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Autonomous buses: Intentions to use, passenger experiences, and suggestions for improvement

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ABSTRACT

Research on the use of autonomous vehicles as a mode of public transport in a city context is lacking. This paper focuses on the use of recently established autonomous buses (self-driving electric shuttle buses) running along a regular public transport line in a residential area of Oslo, Norway. We use a mixed-methods approach based on survey and interview data from two independent studies. The paper examines intentions to use autonomous buses before and after these were introduced in the case area as well as how passengers experience traveling by autonomous bus. Results show that the intention to use the autonomous buses was mostly positive both before and after using them. Most users felt safe while traveling by autonomous bus. Two suggestions for improvement made by the users were to: increase the speed and reduce the abrupt breaking of the autonomous buses. Overall, outcomes from this paper suggest that residents would be willing to use autonomous buses if these offer more frequent bus departures than the existing ones. However, as full automation has not been achieved yet and there is a host on board who can control the vehicle if necessary, passenger experiences and intentions to use should be reassessed with fully automated buses in future studies.

1. Introduction

Research on autonomous vehicles is growing tremendously. The majority of relevant research studies has been focusing on autonomous cars, neglecting what seems to be the more environmentally friendly version of autonomous vehicles: the autonomous buses (Nenseth, Ciccone, & Kristensen, 2019). Autonomous buses – also called self-driving or driverless buses or automated shuttles – are being tested with pilot projects in several cities worldwide (Ainsalu et al., 2018; Nordhoff, de Winter, Madigan, et al., 2018). At the same time, technology is being developed aiming to reach higher automation levels. Early studies on the use of autonomous buses indicate positive attitudes among users and feelings of safety and security during the ride (Nordhoff, de Winter, Madigan, et al., 2018; Rehrl & Zankl, 2018; Salonen & Haavisto, 2019). The few existing studies have been conducted in areas including a university campus, an office campus, and a small village. Insights from the use of autonomous buses in residential areas in cities are lacking. Such insights are important to understand whether and how autonomous buses could be used in a city context, and more specifically: how they are perceived and experienced by urban residents and whether and in what ways urban residents may use them.

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This paper aims to cover this gap in knowledge on the use of autonomous buses in a city context. The paper investigates the use of autonomous buses in a residential area of Oslo, Norway by focusing on residents' intentions to use autonomous buses, passenger experiences, and suggestions for improvement. We examine recently established self-driving electric shuttle buses running along a regular public transport line in a residential area in Oslo. A mixed-methods approach combining survey and interview data is employed in the paper. The analysis is based on two independent studies: "before use" and "after use". The "before use" part examined residents' future intention to use autonomous buses before these were introduced in the case area. The "after use" part was conducted after the autonomous buses were introduced in the area and investigates how users experience their trip and whether they would use autonomous buses in the future. The research questions addressed in the paper are: "do residents intend to use autonomous buses regularly in the future?", "how do users experience travel by autonomous bus?", and "how could traveling by autonomous bus be improved according to the users?"

The contribution of the paper is threefold. (a) It provides empirical evidence on the use of autonomous buses in a residential area of a major city. Evidence from a city context is scarce in existing literature, but it is necessary in order to provide insights into the potential use of autonomous buses as part of cities' transport systems. (b) It presents findings on intentions to use both before and after autonomous buses were introduced in the case area, thus allowing evaluations of whether intentions to use change after a first travel experience with autonomous buses. (c) It employs a mixed-methods approach that provides both quantitative trends on intentions to use autonomous buses and qualitative understanding of residents' attitudes, travel experiences, and suggestions for improvement. Such an approach is conducive to more nuanced answers to the research questions of the paper.

The paper is structured as follows. Section 2 presents an overview of relevant literature, with a particular focus on acceptance and use of autonomous buses. Section 3 presents the methodological background of the paper, including a description of autonomous buses in Oslo, an introduction to the case area, and a description of data collection and data analysis methods used in the paper. Section 4 presents the results of the paper, including the "before use" part, the "after use" part, and an overall synthesis. Section 5 discusses the paper's findings in relation to previous relevant research and relevant ongoing debates, while it also provides some concluding remarks and recommendations for future research.

2. Literature review

Autonomous vehicles are the vehicles that can recognize their environment and drive safely with little or no human interference (Taeihagh & Lim, 2019). Autonomous vehicles can be categorized as (1) private autonomous cars, (2) shared autonomous cars/taxis, and (3) autonomous buses (Bösch, Becker, Becker, & Axhausen, 2018; Litman, 2020). Early studies, based on hypothetical models and simulations, suggest that autonomous cars – both private and shared – will result in increased vehicle miles traveled, shifts from public transport and active travel modes to more car travel, and more urban sprawl (Fagnant & Kockelman, 2015; Milakis, van Arem, & van Wee, 2017; Narayanan, Chaniotakis, & Antoniou, 2020; Soteropoulos, Berger, & Ciari, 2019). Therefore, autonomous vehicle technology seems to be in conflict with the sustainable mobility paradigm (see Banister, 2008).

Autonomous vehicle technology could however be more environmentally friendly if used to support public transport instead of private mobility and car travel (Ainsalu et al., 2018; Fraedrich, Heinrichs, Bahamonde-Birke, & Cyganski, 2019; Litman, 2020). Autonomous vehicles can be used as a public transport mode in the form of autonomous buses. Autonomous buses can be either shuttle buses taking up to around 10 passengers or large mass transit buses (Ainsalu et al., 2018). Thus, they could be used to replace conventional public transport or support existing public transport by adding new departures or providing first and last mile transportation (Ainsalu et al., 2018; Bösch et al., 2018). A more efficient city bus system could increase the modal share of public transport and reduce car travel (Nenseth et al., 2019). Autonomous buses may have demand-driven schedules and could potentially dynamically adjust their capacity, trajectory, and stopping according to passenger demand (Cao & Ceder, 2019; Dai, Liu, Chen, & Ma, 2020). Autonomous buses may have lower operational costs than regular buses (Abe, 2019; Gkartzonikas & Gkritza, 2019). Electric autonomous buses, which are often employed in pilot projects, may offer potential environmental benefits of electric vehicle technology (see e.g. Hawkins, Singh, Majeau-Bettez, & Strømman, 2013; Moradzadeh & Khaffafi, 2017). Although autonomous buses seem to be more environmentally friendly compared to autonomous cars, this does not necessarily mean that they are more environmentally friendly than regular buses. Moreover, if autonomous buses replace regular buses instead of complementing them, there might be negative societal implications such as fewer jobs for bus drivers and unemployment. Further assessment of autonomous buses' environmental and social sustainability especially in comparison to regular buses is necessary.

