Assessing Social Acceptance of Urban Air Mobility using Virtual Reality

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Drone applications are increasingly being developed for urban environments, and drones may soon become additional traffic participants in cities. Thus, drones would be a further component to existing traffic and yet another stimulus in urban areas. Therefore, it is crucial to investigate how urban air mobility (UAM) is perceived by the society. Will the presence of drones be tolerated by the general public? To address this question, a Virtual Reality (VR) study was conducted, which investigates how the factors flight height, visual density and drone noise affect the acceptance of passers-by in an urban scenario. Furthermore, it explored how people perceive the landing of an air taxi nearby. The sample of the study comprises 47 participants.

The results indicate some significant effects of flight height and visual density on acceptance, but no effect of drone noise was observed. Compared to the baseline scenario without drones, the flight height and visual density scenarios with drones were rated more negative. The same applies for the air taxi scenario. After participating in the simulation, participants' worries about noise and privacy significantly decreased. More than half of the participants reported that their attitudes toward drones had changed following the simulation and tended to improve.

Keywords—urban air mobility (UAM), drones, acceptance, virtual reality (VR), simulation, noise, flight height, visual density, air taxi

I. Motivation

Drones have already found use in a wide range of public, commercial, and private sectors. They will therefore probably become a part of urban transportation soon. This implies that they will also fly over or close to people. Due to this, it is crucial to prevent drone flights from disturbing citizen and to learn more about how drone flights are perceived by the general public. The study presented in this paper aims to contribute to this by investigating how drones are perceived in an urban setting through a simulation experiment.

II. Theoretical Background

There are numerous studies indicating that visual [1, 2] or acoustic pollution [1, 3-8] might affect drone acceptance in a negative way A telephone survey carried out by Eißfeldt [3], for example, revealed that 53% of the respondents have concerns about the noise caused by drones. An investigation of Yedavalli and Mooberry [5] came to similar conclusions, as in their study almost half of the of the respondents expressed concerns about drone noise and the number of drones visible. There are, however, investigations that came to different conclusions. Al Haddad [9] and Grossi [10] observed, that only very few of the respondents expressed concerns about visual pollution caused by drones. Grossi's study [10] included field flight tests. Thus, it differs from the aforementioned research, which is based on surveys without letting the participants experience drone flights as part of the study. This might be an explanation for the different observations. According to a study conducted by Lydinia, Philipsen, and Ziefle [4], people who have no experiences with drones tend to have a lot of reservations about their use and a general opposition to autonomous flying drones.

In addition to Grossi's research [10], other studies have used virtual simulations or field experiments to examine the acoustic or visual effects of drones on people. Torija, Li and Self [11] observed that participants feel less annoyance from drones when visual stimuli were presented in addition to acoustic ones. However, a simulation experiment carried out by Aalmoes and Sieben [12] revealed no significant differences in the perceived annoyance caused by drones between purely acoustic and visual-acoustic stimuli. According to Gwak, Han, and Lee [13], perceived annoyance appears to increase with drone size. Small drones are therefore perceived as less disruptive than larger ones. Lastly, research results of Hui [14] point out that the relationship between perceived annoyance and drone type, flight altitude and flight mode is complex. In general, the study found that drones at low altitudes are perceived as more annoying than those at higher altitudes.

In the current study a virtual reality (VR) experiment was conducted with the purpose to investigate how different flight heights, different volumes of drones, in this paper named "visual density", and the noise of drones affect the acceptance of passers-by in an urban environment. The study is an extension of the experiment that the German Aerospace Center (DLR) carried out in the City-ATM project in 2020 [15]. The experiment in 2020 also investigated how flight height and visual density affect people's acceptance, but without including drone noises and with a smaller sample. The current study was conducted within the HorizonUAM project

[16] and additionally involves drone noise and more different flight heights. Moreover, it includes a scenario with an air taxi landing nearby to further explore how a large drone is perceived by people. Lastly, it will investigate, how experiencing drones in the simulation influence attitude and concerns people have with respect to drones.

III. Research Questions

This study addresses the following research questions:

1. How do the factors flight height, visual density and the noise of drones affect the acceptance of passers-by?
2. How do passers-by accept the presence of an air taxi landing nearby?
3. How does experiencing drone flights in the virtual simulation affect attitude and concerns of the participants related to drones?

IV. Method

A. Sample

The study involved 47 individuals in total and was conducted in the summer of 2021. Among the participants 33 were male and 14 were female. The average age was 32 (SD = 12.1) years. The youngest participant was 18 years old and 64 was the oldest. 74 percent of the participants reside in a city with a population greater than 100,000. With a majority of 79 percent having either a high school diploma or a university degree, the sample demonstrates a fairly high level of education.

The study's participants are generally very interested in technology. The average score is 8.70 (SD = 1.53) on a scale of 1 to 10 with 1 being the least interested in modern technology and 10 being the most interested. On a scale from 1 (not at all informed) to 7 (very well informed), the mean value for the test subjects' perceptions of their level of knowledge regarding civilian drones and potential applications is 4.02 (SD = 1.5). (very well informed). This represents a mediocre level of knowledge. Before the study, the vast majority of the subjects (72%) had already used drones for either personal, professional, or both purposes.

Online platforms like Facebook, eBay and the institute's website were used to find the test participants.

