



# A mixed-method approach to investigate the public acceptance of drones

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## Abstract

Drones may play an essential role in future traffic. As with every innovation, not only is the technical maturity decisive for its success, but also whether the general public will accept it. This paper uses a mixed-method approach combining quantitative and qualitative methods to investigate social acceptance concerning drones. The study included 20 participants and comprised a virtual simulation, a team task, and a group discussion. This way, different aspects of drone acceptance were investigated. On the one hand, a simulative approach was tested to explore the visual perception of drone flights in an urban setting. On the other hand, the acceptance of various drone applications such as civil protection, parcel delivery, and air taxis was studied. Furthermore, this research identified requirements for coordinating and managing future drone traffic. This paper combines two acceptance models from the literature as a theoretical framework: an adoption of Chamata's and Winterton's Technical Acceptance Model by Krempel and the Unacceptability–Acceptance Scale by Hofinger.

**Keywords** Acceptance · Drones · U-space · Urban air mobility · Simulation · Virtual reality · Augmented reality · Group discussion · Mixed method

## 1 Motivation

According to market analyses, drones have significant growth potential. A market report published by Droneii forecasts that the global drone market size will reach 55.8 billion USD by 2030 with a compound annual growth rate of 7.8% [1]. A further SESAR study predicts over 15 billion euro growth by 2050 for the European drone market and an offer of more than 100.000 new jobs [2]. Also, for the German market, continuous development of drone volume is anticipated, which will be driven by the commercial drone market [3]. Planned drone applications are, for example, parcel delivery, medical transport, and passenger transport. Consequently, there is a high research potential on

this topic. An EASA survey observed a remarkable increase in urban air mobility (UAM) publications frequency between 2017 and 2020 [4]. These analyses suggest that drones could become increasingly important in future traffic and mobility.

Concepts are already being developed to integrate drones into lower airspaces and existing traffic infrastructures. These concepts are known as U-space concepts. A first comprehensive draft of a concept of operations (ConOps) of the U-space has been developed as part of the European Horizon 2020 CORUS research project [5]. Here, the technical integration of drones into an urban airspace management framework was a particular focus. Aside from manufacturers, operators, and service providers, the general public is an important stakeholder. Society might be affected in different ways by drones. On the one hand, drones might overfly communities, and on the other hand, citizens are possible consumers of drone services, e.g., parcel deliveries [6].

This paper focuses on the public acceptance of drones. It presents a mixed-method approach to address this multifaceted topic adequately. Mixed-method designs combine both qualitative and quantitative research methods [7]. Such techniques provide a deeper insight into research topics than

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if only one methodical approach is used [8]. The quantitative part of this study includes a virtual simulation where people were given an impression of possible drone traffic. Further, their feedback on the perception of flying drones in an urban environment was collected. Here, the simulation part was the first test of our simulative approach. Given this, the simulation gathered input on both drone perception and the simulation itself to improve it for future studies. Two strategies were used in the qualitative part. Participants were first asked to formulate their demands for controlling and coordinating drone traffic in a socially acceptable way as part of a team task. Secondly, the participants discussed their attitudes, perceived risks, and benefits of different drone use cases. The theoretical framework for this research is based on a combination of two acceptance models from the literature: the Hofinger Unacceptability – Acceptance Scale [9] and Krempel's [10] Adoption of Chamata's and Winterton's Technological Acceptance Model [11].

## 2 Theoretical background

### 2.1 Concept for drone operations in Europe

Several concepts for drone operations are currently under development. One example is the U-space concept, developed within the European research initiative SESAR [5]. Its objective is to unify the rules, regulations, and legislations for drone operations in all European member states. The main goal is to provide an architecture that allows safe and efficient drone operations even in airspaces with potentially high air traffic as expected above urban areas. In a first step, common guidelines for drone operations have to be defined and existing drone regulations have to be harmonized. Just when this is done, a European framework can be established that support routine unmanned air traffic. Core components are to be novel services and procedures which facilitate secure, effective, and safe access to the airspace [12]. But they have to be highly automated as well. This has been addressed by the CORUS

project [5] which has developed a concept of operations (ConOps) to be implemented in the U-space framework. CORUS has also introduced three new types of airspace volumes (called Type X, Y, and Z). For U-space, the very low-level (VLL) airspaces are of interest which are Type X (up to 500 ft, approx. 120 m) and Type Z (up to 1000 ft) [12]. These are mainly uncontrolled airspaces and, thus, belongs to Class G of the ICAO airspace classification.