According to public perceptions based on focus group discussions, positive aspects of autonomous buses include the potential decrease in operational costs, reduction of road congestion, and reduction in transport emissions, while negative aspects include the costs of vehicles and infrastructure, certain security risks, and potential unemployment risks (López-Lambas & Alonso, 2019). The use of autonomous vehicle technology for public transport appears to be generally well accepted among citizens (Nordhoff, De Winter, Kyriakidis, Van Arem, & Happee, 2018). On the other hand, the public seems to be more reluctant towards private cars (Kyriakidis, Happee, & de Winter, 2015). According to a Eurobarometer survey conducted in 2014, 6 out 10 European citizens would feel uncomfortable traveling in a car with little or no human intervention (European Commission, 2015). Sociodemographic factors such as age, gender, and education are associated with the acceptance and perception of autonomous vehicles (Herrenkind, Nastjuk, Brendel, Trang, & Kolbe, 2019; Hulse, Xie, & Galea, 2018).

Acceptance of autonomous vehicles might be related to 28 different factors including individual sociodemographic characteristics, but also travel behavior, personality, exposure to autonomous vehicles, as well as contextual, social, and emotional factors (Nordhoff, Kyriakidis, van Arem, & Happee, 2019).

Early studies have been inquiring specific groups about future use of autonomous buses (Dong, DiScenna, & Guerra, 2019; Roche-Cerasi, 2019), while others inquired passengers of autonomous bus pilots (e.g. Madigan, Louw, Wilbrink, Schieben, & Merat, 2017; Nordhoff, de Winter, Madigan, et al., 2018; Papadima, Genitsaris, Karagiotas, Naniopoulos, & Nalmpantis, 2020). Based on existing evidence from users in pilot projects in Austria, Finland, and Germany, overall attitudes as well as perceptions of safety during travel by autonomous bus seem to be positive (Nordhoff, de Winter, Madigan, et al., 2018; Rehrl & Zankl, 2018; Salonen & Haavisto, 2019). It has to be mentioned, however, that during pilot trials of autonomous buses, there is a host who can control the vehicle if necessary, and this might positively influence perceptions of safety and overall travel experience. Some first-time users of autonomous vehicles have idealized expectations that were not fulfilled during their ride (Nordhoff, De Winter, Payre, Van Arem, & Happee, 2019). Although passengers of autonomous buses report feeling safe in terms of traffic safety, they may feel more insecure in terms of fear of attack inside the vehicle (Salonen, 2018). Safety perceptions among citizens who have never used autonomous vehicles are more mixed (see e.g. Pettigrew, Worrall, Talati, Fritschi, & Norman, 2019) compared to the mostly positive ones among those who have used autonomous shuttle buses (Salonen & Haavisto, 2019). Two negative aspects from passengers' experiences seem to be the low vehicle speed and the limited space for carry-on items due to the small size of the shuttle buses used in the pilots (Nordhoff, de Winter, Madigan, et al., 2018). Finally, it seems that travel comfort of autonomous bus passengers, in terms of acceleration and deceleration, needs further improvement (Bae, Moon, & Seo, 2019).

3. Methods

3.1. Autonomous buses in Oslo

The paper focuses on the use of autonomous buses in Oslo, the capital of Norway. The autonomous buses have been introduced in Oslo as a pilot project that is part of a larger smart mobility program called "Smarter transport in the Oslo region (STOR)". The program is undertaken in collaboration between the City Environment Agency of Oslo Municipality, the Norwegian Public Roads Administration, and the Public Transport Authority for Oslo called Ruter. Autonomous buses are running in Oslo as part of line 85B in the residential area of Ormøya (Fig. 1). Norwegian planning laws allow the introduction of autonomous vehicles – in this case autonomous buses – for testing their impact on road safety, traffic efficiency, mobility, and the environment.

The autonomous buses of line 85B in Oslo are self-driving electric shuttle buses that can carry 8 persons plus a host. The buses are not yet fully automated. The host provides assistance and information and may manually control the vehicle if necessary. The buses operate at a speed limit of 18 km per hour. They are running on a predefined route (Ruter, 2020). Technology so far does not allow the bus to diverge from this predefined route, so the host on board may control the vehicle in case the bus needs to drive around obstacles. The bus adjusts its speed based on the distance to the surroundings and other road users. It stops if another road user comes close. The bus cannot distinguish between different objects, so its reaction is the same for any type of object that is scanned by its sensors. For this reason, the bus cannot operate in case of heavy precipitation (Lopatka, 2019). The bus is driving itself using sensors that continuously gather data on the surrounding objects, vehicles, and pedestrians. It uses light detection and ranging (LIDAR) sensors (8 sensors, 4 front and 4 rear), global navigation satellite system (GNSS) for positioning, odometer for scroll wheel information, and inertial measurement unit (IMU) that measures the bus movement pattern to recognize speed bumps and distortions along the route (Ruter, 2020).

Fig. 1. The route of the autonomous bus 85B in Oslo. Source: Ruter.

3.2. Case area

The autonomous buses have been introduced in the residential area of Ormøya in Oslo (Fig. 1) and were planned to drive there for one year in total. Ormøya is a relatively low-density, single use area of suburban character. The travel distance to Oslo city center is around 5 km and the travel time by regular bus is 15 min. The autonomous buses have been introduced as a first-last mile transportation option connecting different locations in the Ormøya area to the main stop (Nedre Bekkelaget) of the conventional buses that drive to Oslo city center. The route (line 85B) that the autonomous buses cover is 1.5 km long (Fig. 2). One of the aims of the autonomous bus pilot project in Ormøya area has been to understand whether frequent autonomous buses would facilitate the use of public transport instead of the car. Before the pilot, route 85B was covered only by a conventional bus with one-hour intervals. This conventional bus covers route 85B and then drives to (and from) Oslo city center. When autonomous buses were introduced, they added around four extra departures per hour along route 85B. This has offered residents of Ormøya additional, more frequent options to arrive at Oslo city center by public transport, as they can use the autonomous buses to arrive at Nedre Bekkelaget and then ride conventional buses to Oslo city center.

3.3. Data collection

The paper is based on two independent studies: a "before use" study and an "after use" study. The "before use" study draws data on residents' future intention to use the autonomous bus that would later be introduced in Ormøya, Oslo. The "after use" study focuses on the use of the newly introduced autonomous buses and investigates how passengers experience their trip and whether they would use autonomous buses again in the future. Future use intentions are assessed in the study since behavioral intention is considered to be a direct predictor of actual behavior (Ajzen, 2002). The targeted population of the "before use" part is Oslo residents who live or work in the wider Ormøya area or visit the area for other purposes. The targeted population of the "after use" part is Oslo residents who used the autonomous bus after its introduction in Ormøya.