B. Apparatus

The experiment took place outside the office building of DLR's Institute of Flight Guidance due to the restrictions from the COVID-19 pandemic that were present to that time. To avoid direct sunlight and precipitation, the participants and the leader of the study sat beneath a tent. For each presented scenario a participant had to wear the VR helmet-mounted display (HMD) and headphones to see and hear the simulated environment.

For this study, we used the HTC VIVE Pro [17] as the VR-HMD which offers a field of view of 110 degrees and uses the external SteamVR [18] tracking together with an inertial measurement unit (IMU) for positional and rotational head tracking. The most relevant technical specifications of this device are shown in Table 1. For the sound we used the Beyerdynamic DT880 Edition [19] over-ear headphones. Both, VR-HMD and headphones, were connected to the simulation host PC.

Table 1: Technical specifications of the HTC VIVE Pro virtual reality head-mounted display

screen resolution	1440 x 1600 pixels per eye
display type	3.5-inch dual AMOLED
display refresh rate	90 Hz
field of view	110 degrees
head tracking	positional: SteamVR tracking rotational: accelerometer, gyroscope
connections	DisplayPort, USB 3.0, Bluetooth

The simulation allows the user to see an urban environment that not only shows air vehicles but also other means of transportation – like pedestrians, cars and buses. As the displayed scenario we chose the square at the main station in Braunschweig, Germany. In this area, many different road users contribute to the traffic volume.

To avoid the 3D modeling of the desired scenery and the simulation of the described traffic, we decided to record a 360-degree video of the real environment. For the recording we used the Insta360 Pro 2 camera to have footage with 8K resolution. The technical specifications of the Insta360 Pro 2 [20] are listed in Table 2.

Table 2: Technical specifications of the Insta360 Pro 2 video camera

lenses	6x F2.4 fisheye
photo resolution	up to 7680 x 7680 px
video resolution	up to 7680 x 3840 px (8K) at 60 fps
video encoding	MP4, H264, H265
battery capacity	5100 mAh
connections	Wi-Fi, Ethernet, GPS, SD card, etc.

The video footage was then played back as a skybox inside the game engine Unity that was used to create the drone simulation. This way, the field of regard (FOR) of the simulation is as large as the real-world FOR which creates an immersive experience.

Independent from the video playback, the drones were simulated to fly along predefined trajectories. These trajectories are designed to follow the course of the roads and cross the user's field of view in a neutral head position. Each drone flies at a constant altitude with constant speed. The simulation comprises five 3D models of drones and one model of an air taxi that are listed below:

- Alpha 800 from Alpha Unmanned Systems
- DeX ProX8 from DeXModels
- Phantom 4 from DJI
- MK Okto XL from Mikrokopter
- PX-31 from Maritime Robotics
- Volocopter 2X from Volocopter

The air taxi performed a continuous descent from 200 meters and hovered above the rooftop of the central bus station that is located in direct vicinity of the main station in Braunschweig. In order to avoid to influence the participants' responses in any way, the company logo of Volocopter was eliminated from the 3D model of the air taxi.

For the sound simulation we used audio footage from drone noise measurements the German Aerospace Center (DLR) conducted together with the German Environment Agency (UBA) [21]. All drones used the same audio clip. The sound played by the air taxi is an audio clip extracted from a video of a Volocopter flight demonstration [22]. As a sound model we used the built-in sound system of Unity that adjusts the volume based on distance and direction.

Figure 1. Visual density scenario with drones flying on all of the four trajectories.

Figure 2. Air taxi landing scenario.

C. Scenarios

The study used a within-subject design and the factors flight height, visual density and drone noise as independent variables. It comprised five different manifestations (10 m, 15 m, 20 m, 50 m, 100 m) of the factor flight height, three of the factor visual density and one additional scenario showing an air taxi landing (cf. Figure 4). In the flight height scenario drones were only flying on trajectory 2 (cf. Figure 3) in the different heights. Visual density was varied by the number of trajectories drones were flying on. In the first manifestation of this factor, drones flew on two trajectories, in the second on three and in the third manifestation on all of the four trajectories (cf. Figure 3). The drones had a flight speed of 10 m/s and a separation of 100 m on each trajectory. On trajectory 1 and 2 drones were flying at 20 m and 10 m on trajectory 3 and 4.

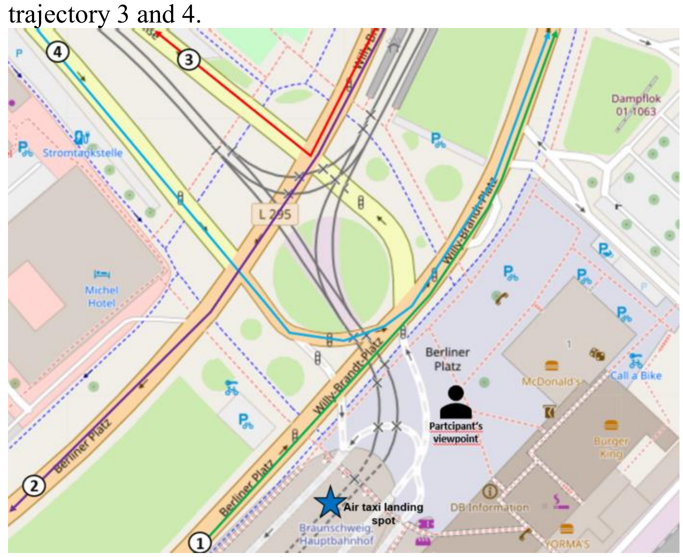

Figure 3. Real location of the central station scenario, which was simulated in the study, on OpenStreetMap. The manikin indicates the viewpoint of the participants. The numbered lines on the roads (1-4) are the four trajectories, drones were flying on in the simulation. The blue star shows the landing spot of the air taxi.