But the idea is that drones in the U-space concept also operate near airports, i.e., in controlled airspaces. In those so-called controlled traffic regions (CTRs), the most significant risk of drone operations is expected. This will be covered by specific U-space services which offer, for example, communication opportunities between the air traffic control (ATC) and drone operators. Information about drone traffic over cities or near airports as well as intended drone flights can then be exchanged. Other U-space services will permanently assess and solve conflicts between manned and unmanned air traffic. However, the relation between risk mitigation and performance changes with respect to the region a drone is actually operating. This is considered by the U-space concept which distinguishes between three distinct drone operation categories as specified by European regulations [13]. Each class provides a specific risk for every drone operation, along with a risk assessment and mitigation strategy. Table 1 lists some U-space services as example. These services are required to enable safe drone operation.

The U-space concept does not explicitly consider the acceptance of drone operations by the general public. This paper investigates this specific aspect. The purpose is that the outcome of acceptance studies can eventually be incorporated into the overall design of U-space.

### 2.2 Drone applications

There are numerous use cases for drones. This paper will focus on six typical applications described in the following.

**Table 1** Potential U-space services

U-space service	Description
Registration	Registration of UAS operators and certified UAS
E-identification	Identification of a drone operator from a drone in operation
Geo-awareness	Service to keep the pilot informed of, e.g., geofences and no-fly zones
Geofence	Geographical boundaries have to be respected during flight
Weather information	Supplying weather forecasts and warnings
Tracking	Position support submission of any drone in a specific area
Dynamical capacity management	Detect and resolve demand and capacity imbalances
Tactical conflict resolution	Checks for conflicts in real time and issues instructions to drones (e.g., change altitude)

### 2.2.1 Parcel delivery

Drones can be applied in logistics for first- and last-mile delivery. This has the potential to reduce costs and make the delivery of goods faster and more efficient compared to conventional road transportation [14]. Various companies are already planning to implement drones for parcel delivery. Prominent examples are Amazon Prime Air, DHL, and UPS.

### 2.2.2 Passenger transport (air taxi)

Air taxis are electric vertical take-off and landing vehicles for passenger transport. Their seat capacity is comparable to that of a conventional taxi. In the project HorizonUAM [15], the German Aerospace Center outlines five possible use cases for air taxi flights. They might be employed as an airport shuttle for flights within cities to get to outlying areas from city centers, or to connect various cities and megacities.

### 2.2.3 Civil protection

Several organizations, including the German Federal Agency for Technical Relief (THW) and the German Red Cross, apply drones for disaster management and civil protection today [16]. They can assist first responders in search and rescue operations using thermal imaging cameras to locate people at night and deliver supplies to victims. Moreover, they can scan and map a location for post-disaster assessment to evaluate the damage and find missing people. In the event of wildfires, drones are also quite beneficial. They can track current fire conditions, find smoldering hot spots and even fight fires [17, 18]. Drones enhance crisis management by avoiding traffic congestion, reaching inaccessible terrains, and enabling first responders to react faster [19].

### 2.2.4 Research

Drones can capture millions of data points during a flight and carry various cameras and sensors. This provides researchers with multiple options to collect different kinds of data. Some examples: drones can be used in agricultural or biological research, archeology, geophysical surveys, environmental and climate monitoring, and meteorological studies [20, 21].

### 2.2.5 Photo and video

Many drones are equipped with cameras, which makes them a popular tool for taking pictures and videos in film industries, journalism, or real estate. This study refers to drones for professional image and video productions for entertainment, documentation, and advertising.

### 2.2.6 Hobby and recreation

Most drones owned and operated today are used for leisure purposes [22], and the market for hobby drones is expanding. Here, the drone owners are private individuals.

## 2.3 Public acceptance of drones: state of research

The public acceptance of drones is a research topic in many publications. Previous studies have uncovered the overall acceptance of drones in society, the acceptance of various drone applications, drone-related concerns, and personal traits affecting acceptance.

A telephone survey by Eißfeldt et al. [23] revealed that opinions about drones are divisive: 42% of the respondents have a primarily positive view and 42% have a predominantly negative one. Gender was found to be a predictor of acceptance. Women are more concerned about drone use than men. Other research yields comparable results [24–26]. Klauser and Pedrozo [27] provide a possible explanation for the observed gender differences. Only 1.8% of the female participants in their study reported having prior experience with drones, compared to 16% of the male participants. According to a survey by Lidynia et al. [28], individuals who have never used a drone have several concerns about their usage and disapprove of drones flying autonomously. Eißfeldt [23] discovered that high income and education are additional indicators of drone acceptance.