The "before use" data collection was performed in December 2018 by Skuterud Kløvstad AS (2018) for Ruter. Skuterud Kløvstad AS and Ruter agreed to provide these data for the purposes of this paper. Data were obtained through a questionnaire survey with residents of Oslo, recruited in the street in the area of Ormøya. Most of them were residents of the area, while some were working in the area and few were simply visitors. The total sample was N = 117 respondents. The survey was conducted in the Norwegian language. The questionnaire was short (2–5 mins) and anonymous. It included questions on demographic attributes (age and gender), residential location, car use, perceptions of main transport challenges along the route connecting Malmøya to Nedre Bekkelaget (route 85B, Fig. 1), and intentions to use autonomous buses if they were introduced along that route in the future. The question on use intentions was phrased so that it describes the planned route of the autonomous buses and explains that the frequency of the departures will be increased compared to the current situation. The wording used for the question was: "if Ruter, in the future, sets up a self-driving bus between the current bus stop in Malmøya and the Shell station at Mosseveien with higher frequency than today's bus schedule, how likely are you to use or try this self-driving bus?". The question was measured on a scale from "very unlikely" (1) to "very likely" (5). It should be noted that due to its short length, the questionnaire survey does not include data that could have made our quantitative analysis even more informative. Such data could have been additional sociodemographic attributes like income and education level; attitudes towards travel and travel preferences; attitudes towards technology; and more detailed information on residential location, trip destinations, and travel behavior. Moreover, the sample of the survey dataset is relatively small. We acknowledge these limitations in our paper.

Table 1 presents survey participant characteristics of the "before use" dataset. The sample included a relatively balanced mix of both genders and diverse age groups. The majority of the survey participants are residents living in the wider area of

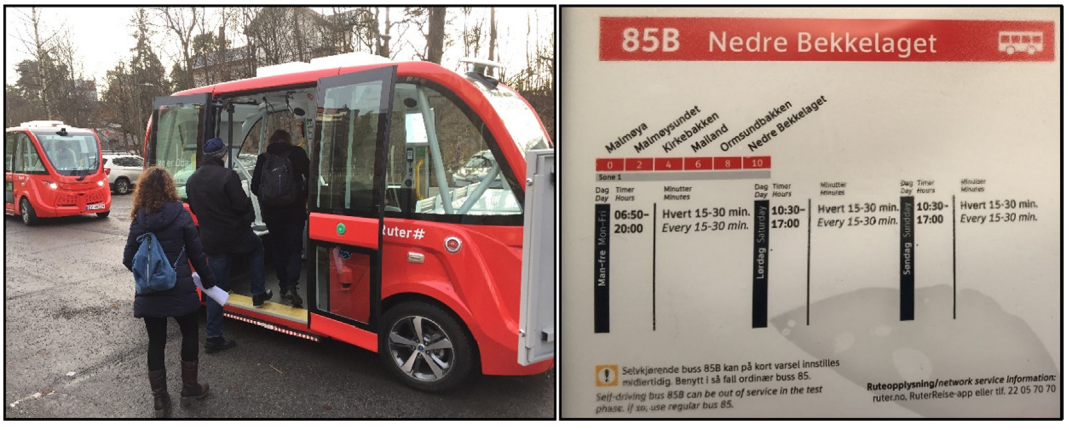

Fig. 2. The autonomous buses in operation (left). Sign with the autonomous bus schedule (right).

Table 1
Participant characteristics of the "before use" survey.

	N	%
Gender		
Female	65	56%
Male	52	44%
Age groups		
15–19	24	21%
20–29	11	9%
30–39	14	12%
40–49	26	22%
50–59	19	16%
60–69	13	11%
70–90	10	9%
Residential area		
Living in the area	100	85.5%
Working in the area	13	11%
Visitor in the area	4	3.5%
Car user		
Uses car	51	44%
Does not use car	66	56%
Perceptions of major transport challenges along the route 85B		
Infrequent conventional bus (perceived)	71	61%
Other	46	39%

Data source: Skuterud Kløvstad (2018). N = 117.

Ormøya (100 local residents). The sample includes both car users and non-users, with 44% of the participants reporting that they use a car for at least some of their trips and 56% reporting that they do not use a car at all. The most commonly reported transport challenge along the examined route (85B) was the low frequency of the conventional bus departures, with 61% of the participants reporting that this is a major transport challenge in the area. This is reasonable since the conventional bus runs in one-hour intervals. The relatively low population density in the wider area does not provide the necessary population base for a more frequent conventional bus.

The "after use" data collection was performed in January-February 2020. These data were collected by the authors. Data were obtained with street interviews in the area of Ormøya in Oslo. Street interviews were chosen as a data collection method for the "after use" study in order to obtain more nuanced information on passengers' experiences and attitudes towards autonomous buses. Participants were recruited in the street, at the bus stops, and on the autonomous bus. Most of the interviews were conducted in the street after the participants' trip by autonomous bus. Two interviews were conducted on the autonomous bus, since the interviewees had already used it earlier on the same day and did not have time available for an interview in the street. The interviews were semi-structured. Questions of both quantitative and qualitative nature were asked. Quantitative type of questions included the intention to use the buses in the future and the feelings of safety during the trip. Qualitative questions included qualitative elaborations on intentions of future use, travel experiences, and attitudes. There were some predefined questions that were asked to all participants, but additional themes were also explored during the interviews based on the interviewee responses. The interview questions can be found in the Appendix. The duration of the interviews ranged from 5 min to 18 min, except for one interview that lasted one and a half minutes because the respondent had to catch the conventional bus. The median duration of the interviews is 7 min. The majority of the people who were approached accepted to be interviewed. The very few ones (six individuals) who did not accept could not do so because of time restrictions. The order of the questions was the same for all interviewees, unless interviewees brought up a theme earlier by themselves. Questions had to be paraphrased when interviewees did not understand them. Supplementary questions were asked when clarifications were necessary. "How" and "why" questions were also asked to obtain an understanding of the reasoning behind the answers. The interviews collected answers from N = 25 participants. A relative high degree of data saturation (Faulkner & Trotter, 2017) was achieved as no new themes emerged during the last round of interviews and the conclusions drawn from the data remained substantially the same. The interviews were conducted in English. They were recorded with an audio recorder. The audios were then transcribed to text (verbatim transcription). The interview data collection was anonymous. Reporting and quoting in the paper are also anonymous. The paper is part of the research project "App Cities". Ethics approval was received by the Norwegian Center for Research Data (NSD), prior to the beginning of this research, with reference number 869419.

Table 2 presents the characteristics of each participant of the "after use" dataset including demographic attributes, residential area, car ownership, mode of commuting, and travel preferences. Table 2 also shows whether interview participants had used autonomous buses before, whether they felt safe during the ride, and whether they would use autonomous buses again in the future. Some participants lived in the area of Ormøya and surrounding areas, and some came from other parts of Oslo. The majority of the respondents owned a car. The sample has high diversity in travel modes for commuting and favorite travel mode. There are many respondents who commuted by public transport, while there are also several who commuted

Table 2
"After use" participant characteristics, perceptions of personal safety, and intentions to use in the future.

