess kilometers travelled due to empty vehicle relocation [17]. The results obtained through our study substantiate knowledge on the acceptability of AMoD by answering the question "How does the level of acceptability before an immersive experience and the level of acceptance after an immersive experience on an autonomous shuttle differ?".

Based on our results, the effectiveness of AMoD seems key to its acceptance. More specifically, waiting time and speed were identified as important contributors to a positive experience. This is in line with research which identified service attributes such as travel cost, time and waiting time as critical determinants of the use of shared autonomous vehicles [17]. However, other authors suggest that at-home pickup would be highly desirable to improve adoption of on demand transport [8]. Thus, one has to take into account that at-home pickup might alter the perception of the waiting time by the users. Effectiveness and competence are indeed considered important factors in human need theories but also in acceptance models (e.g. in CTAM, which takes into account self-efficacy).

It is noteworthy that the perceived usefulness of AMoD decreased significantly after the experience. This is relevant because perceived usefulness is not only considered relevant in the acceptance model TAM, but also in Mahlke's model of User Experience [23]. Effort expectancy is a dimension in all three acceptance models UTAUT, CTAM and TAM (corresponding to the perceived ease of use) and is also included in Mahlke's UX framework under the concept of usability. Participants in our study believed the effort required to use AMoD was low, and the level of effort expectancy stayed fairly similar after the immersive experience.

While Social influence is included into acceptance models such as CTAM and UTAUT, our participants did not rate its importance very high in the context of AMoD, an observation which became particularly clear during the discussion phase. However, we did not intend to specifically explore the impact of social influence nor did we experimentally implemented any variation related to social influence. Further studies would therefore be needed to understand whether social factors play a role in the acceptance of AMoD and how.

Overall, our work suggests that an immersion on an AMoD at its current state (as illustrated by the experimental autonomous shuttle used in the study) might have a negative effect on its global acceptance. While participants could envision use cases where AMoD might be useful (e.g., tourism, leisure time, improve autonomy of certain groups of the population), they did not find it useful for their personal transport habits.

These results are valid for the specific type of AMoD used in our experience only. Different approaches to AMoD might result in different results. However, it is important to note that the immersive experience did indeed have an effect on the acceptance of AMoD, which demonstrates that our methodological approach is of interest in order to explore the influence of a first experience on a new mobility concept. As the shuttle used by our participants in the experiment is indeed open to the public, we might question the value of showcasing such technologies at an early stage of development.

Needs-Driven UX Approach to the Design of AMoD

As indicated previously, there is an overlap between acceptance and UX theories [3], therefore most acceptance questionnaires actually cover UX aspects to some extent. However, it was essential for us to include missing UX factors such as hedonic motivation (be-goals). Thus, we used a UX needs-driven approach as a support to understand acceptability and acceptance more in depth. Our main theoretical contribution is to support the inclusion of human needs theories into existing acceptance models and to provide insights into their respective role in the process. This is in line with Hornbæk and Hertzum [14] who point to the absence of psychological needs in existing models. As our results show, it is indeed essential to understand users' motivations at the pragmatic and hedonic level.

Experiences can be categorized by the primary need they fulfill [13]. It seems that using an AMoD can be considered a competence-experience since participants have identified the lack of effectiveness of the current shuttle as critical during the discussion phase. The importance of effectiveness in the context of AMoD is conform with previous studies which identified travel time and waiting time being critical determinants of the use of shared autonomous vehicles [17]. While the overall effectiveness of the shuttle and the experience are decisive, the user also needs to feel competent by having all important information regarding the trip at disposal (e.g., waiting time, arrival time, current location of the shuttle).