All the scenarios, except the air taxi scenario, were presented to the participants once with drone noises and once without noises. The air taxi scenario was presented with noise. The flight height and visual density scenarios had a duration of one minute each and their order was randomized. The air taxi scenario lasted two minutes and was shown as the last scenario. Furthermore, a baseline scenario was shown in the beginning of the simulation, which did not involve drones, but only the urban scenario. In total the study comprised 18 scenarios.

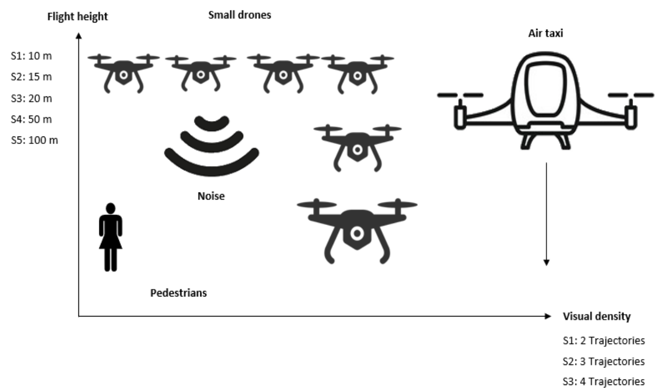

Figure 4. Scenarios of the simulation experiment including, flight height, visual density, noise and an air taxi scenario.

D. Questionnaires

Pre- and post-simulation questions:
To address the question, how the drone experience in the simulations affects attitude and concerns of the participants, attitude and concerns were asked for before and after the simulation experiment. The items were derived from the telephone survey the DLR conducted together with Infas in 2018 [3]. In contrast to the survey in 2018, in this study the attitude on drones and concerns related to them were rated on a 7-point-scale (attitude: 1 = very negative, 7 = very positive; concerns: 1 = not concerned at all, 7 = very concerned). To assess attitudes after the simulation a 5-point-scale was used (1 = much more negative, 2 = rather more negative, 3 = rather the same, 4 = rather more positive, 5 = much more positive). The concerns regarding drones asked for in the study involve criminal actions, violation of privacy, uncertainties regarding liability and insurance, damages due to accidents, endangerment of traffic safety, endangerment of animals and noise.

Technical Acceptance Questionnaire:
In order to asses the acceptance of drone flights in the different scenarios of the simulation, eight items were answered by the participants after each scenario. Three items (feeling comfortable, feeling disturbed, feeling observed) were used from the Technical Acceptance Questionnaire (TAM) adapted to video surveillance by Krempel (TAM-VIS) [23]. Two other items were derived from the TAM 3 related to computer anxiety (CANX) [24]. Three further items have been added by the researchers. Two of them relate to privacy and safety, because previous research identified these aspects as main concerns people have about drones [1, 3, 5-7, 9, 10, 25-31]. The last item asked, whether participants perceived the events in the situation as unpredictable. For the air taxi scenario, a ninth item referring to the perception of the air taxi's noise was included.
Each item was worded in a way that accurately captured how participants felt about it in the different scenarios. The items were answered on a 7-point-scale (1 = totally disagree, 7 = totally agree). Additionally, in order to check if drones in the scenarios were recognized, participants were asked to state whether they had seen and heard the drones before responding to the items.

E. Procedure

The study was held outside under a garden pavilion because of the COVID-19 pandemic. The participants sat at a table beneath the pavilion throughout the experiment. Each participant completed a questionnaire at the start of the study that captured various aspects of their attitudes toward civil drones. Questions about the acceptability of various drone uses, flights in various city types and areas, and the desired minimum flight height that drones should maintain were addressed in the questionnaire. After that, the 18 simulated scenarios were presented to the participants. Each scenario lasted one minute, except the air taxi scenario, which had a duration of 2 minutes. The order of the flight height and visual density scenarios was randomized. The baseline scenario was always presented in the beginning of the experiment and the air taxi scenario in the end.
Following the simulation, the test participants completed a final questionnaire in which aspects from the first questionnaire were recorded again in order to determine how much their attitudes toward drones had changed as a result of the simulation. In addition, demographic information such as age, gender, education, and income were gathered.

F. Analysis

In order to analyze whether there the manifestations of the factors flight height and visual density significantly differ from each other and to compare scenarios with and without drone noise, a two-way ANOVA with repeated measures was conducted for both flight height and visual density. Paired t-tests were performed using the mean values of all flight height and visual density scenarios to look for statistically significant differences between the baseline scenario and the flight height and visual density scenarios. The air taxis scenario was compared with the baseline scenario using a paired t-test, as well.
For comparing participant's attitude on drones before and after the simulation, frequencies were calculated in percent. In order to compare the responses related to concerns about drones a paired t-test was carried out.
For the analyses a significance level of $\alpha = 0.05$ was set.