Participant ID	Age group	Gender	Employment	Residential area in Oslo	Car ownership	Commute mode	Favorite travel mode	First time user	Felt safe	Intention to use in the future
1	35–44	Female	Employee	Nordstrand	Y	Tram	Walk-Bike-Bus-Tram	Y	Y	Y
2	45–54	Male	Employee	Sørenga	Y	Bus	Taxi	Y	Y	Y
3	55–64	Male	Employee	Bjørndal	Y	Bus-Train	Bike-Train	Y	Y	Y
4	45–54	Female	Employee	Bjørndal	Y	Metro-Bus	Train	Y	Y	Y
5	25–34	Male	Employee	Sagene	N	Bus	Bike	Y	Y	n/a
6	25–34	Female	Employee	Sagene	N	Bus	Bike	Y	Y	n/a
7	15–24	Female	Employee	Ormøya	N	Bus-Walk	Car	Y	Y	Y
8	45–54	Female	Employee	Gamle Byen	Y	Walk-Tram-Metro	Walk-Tram-Metro	N	N	N
9	15–24	Female	Student	Ormøya	N	Bus	Car	Y	Y	N
10	35–44	Female	Employee	Ormøya	Y	Bus	Train	Y	Y	Y
11	65–74	Female	Pensioner	Ormøya	N	n/a	n/a	Y	Y	Y
12	35–44	Female	Other	Ormøya	Y	Bus	Bike	Y	Y	N
13	55–64	Female	Employee	Nordstrand	Y	Car	Walk-Tram-Car	Y	Y	Y
14	35–44	Female	Employee	Ekeberg	Y	Bus	Bike	Y	Y	Y
15	n/a	Female	n/a	Ormøya	n/a	n/a	n/a	N	n/a	Y
16	45–54	Male	Employee	Nordstrand	Y	Car	Car-Train	Y	Y	Y
17	35–44	Female	Employee	Nordstrand	Y	Car	Car	Y	Y	Y
18	55–64	Male	Employee	Holtet	Y	Tram	Train	Y	Y	Y
19	15–24	Male	Student	Voksenkollen	Y	Walk	Car	Y	n/a	Y
20	15–24	Female	Student	Tøyen	Y	Bus	Car	Y	Y	Y
21	45–54	Female	Employee	Nordstrand	Y	Car	Car	Y	Y	Y
22	45–54	Female	Employee	Nordstrand	Y	Car	Car	Y	Y	Y
23	25–34	Male	Employee	Årvoll	Y	Bus	Car	Y	Y	N
24	25–34	Female	Employee	Årvoll	Y	Bus	Car-Metro	Y	Y	Y
25	45–54	Female	Employee	Holtet	Y	Tram-Metro	Metro	N	Y	Y

Data source: Data collection by the authors. N = 25. Y = Yes, N = No, n/a = not applicable/don't know/not stated.

by car. Active travel modes like walking and biking, but also public transport modes and the car were all reported among the favorite travel modes of the participants.

3.4. Data analysis

A flowchart of the paper's research design is presented in Fig. 3. The paper includes quantitative and qualitative analysis. Quantitative analysis was performed on the "before use" survey data and the quantitative data obtained from the "after use" interviews. The quantitative analysis was done with descriptive statistics and logistic regression analysis. The limited sample size (N = 117) and lack of important variables on travel behavior prevented us from using more complex statistical analysis techniques. The quantitative analysis was conducted in statistical software SPSS (version 27).

Qualitative analysis focused on the qualitative input from the interviews of the "after use" study. This qualitative analysis attempts to explain and enrich quantitative results in a mixed-methods research design that is useful in studies related to travel experience and travel behavior as it can offer a more in-depth understanding of the examined relationships (Nordhoff, Stapel, van Arem, & Happee, 2020; Næss, 2018). Qualitative data were analyzed with thematic analysis. The six steps by Braun and Clarke (2006) were followed. These were: (1) familiarization with data (transcription of data, listening audios, studying transcribed texts), (2) initial coding, (3) searching for themes (and sub-themes), (4) reviewing themes, (5) defining and naming themes, and (6) reporting the results: "selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis" (Braun & Clarke, 2006, p. 87). We produced six main themes (categories): future use intentions, safety, automation level, speed, braking, and vehicle design. Two of them were based on focused questions of the interview guide (future use intentions and safety), while the other four emerged as common observations among the interviewees (automation level, speed, braking, and vehicle design). The theme "future use intentions" is based mainly on answers to the questions: "Do you intend to use self-driving buses if they run regularly in the future? If yes, why? If no, why?" This question aimed at exploring whether participants would consider using autonomous buses if these became a regular mode of transport in the city after this pilot testing phase. The theme "safety" is based mainly on answers to questions about feelings of safety during the trip: "How safe did you feel during the trip? Did you expect the trip to be safer, less safe or the same?" The themes "automation level", "speed", "braking", "vehicle design" were extracted from interviewees' responses to general questions about their

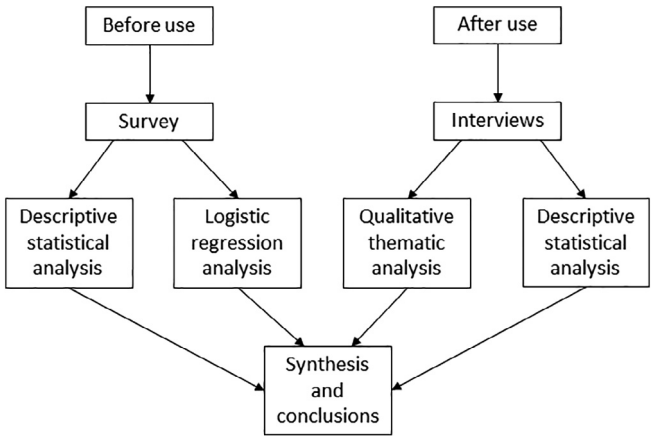

Fig. 3. Research design of the paper.

trip: "What is your overall impression about traveling by self-driving bus? What kind of observations did you make during the trip? Did something surprise you?"

4. Results

4.1. Before use

The "before use" survey included a question examining the intention to use autonomous buses if they were to be set up in the future along this route. Fig. 4 presents the results for this question. The majority of the respondents (64%) stated that it is very likely that they will use or try this bus, while 17% stated that it is quite likely that they will use or try the bus.

Next, we analyzed the "before use" survey data with logistic regression. We aimed to explore whether and how demographic attributes, living or working in the area, car use, and perceptions of the conventional bus relate to the likelihood of using autonomous buses if they were introduced along the examined route in the future. For this analysis, the dependent variable – intention to use autonomous buses – was converted to a dichotomous variable. Intention to use was considered likely (=1) for the responses "quite likely" and " very likely" while for responses "very unlikely", "quite unlikely", and "maybe", the intention to use was considered unlikely (=0). We derived our logistic regression models analytically based on the following rationales. (1) Demographic attributes (age and gender) may directly affect future use intentions. Older adults may be more skeptical towards new technologies. Gender differences may also be linked to car use (Uteng & Cresswell, 2008) and intentions to use public transport. (2) Living or working in the area may affect intentions to use autonomous buses along the examined route, since local residents and workers are the ones who use the route more often. (3) Car use may affect future use intentions as car users may be in a lower need of using public transport. (4) Perceptions of infrequent conventional buses may affect intentions to use autonomous buses, since those who report infrequent bus departures as the major transport challenge in the local area might be those who would be interested in using a more frequent (autonomous) bus in the future.