Several studies have identified privacy [23, 24, 26, 27, 29–31] and safety [23, 25, 26, 29–37] as significant concerns. Further concerns include visual [25, 38] and acoustic [23, 25, 28, 32, 34, 35, 39] pollution that drones might cause.

Social acceptance of drones varies depending on their purpose. Use cases perceived as advantageous by the broader public are generally accepted [23, 26]. Rescue operations, industrial facility monitoring, and research applications are a few examples. On the other hand, the public has minor support for air taxis, hobby use, photo and video recording, and parcel delivery. In contrast, Tan et al. found more support for commercial and recreational usage than industrial and governmental applications [31].

## 2.4 Technology acceptance

In general, technology acceptance is the positive choice to employ an innovation [40]. The opposite is denoted as refusal. But as Krempel [10] points out, the decision between acceptance and refusal is not binary. Accepting an innovation is a process that has cognitive, affective, and connotative dimensions. The cognitive dimension of acceptance is described as a cost versus gain calculation. When the gain outnumbers costs, innovation will likely be accepted. But if the costs outweigh the income, innovation will probably be

rejected. The affective dimension captures feelings about novel technologies. The conative dimension indicates whether and to what extent innovations are employed by people or parties involved, such as whether or not the adoption of innovations is optional or required.

#### 2.4.1 Technology acceptance model for drone operations

The Technological Acceptance Model (TAM) was developed in the 1980s to predict the acceptance of technological innovations. Since then, TAM has been applied to various domains and has been extended [41]. For the study in this paper, it has also been selected as a framework due to its widespread use.

TAM incorporates behavioral intentions, attitudes, and external variables to predict the use of a specific technology. The model's core is to explain—based on customer beliefs—whether target groups are likely to use new technologies, i.e., how high is the “willingness to use” the technology. However, in the drone case, most people will not be the drone operators. They will instead be affected by overflying drones or benefit from provided services, e.g., parcel delivery. Thus, drone acceptance should be defined by further metrics. The willingness of citizens to allow unmanned aerial vehicles to access lower air space in public and private places might be a better way to understand drone acceptance. One appropriate model of drone acceptability has been developed by Chamata and Winterton [11]. Their main focus was on domains related to high risks like nuclear energy or genetically modified crops. Thus, they adapted the TAM with respect to the risk assessment of drone operations. The adapted TAM is shown on the left part of Fig. 1.

#### 2.4.2 Unacceptability – acceptance scale

The Unacceptability–Acceptance Scale was developed by Hofinger in 2001 as a component of a study investigating the acceptance of a biosphere reserve based on interviews. The results of the discussions led to the creation of eight categories that describe acceptance based on individual behavior [9]. A brief overview of the different levels and explanations of how people would behave at certain acceptance levels concerning drones is listed in the following:

1. *Active enmity*: Usually, enmity appears through actions. Regarding drones, this might be, e.g., individual active campaigns, stopping drones, or taking legal action against them.
2. *Refusal*: Verbal comments are used to express refusal. When acceptance reaches this level, people criticize drones and refuse to use them.
3. *Indifference*: Different tendencies might be found in an ambivalent mindset. Therefore, neither acceptance nor non-acceptance can be attributed to this level. A reference to drones is made here with both positive and bad connotations.
4. *Disinterest*: People's attitudes toward drones are indifferent; they don't raise any subjective concerns. Again, neither acceptance nor rejection can be assigned in this case. Drones are not a topic of discussion or curiosity among people.
5. *Tolerance*: Acceptance is shallow at this level and results from power initiatives. This might indicate that people are reluctant to use drones despite being required to do so, such as in a professional setting.