V. RESULTS

A. Recognition of drones

In each scenario, the subjects answered yes to the question of whether they saw the flying drones in the simulation by a large majority (more than 91 percent). However, responses to the question of whether drones could be heard were mixed. In the scenarios involving flight height and visual density, the majority of the test subjects (ranging from 61 to 81 percent, depending on the scenario) consistently stated that they had not heard any drones. Only in the first visual density scenario, in which drones were flying on two trajectories including their noise, half of the participants stated they could hear the drones. In the air taxi scenario, the flying taxi was heard over 95% of the time (cf. Table 3).

TABLE 3: RESPONSES OF WHETHER PARTICIPANTS HAVE SEEN AND HEARD DRONES IN THE SCENARIOS GIVEN IN PERCENT

		seen drone		heard drone	
		yes	no	yes	no
baseline		4.3	95.7	2.1	97.9
flight height	10 m (noise)	100	0	25.5	74.5
	15 m (noise)	100	0	25.5	74.5
	20 m (noise)	100	0	23.4	76.6
	50 m (noise)	97.9	2.1	25.5	74.5
	100 m (noise)	91.5	8.5	19.1	80.9
	10 m	100	0	29.8	70.2
	15 m	100	0	27.7	72.3
	20 m	100	0	21.3	78.7
	50 m	100	0	23.4	76.6
	100 m	97.9	2.1	21.3	78.7
visual density	2 traj. (noise)	97.9	2.1	51.1	48.9
	3 traj. (noise)	97.9	2.1	29.8	70.2
	4 traj. (noise)	97.9	2.1	38.3	61.7
	2 traj.	100	0	31.9	68.1
	3 traj.	100	0	29.8	70.2
	4 traj.	100	0	38.3	61.7
air taxi		100	0	95.7	4.3

B. *Flight height*

It was determined whether the different flight heights and the presence of drone noises have a significant impact on the eight acceptance items using a two-way ANOVA with repeated measures.

The findings show that flight height has a significant effect on feeling comfortable, nervous and having the feeling the events in the scenario seem to be unpredictable (cf. Figure 5). Pairwise comparisons reveal, that regarding feeling comfortable responses significantly differ between 10 m (M = 5.80, SEM = 0.18) and 50 m (M = 6.23, SEM = 0.12), p =.021, with respect to feeling nervous between 10 m (M = 1.97, SEM = 0.17) and 15 m (M = 1.55, SEM = 0.11), p =.013 and between 10 m (M = 2.10, SEM = 0.19) and 20 m (M = 1.71, SEM = 0.17), p = .002 related to the question, whether events seemed unpredictable. In all cases the responses are more positive the higher drones were flying.

There are no significant differences in flight noise between the scenarios with and without drone sounds.

To analyze if the flight height scenarios significantly differ from the baseline measurement, a paired t-test was used. Because drone noise has no significant effect in the ANOVA, mean values for the eight items from all flight height scenarios with and without noise were calculated. The t-test is based on these variables. The results show that the mean values significantly differ in six of the items compared to the baseline (cf. Table 4). Only the items asking for feeling safe and whether the events in the scenario seemed unpredictable did not turn significant. The baseline scenario's responses are rated more positively in contrast to the flight heights scenarios.

TABLE 4: RESULTS OF THE T-TEST COMPARING BETWEEN FLIGHT HEIGHT SCENARIOS AND THE BASELINE SCENARIO (α = 0.05); 1 = TOTALLY DISAGREE, 7 = TOTALLY AGREE

	baseline	flight height	t	p
I felt comfortable in the scenario.	6.36	6.06	2.64	.011
I felt safe in the scenario.	6.38	6.15	1.69	.096
In the scenario I felt restricted in my privacy.	1.66	2.22	-3.01	.004
I felt disturbed in the scenario.	1.64	2.07	-2.07	.044
I felt observed in the scenario.	1.74	2.21	-2.23	.030
The events in the scenario seemed unpredictable.	1.81	1.90	-0.72	.474
I felt scared in the scenario.	1.06	1.35	-3.34	.002
I felt nervous in the scenario.	1.21	1.64	-3.48	.001

C. *Visual density*

It was determined whether the different manifestations of the factor visual density and the presence of drone noise have a significant influence on the eight items for recording the perception of the individual scenarios using a two-way ANOVA with repeated measures.

The results show that visual density has a significant effect on all items (cf. Figure 5). In all cases responses are more negative the more drones were flying. However, with respect to have the feeling of being restricted in privacy the ANOVA turned significant, but not the pairwise comparisons.

Regarding feeling comfortable in the scenario, responses significantly differ between 2 trajectories (M = 5.60, SEM = 0.16) and 3 trajectories (M = 5.28, SEM = 0.18), p = .036, between 2 trajectories (M = 5.60, SEM = 0.16) and 4 trajectories (M = 4.97, SEM = 0.18), p = .000 and between 3 trajectories (M = 5.28, SEM = 0.18) and 4 trajectories (M = 4.97, SEM = 0.18), p = .039.

Regarding feeling safe in the scenario, responses significantly differ between 2 trajectories (M = 5.59, SEM = 0.17) and 4 trajectories (M = 5.23, SEM = 0.17), p = .002.