Table 3 presents the results of the logistic regression analysis. Table 3 indicates the following main outcomes. First, perceptions of infrequent conventional buses are positively associated with the likelihood of using autonomous buses in the

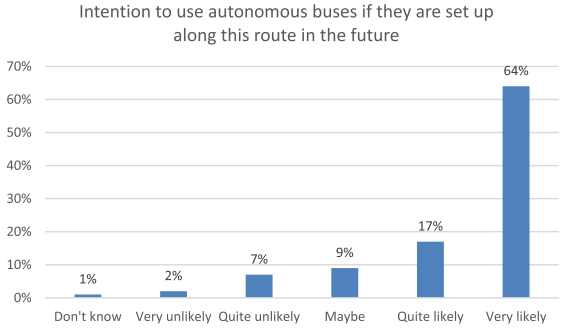

Fig. 4. Intention to use autonomous buses if they are set up in the future (before use).

future. The association is significant at the p < 0.01 level. This finding confirms the hypothesis that those who report infrequent bus departures as the main transport challenge in the area could be those who would be more interested in using a more frequent autonomous bus in the future. Model 2 in Table 3 shows that the inclusion of the "car user" variable but mainly the variable on perceptions of infrequent conventional buses substantially increases the amount of variation explained in the analysis. The second major outcome of the regression analysis is that age is negatively associated with the likelihood of using autonomous buses in the future. Older individuals seem to be less willing to use autonomous buses, possible because they are more reluctant to use new technologies and/or because they are more indifferent or more tolerant to the low frequency of the conventional bus departures in the area.

4.2. After use

4.2.1. Future use intentions

The "after use" dataset examined the intention of the autonomous bus passengers to use autonomous buses again in the future. Participants were asked whether they intend to use autonomous buses if they run regularly in Oslo in the future. As seen in Fig. 5, the majority, 76%, responded that they would use autonomous buses in the future. Table 2 above also indicates that both public transport users and car users among the sample were positive about using autonomous buses in the future.

Several participants felt that it is useful to have autonomous buses driving in areas where public transport in not very frequent, and that they would use them quite often. These insights support the "before use" findings (Section 4.1) that perceptions of infrequent conventional buses are linked to intentions to use autonomous buses. Some participants claimed that it does not make a difference to them whether the bus has a driver or not, and that they would take the first bus that arrives at their bus stop. Some examples of all these qualitative insights are:

> Yes I think so, especially if they set up these buses to routes that are poorly served by the regular big buses. That would be a very nice thing. And we are actually looking for that because we live at Sørenga, and the bus that normally drives out here, the 85 bus, it is only one-hour interval. And that means that from Sørenga into the downtown, it is only one-hour interval. That is quite a long interval to be that central. So, when I heard about these buses, I was hoping they would extend the route all the way into the city. But of course, not yet. But if they do that, I would probably use it quite often. (ID2, male, 45–54 years)

Table 3
Logistic regression analysis of how demographic attributes, car use, living or working in the area, and perceptions of conventional buses along the route relate to the likelihood of using autonomous buses in the future.

	Intention to use autonomous buses in the future					
	Model 1			Model 2		
	β	S.E.	OR (95% CI)	β	S.E.	OR (95% CI)
Age	−0.039**	0.015	0.962 (0.935–0.990)	−0.027[a]	0.015	0.973 (0.945–1.002)
Female	−0.098	0.528	0.907 (0.322–2.554)	−0.419	0.568	0.658 (0.216–2.001)
Living in the area	2.127[a]	1.154	8.386 (0.874–80.510)	1.496	1.203	4.463 (0.422–47.144)
Working in the area	1.962	1.346	7.116 (0.509–99.516)	1.886	1.366	6.594 (0.453–95.948)
Visitor in the area (reference)						
Car user				−0.628	0.561	0.534 (0.178–1.602)
Infrequent conventional bus				1.895**	0.601	6.651 (2.046–21.617)

Notes: [a]p < 0.10, *p < 0.05, **p < 0.01, ***p < 0.001. N = 116. Nagelkerke R Square for Model 1 is 0.140 and for Model 2 is 0.297.

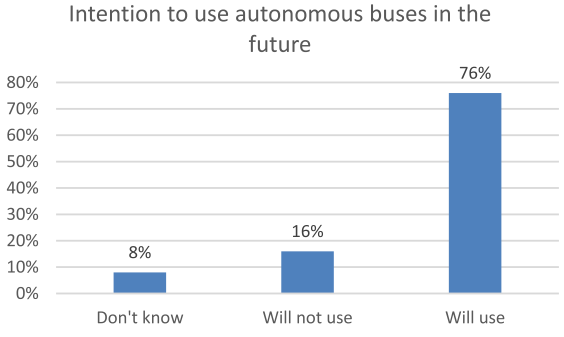

Fig. 5. Intention to use autonomous buses in the future (after use).

It's the same. You take the bus that you need to take. (ID3, male, 55–64 years)
I think it was cool. It's very funny to see the bus that drives by itself. I think it's a smart idea. [...] Yes of course if they become more common to take, I would probably use them. [...] I think I would choose the first bus that comes along. (ID7, female, 15–24 years)
Everyone is telling me that it is good that they are here. [Can you imagine yourself using this type of buses in the future?] Yes absolutely. (ID11, female, 65–74 years)
I think it was smooth and I thought it would be quite smooth. And the assistant on the bus... It's not totally perfect yet. But for me as a passenger I think it was perfect. It's nice. I think it's a really good way to move around. (ID13, female, 55–64 years)
Yes, I think so. Depending on what arrives first. Whether or not is the big bus or the small one. I think yes. (ID16, male, 45–54 years)

According to some participants, autonomous buses, with the existing technology, would be more useful for shorter distances because of their low speed:

Yeah if it's a short distance I would absolutely use the self-driving bus. But if it's a long distance probably not because it goes very slowly. (ID18, male, 55–64 years)
I feel that it is safe. It is very practical that they go so often. And I like them very much. I think that they are cute. And it's just fine that they are slow. Not a problem at all. Because usually you just had to walk the same distance so that they go that often is just a bonus. So, it's really great. And in this area, at this place, there are small roads so it's perfect and they are so small. [...] The positive thing was that they are going so often. That I didn't know. I thought that they might go like twice a day or something. And it's four times an hour. So, it's very very good. (ID25, female, 45–54 years)

Despite the generally positive attitudes among participants, there were certain participants who were skeptical about autonomous buses and their usefulness. These participants would not use them in the future. ID8 and ID9 mentioned that the reason for not using them is the low speed, while ID12 and ID23 felt uncomfortable about not having a driver.