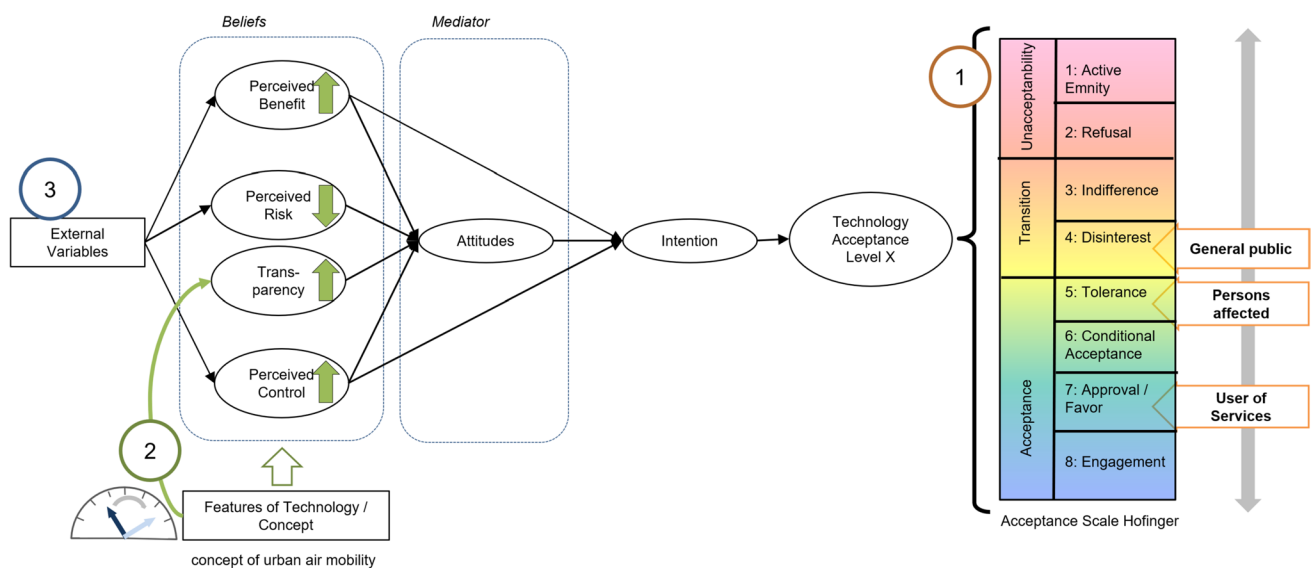


Fig. 1 Proposal for acceptance in developing a traffic management concept for urban drone traffic

6. *Conditional acceptance*: This level denotes a low level of rationally motivated acceptance connected to situations. People would prefer to view the usage of drones as beneficial under specific circumstances.
7. *Approval/favor*: This level equates to a high level of acceptance when the acceptor genuinely believes that the acceptance object is beneficial. Regarding drones, the benefits of the technology exceed the drawbacks. Here, people perceive drones as valuable, and they are very willing to employ them voluntarily.
8. *Engagement*: This level equates to high acceptance, shown by behavior motivated by internal conviction. People are firmly convinced of the value of drones and actively participate in technology development.

### 3 Theoretical framework for assessing public acceptance

Based on the theoretical models explained in Sect. 3, we defined a framework for assessing and enhancing the acceptance of drone traffic management. This framework is depicted in Fig. 1. The acceptance model from Chamata and Winterton [11] is a foundation, with Krempel's [10] added transparency factor. The wording "technology acceptance" has replaced "technology usage." The grade of acceptability is measured or defined using Hofinger's scale [9].

We combined the two theoretical models to provide a framework to theoretically define necessary levels and assess the acceptance of urban drone operating concepts. Similar to Chamata's and Winterton's approach [11], we believe that the following four elements affect people's attitudes toward emerging technologies:

- perceived benefit,
- perceived risk,
- transparency and
- perceived control.

This, in turn, affects how our society perceives new technologies. Furthermore, the elements above determine where a person's attitude is ranked on Hofinger's acceptance scale [9].

#### 3.1 Research questions

This study addresses three main aspects:

- the perception and acceptance of drone flights in an urban scenario,
- the acceptance of different drone applications, and
- public requirements on operational concepts.

Based on the collected data, a classification of the current social acceptance level is proposed according to Hofinger's scale [9].

Since many have not encountered drones, this study used a virtual simulation depicting an urban scene with drone traffic. With the simulation, we aimed to accomplish two objectives: first, we want to give participants an impression of what drone traffic in the future might look like; second, we intended to develop a first simulative approach and conduct an initial investigation on how people experience flying drones in cities. The simulation served as an initial test. Therefore, we requested feedback from participants to improve it. This will lead to recommendations for future simulation experiments on drone acceptance.

A significant concern of the general public is that drones might cause visual [25, 38] and acoustic [23, 25, 28, 32, 34, 35, 39] pollution (see chap. 3.3.). However, the focus in this study is solely on the visual perception of drones. Due to the fear of visual pollution, scenarios involving different visual densities were shown to the participants within the simulation. Visual density refers to the number of drones flying in the vicinity. Furthermore, flight altitude was varied to cause different levels of visibility of drones. The simulated scenarios evaluated acceptance by measuring participants' perceived risk and control. The simulation part of the study is supposed to shed light on the following questions:

RQ 1: How do people perceive different flight altitudes and visual densities of drone traffic in an urban scenario?

RQ 2: Which aspects are important to consider in future simulation experiments related to drone acceptance?