Figure 5. ANOVA results for flight height and visual density including the factor noise (α = 0.05). 1 = totally disagree, 7 = totally agree.

	flight height					noise					flight height*noise				
	F	df_{num}	df_{den}	p	η_p^2	F	df_{num}	df_{den}	p	η_p^2	F	df_{num}	df_{den}	p	η_p^2
I felt comfortable in the scenario.	3.28	2.80	129.03	.026	.067	1.77	1	46	.190	.037	0.61	3.59	165.25	.636	.013
I felt safe in the scenario.	1.90	2.73	125.66	.138	.040	0.89	1	46	.350	.019	0.70	4	184	.592	.015
In the scenario I felt restricted in my privacy.	0.47	3.10	142.74	.704	.010	0.05	1	46	.821	.001	1.17	4	184	.323	.025
I felt disturbed in the scenario.	1.86	2.69	123.84	.144	.039	1.54	1	46	.221	.032	0.81	3.54	163.24	.508	.017
I felt observed in the scenario.	1.37	2.87	132.39	.254	.029	0.23	1	46	.633	.005	0.33	4	184	.851	.007
The events in the scenario seemed unpredictable.	2.99	3.11	143.23	.031	.061	0.23	1	46	.632	.005	1.30	3.52	162.05	.274	.028
I felt scared in the scenario.	1.40	2.83	130.29	.246	.030	1.74	1	46	.193	.037	0.04	3.20	174.42	.990	.001
I felt nervous in the scenario.	4.13	2.92	134.47	.008	.082	0.00	1	46	.953	.000	1.26	3.45	158.93	.287	.027

	visual density					noise					visual density*noise				
	F	df_{num}	df_{den}	p	η_p^2	F	df_{num}	df_{den}	p	η_p^2	F	df_{num}	df_{den}	p	η_p^2
I felt comfortable in the scenario.	14.48	2	92	.000	.239	1.58	1	46	.215	.033	0.20	2	92	.819	.004
I felt safe in the scenario.	6.83	2	92	.002	.129	2.31	1	46	1.35	.048	1.26	2	92	.289	.027
In the scenario I felt restricted in my privacy.	3.53	2	92	.033	.071	0.96	1	46	.332	.020	0.53	1.58	72.83	.547	.011
I felt disturbed in the scenario.	9.80	2	92	.000	.176	1.60	1	46	.211	.034	1.00	1.75	80.87	.362	.021
I felt observed in the scenario.	5.14	2	92	.008	.101	1.02	1	46	.317	.022	0.59	1.63	75.08	.524	.013
The events in the scenario seemed unpredictable.	37.01	2	92	.000	.446	2.17	1	46	.147	.045	0.06	2	92	.942	.001
I felt scared in the scenario.	9.84	2	92	.000	.176	0.73	1	46	.397	.016	0.49	1.51	69.65	.558	.011
I felt nervous in the scenario.	17.06	2	92	.000	.271	0.77	1	46	.385	.016	0.32	1.80	82.78	.703	.007

Regarding feeling disturbed in the scenario, responses significantly differ between 2 trajectories (M = 2.61, SEM = 0.19) and 4 trajectories (M = 3.33, SEM = 0.22), p = .000.
Regarding feeling observed in the scenario, responses significantly differ between 2 trajectories (M = 2.54, SEM = 0.20) and 4 trajectories (M = 2.91, SEM = 0.24), p = .016.
Regarding having the feeling the events seem unpredictable in the scenario, responses significantly differ between 2 trajectories (M = 2.18, SEM = 0.17) and 3 trajectories (M = 3.23, SEM = 0.22), p = .000 and between 2 trajectories (M = 2.18, SEM = 0.17) and 4 trajectories (M = 3.52, SEM = 0.21), p = .000.
Regarding feeling scared in the scenario, responses significantly differ between 2 trajectories (M = 1.59, SEM = 0.11) and 3 trajectories (M = 1.87, SEM = 0.16), p = .048 and between 2 trajectories (M = 1.59, SEM = 0.11) and 4 trajectories (M = 2.10, SEM = 0.15), p = .001.
Regarding feeling nervous in the scenario, responses significantly differ between 2 trajectories (M = 1.91, SEM = 0.14) and 3 trajectories (M = 2.37, SEM = 0.20), p = .008, between 2 trajectories (M = 1.91, SEM = 0.14) and 4 trajectories (M = 2.75, SEM = 0.18), p = .000 and between 3 (M = 2.37, SEM = 0.20) trajectories and 4 trajectories (M = 2.75, SEM = 0.18), p = .024.
To analyze if the visual density scenarios significantly differ from the baseline measurement, a paired t-test was used. Because drone noise has no significant effect in the ANOVA, mean values for the eight items from all flight height scenarios with and without noise were calculated. The t-test is based on these variables. The results show that the mean values significantly differ in all items compared to the baseline (cf. Table 5). The responses in the baseline scenario are more positive than in the visual density scenarios.