It's just, it's a luxurious offer. You pay the driver, you have the car, but you could actually walk yourself. It's like a limousine bus. It's not useful. But it's fun. [...] I was maybe expecting more. So, it's more like... I said: why do we have this thing...? What does it improve...? So, no it (my impression) didn't really change. It was more a fun thing. (ID8, female, 45–54 years)
...it's very slow so I'm not sure if I'm going to prioritize taking it. [...] I think it was fun trying it, but I think it will be the last time I take it. (ID9, female, 15–24 years)
To be really honest I don't feel so comfortable about not having a driver because I would feel like it's less control and if something happens... And then I don't know maybe something happens with the computer system and it will drive down in the river... Thoughts like everybody has, I guess. (ID12, female, 35–44 years)
I am too old for new technologies, so I prefer actually when there are people driving. (ID23, male, 25–34 years)

4.2.2. Automation level

Several participants highlighted that autonomous vehicle technology needs further improvement. One identified problem is the interaction between autonomous vehicles and regular car users or pedestrians. As participants indicated, human intervention by a host on board is still required at times during the ride. It is also mentioned that with current technology, it is difficult to have autonomous buses running in dense urban settings with high traffic and pedestrian movement. Two issues identified by the users during their travel experience was the relatively low speed and the abrupt breaking.

It's too soon... They are not mature enough... The technology... They have some difficulties. They have bumped into cars and people. So that will have to be better. And maybe they have to go a bit faster...and to more places. (ID1, female, 35–44 years)
It is not really ready for self-driving yet. But of course, you have to test and develop to get there, so... For daily commutes as long as there is a guy on board, I think it's fine for me and I wouldn't worry about it. If there was no person on board, I would be a little bit skeptical yet. Because I know that technology isn't quite there yet. Because the roads are not really... the roads are still too chaotic I think for a fully automated route like this. (ID2, male, 45–54 years)
...as far as I can see these are not self-driving yet. Each trip is required that the bus driver prevents an accident and the vehicle needs help. So, I cannot see that they will... And these are in remote areas. So how these buses would function on their own in the city center I cannot imagine. (ID8, female, 45–54 years)
Of course, now it's... They are sort of first-generation buses with all the hiccups and all that. It's a bit too early with regards to the product itself. Which could be a bit more. I think there are a lot of things that are quite irritating, and they will get rid of...the speed and the breaking...and the self-driving aspect of it (the fact that they are not fully automated). (ID15, female, unknown age group)
I think the problem is that it has to co-drive with humans. If you only envision blocks or areas with only this kind of communication of course it will be much smoother and seamless because they would communicate with each other, so you

have much more precision in the coordination of the vehicles. I think the problem now is that we have drivers that drive around and that makes it stop by itself. That would not happen if everything was the same. . .automatic. [. . .] If everyone is self-driving, I think it would be much more efficient. Everyone you know, everything. . .synchronized. The problem is the mix of machines and people. (ID16, male, 45–54 years)
What is different is that as we talked about on the bus, it does not see a difference. If a cyclist comes in front, it stops really hard. If you're sitting on the back, you might fall forward. While if you have a driver, he might see if there is a danger or not. So, it stops really hard. (ID18, male, 55–64 years)
I think it's not so bad but this technology is still in progress so I think in a few years it will be much better. It's working slowly and safely but maybe in the future it will be much more speedy and better and better. (ID23, male, 25–34 years)

4.2.3. Safety

Participants were asked whether they felt safe during travel by autonomous bus. As seen in Fig. 6, the majority of the participants felt safe during the ride.

The users generally felt that the sensors reacted quickly, and this in combination with the low vehicle speed made them feel safe:

I think the sensors are getting better and better. And I expect that the testing is also like. . . What happens if someone just runs into the road. . . It seems that the bus is really reacting to obstacles, it is really breaking quickly. That's the most important thing. And it seems to follow the road pretty good. (ID2, male, 45–54 years)
I believe that it doesn't drive as a normal bus and in that sense, they are safer, I guess. (ID4, female, 45–54 years)
Before (using them) I thought they would be a bit dangerous because 'how do you know if they drive into the water?' (laughs) [So feelings of safety improved compared to what you had thought?] Yes absolutely. (ID7, female, 15–24 years)
It seems like it has a good sensor, I think. (ID10, female, 35–44 years)
I think it's safe enough. (ID14, female, 35–44 years)
It was just fun, and I didn't feel insecure or anything. (ID17, female, 35–44 years)

Some participants clarified that they felt safe for the present speed, but they would not feel the same for higher speeds:

During the ride I think we changed a bit our opinion. But I think it has something to do with the max speed. If it drove 90 or 100 km per hour it would be different, I think. [. . .] Yeah in a positive way. . .it (our opinion) changed in a positive way. . .in terms of safety. (ID5, male, 25–34 years)
It was exciting but I cannot imagine that I am in such a bus on the highway with a higher speed. (ID6, female, 25–34 years)
It goes really slowly so I felt OK. And there is a person on board, so it feels OK. (ID12, female, 35–44 years)

One participant did not feel safe, because she thought that the autonomous bus does not react quickly enough to unexpected moves by other vehicles, and that the host might need to intervene in some occasions:

You have the idea that you are safe because you are in a box, but I have seen that the driver prevented an accident every time I took this so that needs to be improved. And it has to do with the speed of the other traffic. I mean if you have a line with only these kind of car robots, only pedestrians, then it's probably safe because the sensors can react. It doesn't react fast enough with cars. We didn't have an accident here because the (regular) bus stopped. That would need a lot of improvement. [. . .] I was surprised that we actually had near accidents and that you need to have a driver in there. (ID8, female, 45–54 years)

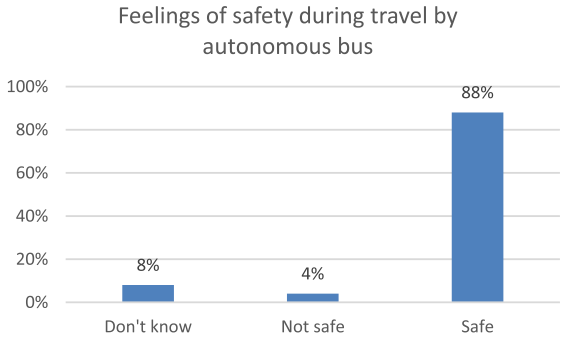

Fig. 6. Feelings of safety during travel by autonomous bus.

4.2.4. Speed

A common observation among participants was that the autonomous buses drive slowly. Several participants suggested that vehicle speed needs to increase in the future.