The temporality of in-vehicle user experience has been studied by Petterson [29], who explored the experiential values of assistance systems in vehicles, suggesting that different sequences of an experience are linked to different experience aspects. We made similar observations about the temporality of user experience and technology acceptance. Before the immersive experience, there was a certain uneasiness amongst participants regarding the safety of autonomous vehicles (both individual and shared vehicles). This matches the results of previous studies [16], which also pointed out safety concerns of participants, particularly concerning hacker attacks. After the immersion, safety was mostly judged as sufficient, and participants felt reassured. However, acceptance factors such as perceived usefulness or behavioral intention to use an AMoD still decreased. This is consistent with existing studies [10], which state that the pragmatic quality of an interactive technology is a "hygiene factor" rather than a "motivator". It is essential for participants to feel safe during their trip, but the fulfillment of this need is not sufficient to create acceptance.

Participants stated that AMoD could improve the autonomy of certain groups of the population, e.g. children and the elderly, persons with disabilities and persons who do not possess a car. The fact that an AMoD is able to respond to mobility needs in a flexible manner was considered valuable. These advantages are linked to a very high presumed autonomy of the autonomous shuttle (which would be able to pick them up at home and to support their accessibility needs if required).

Given that the autonomy of the shuttle is not complete, participants addressed this issue after the immersive experience, questioning the increases in autonomy of certain groups of the population. Our results therefore indicate that a higher autonomy (linked to a higher effectiveness) of the shuttle might increase acceptance of this mode of transportation. If this proved to be consistent with larger sample sizes of the population, it would contradict findings suggesting that higher levels of car autonomy are associated to lower acceptance [30]. This would hence suggest that the needs and values associated to individual autonomous cars and AMoD are different. One might value high autonomy of shared transport options but prefer to keep more control over one's individual car. It is necessary to conduct comparative studies to further investigate potential differences.

The present study has also shown some limitations. The presence of an operator on board of the shuttle might have impacted the perception of autonomy. However, this safety controller has minimal interaction with users and only presses a button for the vehicle to start its journey. In most countries, the presence of an operator is a legal requirement, this constraint is therefore hard to avoid at this development stage. It is possible that his presence also contributed to the feeling of safety which was addressed by participants during the discussion phase of the workshop. Another limitation was related to our smartphone application prototype, which only gave a limited choice of itineraries in order to fit the itinerary of the existing shuttle which we used for the Wizard of Oz simulation.

In our AMoD scenario, we were not able to control certain aspects of the experience. The autonomous shuttle was not always on time, leading to waiting times between 5 and 25 minutes, which differed between groups. This might influence the group's judgement (particularly regarding the effectiveness) of the shuttle. On another perspective, the difference in waiting times between groups might create even more realistic experiences. Even though we used questionnaires during the experiment, we have chosen to use a qualitative approach to address our research question. The number of participants involved in our study is therefore too low to compute inferential statistics or to obtain quantitative generalizable results. Qualitative researchers typically don't set generalizability as a goal [21] but rather use this approach to explore a new area and develop hypotheses [25]. While we do not claim a strong generalizability of our results, we reasonably assume that our analysis speaks beyond its few participants. In the study, we attempted to maximize the validity of the research by: sampling representative participants, designing a realistic AMoD experience, and basing our research on existing theoretical models while also contrasting findings on AMoD with autonomous cars. The congruence of our findings with prior theory adds support to their potential generalizability.

While we could not conduct any meaningful comparison of the different subgroups with divergent waiting times, this would be an interesting approach for further investigations.

Our original methodology allowed us to gain rich insights. On a qualitative level, the sample size is reasonable enough to gain significant and compelling insights on factors that need to be taken into consideration when designing AMoD experiences. Given that we conducted three workshops, biases linked to conducting one focus group only were mitigated. The topics which were brought up by participants became largely recurrent in the third focus group, allowing us to understand the main thoughts and concerns linked to AMoD. We were also able to demonstrate that the methodology used is capable of providing highly useful outcomes. Future studies with a bigger sample of representative participants could provide generalizable findings which would be highly valuable for all stakeholders.