TABLE 5: RESULTS OF THE T-TEST COMPARING BETWEEN VISUAL DENSITY SCENARIOS AND THE BASELINE SCENARIO (α = 0.05); 1 = TOTALLY DISAGREE, 7 = TOTALLY AGREE

	baseline	visual density	t	p
I felt comfortable in the scenario.	6.36	5.29	6.26	.000
I felt safe in the scenario.	6.38	5.42	5.03	.000
In the scenario I felt restricted in my privacy.	1.66	2.67	-4.28	.000
I felt disturbed in the scenario.	1.64	2.96	-5.46	.000
I felt observed in the scenario.	1.74	2.71	-3.77	.000
The events in the scenario seemed unpredictable.	1.81	2.97	-5.87	.000
I felt scared in the scenario.	1.06	1.85	-6.08	.000
I felt nervous in the scenario.	1.21	2.34	-7.07	.000

D. Air taxi

A t-test, like the factors flight height and visual density, shows that in the air taxi scenario, all of the eight items were rated significantly more negative compared to the baseline (cf. Table 7). A ninth item was answered in the air taxi scenario measuring how bothered the participants were by the noise of the air taxi. The average is 3.15 (*SEM* = 0.28), indicating a low to medium level of noise pollution (cf. Table 6).

TABLE 6: MEANS VALUES AND STANDARD ERROR OF THE RESPONSES IN THE AIR TAXI SCENARIO; 1 = TOTALLY DISAGREE, 7 = TOTALLY AGREE

	M	SEM
I felt comfortable in the scenario.	4.87	0.23
I felt safe in the scenario.	4.89	0.25
In the scenario I felt restricted in my privacy.	2.34	0.25
I felt disturbed in the scenario.	3.13	0.26
I felt observed in the scenario.	2.26	0.21
The events in the scenario seemed unpredictable.	2.77	0.26
I felt scared in the scenario.	2.38	0.24
I felt nervous in the scenario.	2.94	0.26
The noise of the air taxi bothered me.	3.15	0.28

TABLE 7: RESULTS OF THE T-TEST COMPARING BETWEEN THE AIR TAXI SCENARIO AND THE BASELINE SCENARIO ($\alpha = 0.05$); 1 = TOTALLY DISAGREE, 7 = TOTALLY AGREE

	baseline	air taxi	t	p
I felt comfortable in the scenario.	6.36	4.87	6.38	.000
I felt safe in the scenario.	6.38	4.89	5.32	.000
In the scenario I felt restricted in my privacy.	1.66	2.34	-2.57	.014
I felt disturbed in the scenario.	1.64	3.13	-5.17	.000
I felt observed in the scenario.	1.74	2.26	-2.10	.041
The events in the scenario seemed unpredictable.	1.81	2.77	-3.23	.002
I felt scared in the scenario.	1.06	2.38	-5.74	.000
I felt nervous in the scenario.	1.21	2.94	-6.65	.000

E. Attitude and concerns

Before the simulation experiment almost all of the participants had a neutral or quite positive opinion (97.9 %) before watching. The majority of the responses are in the positive range of the scale (76.6 %) (cf. Figure 6). After the simulation participants were asked, how their attitude on drones changed. The results indicate that 34 percent of the participants had the same attitude and 42.6 percent a more positive attitude afterwards. However, 25 percent had a more negative attitude after experiencing the simulation (cf. Figure 7).

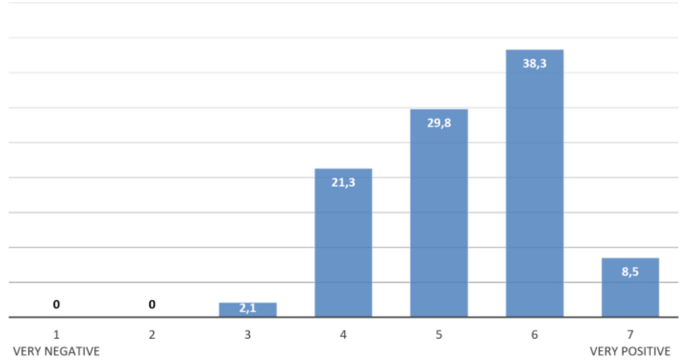

Figure 6. The bar chart indicates participant's attitude on drones before the experiment in percent.

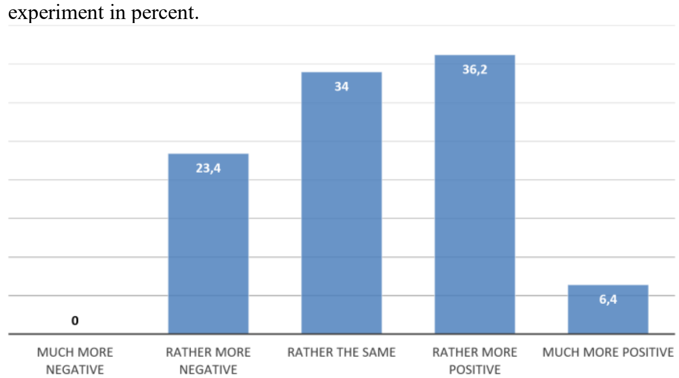

Figure 7. The bar chart indicates participant's attitude on drones after the experiment in percent.

In terms of concerns related to drones the mean values range from being medium to rather high concerned in all respects. Participants mostly fear that drones might violate the privacy of people. After participants have experienced the simulation their concerns slightly decreased in almost all respects. Exceptions include worries about criminal actions and damages due to accidents, where a slight increase in mean values can be seen. A t-test reveals significant decreases in concerns with respect to violation of privacy $t(46) = 2.99$, $p = .004$ and noise $t(46) = 2.31$, $p = .025$ after the simulation experiment (cf. Figure 8).