> The speed is slow which is OK because I know it's a test ride. Then there are small roads and there is not too much space (to go faster). (ID2, male, 45–54 years)
> It was a little bit slow but fun. [...] It felt faster when you were set in the bus. I had seen it driving past me a lot and it was very slow but now that we were driving it ourselves it was a little bit faster. It was cool. (ID7, female, 15–24 years)
> It drives slower than what you could walk yourself. So, it's fun to do it but you would actually walk the same distance. (ID8, female, 45–54 years)
> A normal bus is faster. (ID11, female, 65–74 years)
> The problem is that you mix it with ordinary drivers and that may be the biggest concern because that makes it goes slower. (ID16, male, 45–54 years)
> It's slow but fun. [...] It has to go a little bit faster, I think, if it's going to be used. Because now I could walk the same distance almost as fast as this went. (ID17, female, 35–44 years)
> If it was part of the normal traffic and it would go that slowly I think probably it would be a little bit negative because I might need to go to work a little bit faster. But as long as it's on a Sunday and I'm not on my way to work it's not a problem that it goes slowly. (ID25, female, 45–54 years)

4.2.5. Breaking

Another common observation among interviewees was that the autonomous bus had to stop abruptly in some situations. Some interviewees pointed out that this is something that could be improved. ID9 pointed out that the bus "*stops suddenly*", ID10 felt the "*abrupt breaking...*", while ID21 observed that the bus was "*hard on the brakes*". Other interviewees further explained:

> I can feel that it's sort of stopping quite hard but it's not a problem for me. (It's)...not very hard. It's just not soft like a car or other buses. But I think it's just to get used to it. It's just a different experience, it's no problem. It's like a tram... They do it differently than a bus. I mean it's no problem. [...] If it would be a little bit softer when it stops... When all of a sudden comes something, of course it cannot see the difference between something that is not dangerous and something that you have to stop fast. But I think it's functional, I think it's good. I am not smart enough to find an idea to make it better. (ID13, female, 55–64 years)
> I thought it was maybe stopping unintentionally quite a few times so it's obvious that it's not completely ready yet. So, it needs some development. (ID16, male, 45–54 years)
> Yes. it's only one thing that it's a little bit minus and it's that they break very powerful and it's nice to be aware of that before you start using them. But it's very clearly written inside the bus and the people who work there now tell us clearly that we need to know about this. (ID25, female, 45–54 years)

4.2.6. Vehicle design

Interview participants also made observations which were relevant to the vehicle design and not the automation technology. Such observations were about social interaction in the bus, the seatbelts, the size of the seats, and the space for wheelchairs and large carry-on items. ID10 highlighted the fact that "*it's social – you can connect to other people*". During the trip by autonomous bus, it was common that passengers interacted with each other as well as with the host on board. This is probably due small size of the vehicle, the arrangement of the seats, but also due to the fact that automated driving was a new experience for the passengers, and they were eager to discuss about it. On the other hand, ID8, who was skeptical about the usefulness of the autonomous buses, explained that this type of bus does not have enough space for wheelchairs or for people who are carrying large items. Therefore, as ID8 suggested, this would prevent disabled people or people with large carry-on items from using the bus: "*I know that my father would not use it. He's a wheelchair user so this would never be accessible to him. And my sister with small children. The bags that she's carrying around... She would not make use of it. It is really for young and healthy people.*" ID4 felt uncomfortable with the seats and the seatbelts of the bus: "*...a bit narrow space to sit. And the safety belts are not the best.*"

4.3. Synthesis of the results

Table 4 summarizes all the above the findings. The intention to use autonomous buses was found to be mostly positive before and after using them. Users were satisfied with the additional departures provided by the newly introduced autonomous buses. They also felt generally safe during travel by autonomous bus. The low speed and abrupt breaking of the autonomous buses were two negative observations made by the users. The small size of the shuttle buses provided increased social interaction but limited seat space and limited space for carry-on items, and did not provide space for a wheelchair.

Table 4
The use of autonomous buses: a synthesis.

Intention to use	Before use	+
	After use	+
Travel experience	Frequent departures	+
	Safety	+
	Low speed	–
	Abrupt breaking	–
Vehicle design	Social interaction on board	+
	Uncomfortable seats and seatbelts	–
	No space for wheelchair and limited space for carry-on items	–

The plus sign (+) indicates a positive outcome, while the minus sign (–) indicates a negative outcome.

5. Discussion and conclusions

Development in autonomous vehicle technology has been rapid. At the same time, research on autonomous vehicles has been increasing tremendously. However, studies on the use of autonomous buses in residential areas in cities have been scarce. This paper has provided such insights by focusing on the use of autonomous electric shuttle buses in a residential area of Oslo, the capital city of Norway. The paper has examined future use intentions before and after traveling by autonomous bus for the first time, as well as users' travel experiences and suggestions for improvement. These insights contribute to understanding whether and how autonomous buses could be used in a city context and such knowledge could be useful for a potential future introduction of autonomous buses into cities' transport systems. Moreover, the paper's outcomes can offer some preliminary input to debates around societal and environmental implications of autonomous buses due to possible increased accessibility and mobility by public transport and possible reductions in car use.

Findings from this paper suggest that residents would be willing to use autonomous buses, especially in areas where public transport is infrequent. Most study participants were eager to use autonomous buses before they were introduced in the case area examined in this paper. Intention to use autonomous buses, before these were introduced, was found to be associated with perceptions of infrequent conventional buses and lower age of the respondents. After the introduction of autonomous buses in the case area, most passengers had a generally positive attitude and reported that they intend to use autonomous buses regularly in the future if these run in their residential area. These overall positive attitudes of passengers towards autonomous buses are in accordance with previous relevant studies (Nordhoff, de Winter, Madigan, et al., 2018; Rehrl & Zankl, 2018; Salonen & Haavisto, 2019). The results of the "after use" part are in line with those of the "before use" part, as most participants in both parts seem to be positive about using autonomous buses. As some participants claimed, it may not make a difference to the user whether the buses have a driver or not as long as bus departure frequency improves – of course, considering that aspects such as travel cost, safety, speed, and travel comfort are satisfactory. Overall, the "before use" and "after use" studies of future use intentions indicate that most residents would be willing to use autonomous buses if these offer more frequent bus departures than the existing ones. This confirms findings by Salonen and Haavisto (2019) that contextual factors such as route and flexibility may influence use or non-use of autonomous buses. The more frequent bus departures is not an attribute of automated technology per se. Autonomous buses, due to their potential lower operational cost (Abe, 2019), may enable more frequent departures in areas where frequent regular buses are economically inefficient. Overall positive attitudes and intentions to use found in the present paper could be influenced by the fact that most of the study participants were first-time users. There might be a "novelty effect" that makes users more enthusiastic towards this new technology, and thus the results should be interpreted with caution.