CONCLUSION

In the present study, we placed 14 participants in an immersive AMoD experience in order to compare the acceptability (before first use) and acceptance (after first use) of an AMoD system. We used a mixed methods approach, complementing acceptance questionnaires with a psychological needs-driven approach using UX cards. Thereby, we were able to understand underlying factors which influence acceptability and acceptance. Our results show that that participants were reassured regarding safety concerns they had expressed. Nevertheless, the AMoD experienced during this study was perceived as not sufficiently effective. Consequently, perceived usefulness and performance expectancy both decreased significantly. These results shed light on factors which are essential for an optimal AMoD experience. Our study also revealed points of improvement, thereby providing leads to AMoD designers and researchers striving to develop a positive AMoD experience. We expect the results of this study to contribute to the development of user-centered AMoD and to inspire future studies in the context of new forms of mobility.

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REFERENCES

1. Adell, E. (2010). Acceptance of driver support systems. In Proceedings of the European Conference on Human Centred Design for Intelligent Transport Systems. Berlin, Germany.

2. Auvray, M., Lefèvre, J., Lenay, C., & O'Regan, K. (2005). Suppléance perceptive, immersion et informations proprioceptives, Arob@se, 1, 94-113.

3. Barcenilla, J., & Bastien, J.-M.-C. (2009). L'acceptabilité des nouvelles technologies : quelles relations avec l'ergonomie, l'utilisabilité et l'expérience utilisateur ? Le travail humain, 72(4), 311.

4. Bellet, T., Paris, J.-C., & Marin-Lamellet, C. (2017). The difficulties of elderly drivers when driving and their expectations concerning driving aids. Transportation Research Part F: Traffic Psychology and Behaviour.

5. Chong, Z. J., Qin, B., Bandyopadhyay, T., Wongpiromsarn, T., Rankin, E. S., Ang, M. H., Low, K. H. (2011). Autonomous personal vehicle for the first- and last-mile transportation services. MIT Web Domain.

6. Davis Jr, F. D. (1986). A technology acceptance model for empirically testing new end-user information systems: Theory and results (Doctoral dissertation). Massachusetts Institute of Technology.

7. Etherington, D. (2017). Las Vegas launches the first electric autonomous shuttle on U.S. public roads. Retrieved March 21, 2017, from https://techcrunch.com/2017/01/11/las-vegas-launches-the-first-electric-autonomous-shuttle-on-u-s-public-roads

8. Frei, C., Hyland, M., & Mahmassani, H. S. (2017). Flexing service schedules: Assessing the potential for demand-adaptive hybrid transit via a stated preference approach. Transportation Research Part C: Emerging Technologies, 76, 71–89.

9. Green, P., & Wei-Haas, L. (1985). The Rapid Development of User Interfaces: Experience with the Wizard of OZ Method. Proceedings of the Human Factors Society Annual Meeting, 29(5), 470–474.

10. Hassenzahl, M. (2001). The effect of perceived hedonic quality on product appealingness. International Journal of Human-Computer Interaction, 13(4), 481–499.

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

12. Hassenzahl, M. (2008). User experience (UX): towards an experiential perspective on product quality. In Proceedings of the 20th Conference on l'Interaction Homme-Machine (pp. 11–15). ACM.

13. Hassenzahl, M., Eckoldt, K., Diefenbach, S., Laschke, M., Len, E., & Kim, J. (2013). Designing moments of meaning and pleasure. Experience design and happiness. International Journal of Design, 7(3).

14. Hornbæk, K., & Hertzum, M. (2017). Technology Acceptance and User Experience: A Review of the Experiential Component in HCI. *ACM Transactions on Computer-Human Interaction*, *24*(5), 1–30.

15. Kim, J., Park, S., Hassenzahl, M., & Eckoldt, K. (2011). The essence of enjoyable experiences: the human needs. In International Conference of Design, User Experience, and Usability (pp. 77–83). Springer.

16. König, M., & Neumayr, L. (2017). Users' resistance towards radical innovations: The case of the self-driving car. Transportation Research Part F: Traffic Psychology and Behaviour, 44, 42–52.

17. Krueger, R., Rashidi, T. H., & Rose, J. M. (2016). Preferences for shared autonomous vehicles. Transportation Research Part C: Emerging Technologies, 69, 343-355.