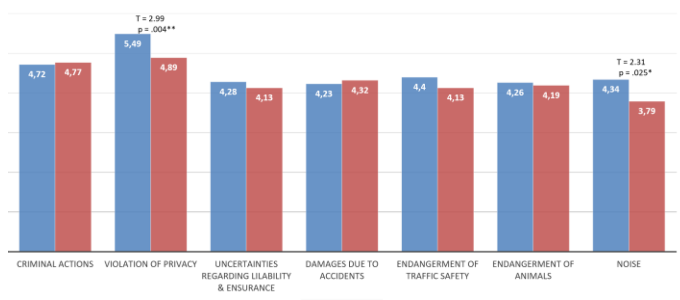

Figure 8. The bar chart indicates the mean values of participant's concerns before and after the experiment. 1 = not concerned at all, 7 = very concerned

VI. DISCUSSION

A. Discussion of empirical results

This study investigated how drones are perceived in an urban environment. For this purpose, a simulation experiment was conducted, in which different flight heights and volumes (visual density) of drones were presented to participants. Furthermore, it compared the flight height and visual density with and without sound. Besides that, a scenario with the landing of an air taxi was shown.

With respect to the factors flight height significant effects were found in three of the eight acceptance items, all indicating a lower acceptance for lower flight heights. This is similar to the research of Hui [14], in which drones flying at lower altitudes were found to be more annoying. Regarding visual density significant effects were observed on all items. Responses were more negative the more drones were visible. For both, flight height and visual density, there is no evidence for drone noise having a significant influence on acceptance in an urban environment. A possible explanation for this is provided by the participant's rating, whether drone noises were recognized in the scenarios. The majority of the participants constantly stated, that they did not hear drones in the flight height and visual density scenarios. As there were also noises from ground traffic in the scenarios, drone noises might have been covered by them. This observation is consistent with Torija, Self, and Li's [11] discovery that drone noises appear to be partially masked in noisy environments, such as at heavily trafficked intersections.

With respect to the air taxi scenario this study revealed, that responses for all items are significantly more negative compared to the baseline measurement. Moreover, the annoyance ratings of the air taxi noise are in a positive to medium range of the answer scale.

It was further observed, that attitudes on drones mostly stayed the same or turned more positive after the participants took part in the simulation experiment. The sample is noteworthy because it is relatively educated, young, and highly interested in contemporary technology. In addition, many participants have already used drones in either a professional or personal setting. This might have indicated that participants in the study were more open-minded about drones from the start.

Lastly, after the simulation experiment participant's concerns regarding to privacy and noise significantly decreased. The findings related to attitude and concerns suggest, that more experiences with drones might increase their acceptability.

B. Limitations

The fact that this study was conducted outside of a lab because of the COVID-19 pandemic is one of its limitations. For this reason, external noises might have influenced the results. To reduce this risk noise-absorbing headphones were used and the order of the flight height and visual density scenarios randomized. With respect to the simulation, the occlusion of the drones was incorrect, due to the video shown as skybox that is always behind all objects. Furthermore, flight dynamics were not considered as drones flew along splines with constant speed. A constraint regarding drone noises is the fact, that one sound sample was used for all drones in the flight height and visual density scenarios. However, different drone types might have different sound characteristics. Furthermore, parameters like wind or sound reflections on buildings were not taken into account. Consequently, the simulation cannot be entirely applied to reality.

VII. CONCLUSION

This study revealed some significant effects of the factors flight height and visual density on drone acceptance in an urban setting. However, drone noises did not affect participant's ratings significantly, probably, because most of them did not hear drones in the different scenarios. In order to minimize disruption, drone routes may pass close to noisy infrastructure. Additionally, it should be taken into consideration when planning flight routes that drones do not fly too close to the ground and are not overly prevalent in urban areas. Air taxi landing zones should be placed so that they do not fly too close to people in order to ensure that their noises do not cause any disturbance.

As some concerns related to drones significantly decreased after the experiment and attitudes for some of the participants turned more positive, experiencing drone flight might improve acceptance. In order to allow the public to experience drones and test different applications, real laboratories may be set up or citizen could be invited to flight demonstrations.

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REFERENCES

[1] Ferreira, T. and S. Kalakou. Strategic Planning for Urban Air Mobility: Perceptions of Citizens and Potential Users on Autonomous Flying Vehicles. in Conference on Sustainable Urban Mobility. 2020. Springer.J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[2] Boucher, P., 'You wouldn't have your granny using them': drawing boundaries between acceptable and unacceptable applications of civil drones. Science and engineering ethics, 2016. 22(5): p. 1391-1418.

[3] Eißfeldt, H., et al., The acceptance of civil drones in Germany. CEAS Aeronautical Journal, 2020. 11(3): p. 665-676.

[4] Lidynia, C., R. Philipsen, and M. Ziefle, Droning on about drones—acceptance of and perceived barriers to drones in civil usage contexts, in Advances in human factors in robots and unmanned systems. 2017, Springer. p. 317-329.