This paper has also examined the experience of traveling by autonomous bus. Results suggest that feelings of safety during travel by autonomous bus are positive. The users of the autonomous buses in the "after use" study generally felt safe during their trip. This is in accordance with previous studies that examined user perceptions of autonomous buses (Rehrl & Zankl, 2018; Salonen, 2018; Salonen & Haavisto, 2019). It has to be noted again however that buses in the present paper as well as in previous studies are not fully automated. There was a host on board who could intervene if necessary. As some study participants mentioned (see Section 4.2 above), the host intervened on certain occasions during the ride with autonomous bus in Oslo. This may have positively affected perceptions of safety and some participants already pointed this out. The presence of the host and the associated sense of safety may have in turn positively influenced passengers' overall travel experience and their intentions to use this type of bus again in the future. Another aspect that might have played a role in the positive evaluations of safety is the fact that the rides occurred during daytime. We do not know how safe the rides would have been perceived during nighttime.

Two negative aspects regarding the experience of traveling by autonomous bus were reported: low vehicle speed and abrupt breaking. Users suggested that the buses need to drive faster and that breaking could be softer. The low vehicle speed was also found to be a source of travel dissatisfaction in a study by Nordhoff, de Winter, Madigan, et al. (2018). Under existing automation technology and city infrastructure, it seems that, as study participants point out, autonomous buses would be more applicable for areas with relatively low vehicle speeds and low traffic. In such areas, the low speed of autonomous buses would be less problematic and abrupt breaking would be less frequent, so the travel experience would be more positive.

Driving with higher speed and minimizing abrupt breaking without compromising safety is a challenge for autonomous buses and autonomous vehicles in general. To achieve higher speeds and softer breaking while maintaining high safety, automation technology needs to be improved, as study participants also highlighted. Vehicles need to be able to distinguish between different objects and potential risks so that abrupt breaking is performed only when really necessary. The travel experience would then become smoother and more pleasant. In the future, vehicles may be able to diverge from predefined routes when objects are obstructing these routes (Fernández, Domínguez, Fernández-Llorca, Alonso, & Sotelo, 2013), and that would reduce sudden braking. This greater level of automation would also make the role of the host on board less active.

Passengers' overall attitudes towards autonomous buses seem to be positive as findings from the present paper and from previous studies suggest (e.g. Nordhoff, de Winter, Madigan, et al., 2018; Papadima et al., 2020; Rehrl & Zankl, 2018). Participants of the "before use" survey in the present paper reported that public transport frequency was the major transport challenge in their residential area and that they intended to use or at least try autonomous buses that would offer additional, more frequent departures in the area. The intention to use remained high also "after use" since autonomous buses may offer more frequent departures. This supports the suggestion that desired frequency of public transport increases intentions to use public transport (De Vos, Waygood, & Letarte, 2020). The overall positive attitudes towards autonomous buses found in the present paper, both before and after using the buses, contrast with the findings of the Eurobarometer survey that the majority of European citizens, including North Europeans, would feel uncomfortable in autonomous cars (European Commission, 2015). This difference might be explained by the fact that several years have passed since the Eurobarometer survey and citizens may have become for familiar with automation technology. Another possible explanation is that the Eurobarometer survey asks about autonomous cars and not autonomous buses. Automated car driving may be associated with higher speeds, while autonomous shuttle buses, for now, may be associated with generally low speeds combined with the presence of a human host on board who can intervene if necessary.

Autonomous buses could potentially offer opportunities to promote sustainable mobility. As the case of this paper shows, autonomous buses could be used to supplement existing public transport and increase the overall frequency of public transport departures. This scenario has also been explored in previous literature, and has been linked to societal benefits such as increased mobility and accessibility and environmental benefits from a possible reduction in car use (Litman, 2020; Nenseth et al., 2019). To promote sustainable mobility with autonomous buses by increasing the public transport modal share and reducing car use, automation technology for public transport needs to be improved considering the rationales behind travel behavior (see e.g. Næss, 2013; Næss, Peters, Stefansdottir, & Strand, 2018) and the impact of travel on well-being (Chatterjee et al., 2020). The increased frequency of public transport departures achieved with autonomous buses could lead to time savings and additional travel comfort. This increased frequency would make public transport more accessible, for example in areas with lower population density, and would enable, to some extent, residents to realize their preferred travel behavior (De Vos, Derudder, Van Acker, & Witlox, 2012). Increased safety, reduced travel costs, and environmental benefits offered by autonomous buses could be other potential reasons to shift from car travel to public transport. On the other hand, the current low speed and frequent abrupt breaking would result in increased travel time and reduced travel comfort respectively. Vehicle speeds will need to be increased to achieve travel times that would improve travel satisfaction and needs satisfaction (Mouratidis, 2019, 2020; Mouratidis, Ettema, & Næss, 2019) and make autonomous buses competitive compared to the private car. Deceleration will also need to be smoother to improve travel experience and comfort. Finally, as passengers' insights in this research have shown, to offer a more inclusive mobility option that covers the needs of diverse population groups, the design of autonomous bus vehicles will need to be readjusted to be more accessible for people with mobility difficulties, older adults, overweight and obese individuals, and people with large carry-on items.

As full automation has not been achieved yet and there is a host on board that can control autonomous buses if necessary, passenger experiences and intentions to use should be reassessed with fully automated buses in future studies. Future research could also explore the use of autonomous buses in other geographical and cultural contexts. While the findings from this paper together with previous evidence suggest a positive overall attitude towards autonomous buses, further research could examine attitudes and future use intentions in contexts where citizens are more skeptical towards new technologies. This paper has investigated the use of autonomous buses in a low-density residential area. Future studies could explore the potential use of autonomous buses in other types of urban form. Moreover, to understand the possible impacts of autonomous buses on travel behavior, future investigations should focus on whether, in the long run, people's travel behavior indeed changes in areas where autonomous buses have been introduced. Automation technology possibly needs to be more mature to identify substantial impacts on travel behavior, but early studies can still identify emerging trends. Finally, the societal and environmental implications and risks of future use of autonomous buses should be systematically examined by future studies.

CRediT authorship contribution statement

Kostas Mouratidis: Conceptualization, Methodology, Investigation, Formal analysis, Visualization, Writing - original draft, Writing - review & editing. **Victoria Cobeña Serrano:** Methodology, Investigation, Writing - review & editing.

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Appendix

Interview questions for the "after use" data collection:

- Have you used self-driving buses before? How many times?
- Do you intend to use self-driving buses if they run regularly in the future? If yes, why? If no, why?
- What is your overall impression about traveling by self-driving bus?
- What kind of observations did you make during the trip?
- Did something surprise you?
- How safe did you feel during the trip?
- Did your impression about the self-driving bus change after the trip? If so how?
- Did you expect the trip to be safer, less safe or the same?
- What do think your friends and family think about self-driving buses?
- Which adjectives describe your feelings towards autonomous buses the best?
- Age group: 15–24, 25–34, 35–44, 45–54, 55–64, 65–74, over 74
- Gender: female, male, other
- Employment: student, employee, entrepreneur, pensioner, other
- Do you own a car?
- How do you travel to work? For other purposes?
- What is your favorite transport mode?
- What is the name of your residential area?

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