18. Lallemand, C. (2015). Towards consolidated methods for the design and evaluation of user experience (Doctoral dissertation).
19. Law, E. L.-C., Vermeeren, A. P., Hassenzahl, M., & Blythe, M. (2007). Towards a UX manifesto. In Proceedings of the 21st British HCI Group Annual Conference on People and Computers: HCI... but not as we know it-Volume 2 (pp. 205–206). British Computer Society.
20. Liamputtong, P. (2011). Focus Group Methodology. London: Sage.
21. Leung, L. (2015). *Validity, reliability, and generalizability in qualitative research* (Vol. 4).
22. Madigan, R., Louw, T., Dziennus, M., Graindorge, T., Ortega, E., Graindorge, M., & Merat, N. (2016). Acceptance of Automated Road Transport Systems (ARTS): an adaptation of the UTAUT model.
23. Mahlke, S. (2008). User experience of interaction with technical systems (Doctoral dissertation).
24. Martin, N., Jamet, É., Erhel, S., & Rouxel, G. (2016). From Acceptability to Acceptance: Does Experience with the Product Influence User Initial Representations? In C. Stephanidis (Ed.), HCI International 2016 – Posters' Extended Abstracts (Vol. 617, pp. 128–133). Cham: Springer International Publishing.
25. Miles, H., Huberman, M., Saldana, J. (2014) Qualitative Data Analysis. London: Sage.
26. Osswald, S., Wurhofer, D., Trösterer, S., Beck, E., & Tscheligi, M. (2012). Predicting information technology usage in the car: towards a car technology acceptance model. Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 51–58). ACM.
27. Partala, T., & Kallinen, A. (2012). Understanding the most satisfying and unsatisfying user experiences: Emotions, psychological needs, and context. Interacting with Computers, 24(1), 25–34.
28. Pavone, M. (2016). Autonomous Mobility-on-Demand Systems for Future Urban Mobility. In M. Maurer, J. C. Gerdes, B. Lenz, & H. Winner (Eds.), Autonomous Driving (pp. 387–404). Berlin, Heidelberg: Springer Berlin Heidelberg.
29. Petterson, I. (2016). The temporality of in-vehicle User Experience. Retrieved from http://publications.lib.chalmers.se/records/fulltext/236743/236743.pdf
30. Rödel, C., Stadler, S., Meschtscherjakov, A., & Tscheligi, M. (2014). Towards Autonomous Cars: The Effect of Autonomy Levels on Acceptance and User Experience (pp. 1–8). ACM Press.
31. Schade, J., & Schlag, B. (2003). Acceptability of urban transport pricing strategies. Transportation Research Part F: Traffic Psychology and Behaviour, 6(1), 45–61.
32. Schuitema, G., Steg, L., & Forward, S. (2010). Explaining differences in acceptability before and acceptance after the implementation of a congestion charge in Stockholm. Transportation Research Part A: Policy and Practice, 44(2), 99–109.
33. Sheldon, K. M., Elliot, A. J., Kim, Y., & Kasser, T. (2001). What is satisfying about satisfying events? Testing 10 candidate psychological needs. Journal of Personality and Social Psychology, 80(2), 325.
34. Somat, A., Jamet, E., Menguy, G., Forzy, J.-F., & El-Jaafari, M. (2012). Acceptabilité individuelle, sociale & acceptation. Livrable L5.3 du projet PARTAGE (ANR--08--VTT--012--01).
35. Spieser, K., Treleaven, K., Zhang, R., Frazzoli, E., Morton, D., & Pavone, M. (2014). Toward a systematic approach to the design and evaluation of automated mobility-on-demand systems: A case study in Singapore. In Road Vehicle Automation (pp. 229–245). Springer.
36. Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. MIS Quarterly, 425–478.
37. Venkatesh, V., Thong, J. Y., & Xu, X. (2012). Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology. MIS Quarterly, 36(1), 157–178.