[5] Yedavalli, P. and J. Mooberry, An assessment of public perception of urban air mobility (UAM). Airbus UTM: Defining Future Skies, 2019: p. 2046738072.1580045281-1681120550.

[6] Chang, V., P. Chundury, and M. Chetty. Spiders in the sky: User perceptions of drones, privacy, and security. in Proceedings of the 2017 CHI conference on human factors in computing systems. 2017.

[7] Walther, J., et al., How people make sense of drones used for atmospheric science (and other purposes): hopes, concerns, and recommendations. Journal of Unmanned Vehicle Systems, 2019. 7(3): p. 219-234.

[8] Wang, Y., et al., Flying Eyes and Hidden Controllers: A Qualitative Study of People's Privacy Perceptions of Civilian Drones in The US. Proc. Priv. Enhancing Technol., 2016. 2016(3): p. 172-190.

[9] Al Haddad, C., et al., Factors affecting the adoption and use of urban air mobility. Transportation research part A: policy and practice, 2020. 132: p. 696-712.

[10] Grossi, C., L. Martin, and C. Wolter. Obtaining Public Opinion About sUAS Activity in an Urban Environment. in International Conference on Applied Human Factors and Ergonomics. 2020. Springer.

[11] Torija, A.J., Z. Li, and R.H. Self, Effects of a hovering unmanned aerial vehicle on urban soundscapes perception. Transportation Research Part D: Transport and Environment, 2020. 78: p. 102195.

[12] Aalmoes, R. and N. Sieben. Noise and visual perception of Urban Air Mobility vehicles. in Delft International Conference on Urban Air Mobility (DICUAM), virtual. 2021.

[13] Gwak, D.Y., D. Han, and S. Lee, Sound quality factors influencing annoyance from hovering UAV. Journal of Sound and Vibration, 2020. 489: p. 115651.

[14] Hui, C.J., et al., Quantification of the psychoacoustic effect of noise from small unmanned aerial vehicles. International Journal of Environmental Research and Public Health, 2021. 18(17): p. 8893.

[15] Stolz, M. and A. Papenfuß, Ergebnisbericht: Mixed-Method-Studie zur gesellschaftlichen Akzeptanz unbemannter Luftfahrzeuge im Projekt City-ATM 2020, German Aerospace Center.

[16] Schuchardt, B.I. HorizonUAM Project Overview. in HorizonUAM Symposium 2021. 2021.

[17] Vive. Introducing The New VIVE Pro With Precision Eye Tracking. 2019 [cited 2022 15.06.2022]; Available from: https://www.vive.com/us/product/vive-pro/.

[18] Steam. SteamVR. 2016 [cited 2022 16.06.2022]; Available from: https://store.steampowered.com/app/250820/SteamVR/?

[19] Beyerdynamic. DT 880 Edition. 2008 [cited 2022 16.06.2022]; Available from: https://north-america.beyerdynamic.com/dt-880-edition.html.

[20] nsta360. Insta360 Pro 2. 2018 [cited 2022 15.06.2022]; Available from: https://www.insta360.com/de/product/insta360-pro2/.

[21] Treichel, J., et al. Applicability of ISO standard 3744 to UA. in EUROREGIO BNAM Joint Acoustics Conference. 2022. Denmark.

[22] Volocopter. Volocopter footage MP4. 2021 [cited 2021 16.03.2021]; Available from: https://16d165b0a0819ec55eee-ffd6b8bcd2fb0d81e63f460c4f848bb5.ssl.cf3.rackcdn.com/dai_190914_volocopter_footage.mp4.

[23] Krempel, E.L., Steigerung der Akzeptanz von intelligenter Videoüberwachung in öffentlichen Räumen. Vol. 28. 2017: KIT Scientific Publishing.

[24] Venkatesh, V. and H. Bala, Technology acceptance model 3 and a research agenda on interventions. Decision sciences, 2008. 39(2): p. 273-315.

[25] Reddy, L.B. and D. DeLaurentis, Opinion survey to reduce uncertainty in public and stakeholder perception of unmanned aircraft. Transportation Research Record, 2016. 2600(1): p. 80-93.

[26] (BDL), B.d.D.L. Chancen und Risiken ziviler Drohnen. Ergebnisse einer repräsentativen Umfrage im Auftrag des BDL. 2016 [cited 2022 15.06.2022]; Available from: https://www.bdl.aero/wp-content/uploads/2018/09/umfrage_chancen_und_risiken_ziviler_drohnen-1.pdf.

[27] Klauser, F. and S. Pedrozo, Big data from the sky: popular perceptions of private drones in Switzerland. Geographica helvetica, 2017. 72(2): p. 231-239.

[28] Nelson, J.R., et al., The view from above: A survey of the public's perception of unmanned aerial vehicles and privacy. Journal of urban technology, 2019. 26(1): p. 83-105.

[29] Tan, L.K.L., et al., Public acceptance of drone applications in a highly urbanized environment. Technology in Society, 2021. 64: p. 101462.

[30] Çetin, E., et al., Implementing mitigations for improving societal acceptance of urban air mobility. Drones, 2022. 6(2): p. 28.

[31] Burukina, O. and I. Khavanova. Human–Drone Interaction: Virtues and Vices in Systemic Perspective. in International Conference on Applied Human Factors and Ergonomics. 2019. Springer.