In terms of drone applications, social acceptance is examined for using drones for civil protection, research, taking photos and videos, as air taxis, for parcel delivery, and hobby purposes (see chap. 3.2). Gaining more insights into people's attitudes toward commercial applications is of particular interest, as according to previous research, they are less acceptable than non-commercial ones [23, 26, 31] (see chap. 3.3). Participants were asked to give anonymous votes on the use cases mentioned above to assess their current level of acceptance. The reason for higher or lower acceptability ratings for particular drone applications was debated in a group discussion. We assume that a minimum acceptance level between 4 and 5 on the Hofinger scale [9] should be attained for drones used in civil protection and research. It would probably be sufficient if people tolerated such drones because society is not actively involved in these applications. Further, we assume that higher acceptance levels are required for drones for photos and videos, parcel delivery, and air taxis. Taking pictures and videos with drones, e.g., for news reports, affects the sensitive topic of data protection and privacy. Since privacy is a significant concern for the general public, as indicated by recent research [23, 27, 29–31], we suggest that this use case requires approval from



society. The same applies to hobby drones, which can capture pictures as well. Privacy issues may be even more critical since anyone can buy and use hobby drones.

For the general public to adopt services like air taxis and delivery drones, they need to perceive high benefits and minimal risks. In conclusion, we suggest that hobby drones, air taxis, and parcel delivery require a minimum level of 7 on the Hofinger Acceptance Scale [9], which implies approval or favor. The group discussion is supposed to answer the following questions:

RQ 3: Which attitude do individuals have toward different drone applications?

RQ 4: Can we assume the required minimum acceptance levels on the Hofinger scale within society concerning different drone applications?

Table 2 summarizes our proposed acceptance levels on the Hofinger scale for different use cases.

Lastly, this study aims to determine how society would prefer future drone traffic to be coordinated and regulated. Here, participants were instructed to formulate recommendations for future drone traffic as part of a team task, which addresses the following questions:

RQ 5: What are the requirements regarding the coordination and implementation of future drone traffic as proposed by the participants?

Table 3 provides an overview of the research questions and data collection methods.

**Table 2** Overview of minimum acceptance levels for different drone applications on the Hofinger Acceptance Scale

Drone application	Proposed minimum level on the Hofinger Acceptance Scale
Civil protection	4 (disinterest) to 5 (tolerance)
Research	4 (disinterest) to 5 (tolerance)
Photos and videos	7 (approval /favor)
Air taxis	7 (approval /favor)
Parcel delivery	7 (approval /favor)
Hobby and recreation	7 (approval /favor)

**Table 3** Overview of research questions and methods

Research question	Method	Type of data collection
RQ 1: How do people perceive different flight altitudes and visual densities of drone traffic in an urban scenario?	Simulation experiment	Quantitative
RQ 2: Which aspects are important to consider in future simulation experiments related to drone acceptance?	Group discussion	Qualitative
RQ 3: Which attitude do individuals have toward different drone applications?	Voting, group discussion	Quantitative, Qualitative
RQ 4: Can we assume the required minimum acceptance levels on the Hofinger scale within society concerning different drone applications?	Group discussion	Qualitative
RQ 5: What are the requirements regarding the coordination and implementation of future drone traffic as proposed by the participants?	Team task	Qualitative

## 4 Methodology

### 4.1 Approach and overall procedure

To address our research questions, a mixed-method approach [42] was used, combining quantitative and qualitative data collection. The qualitative method included a team task and a group discussion. The quantitative data were collected during the testing of a simulative technique.

Three days in March 2020 were spent conducting the study with three separate participant groups. Participants went through the simulation, the team task, and the group discussion on each test day. A brief presentation was shown to the participants at the beginning of each trial to ensure a shared knowledge of drones' definitions and potential use cases. This comprised a general description of drones and some fundamental technological details. Additionally, several drone types and potential use cases were introduced. Two short YouTube video clips on air taxis and delivery drones were displayed as use case examples [43, 44]. Finally, the idea of U-space was described, and details on the services that will enable drone operations in the future were given.

After the presentation, participants were randomly divided into two groups. One group experienced the simulation first, while the second group was absolved the team task. Afterward, the groups switched, and the first group worked on the team task, whereas the participants of the second one experienced the simulation. In the simulation group, individuals took part in the simulation test one after the other. Participants rested in a waiting area while not actively participating in the trial. After completing the simulation and the team task, the groups got back together. Each group presented the ideas and concepts they developed within the team task to the others. Finally, the group discussion started involving all participants.

The procedure described above was identical for all three study trials. Overall, each trial lasted around 5 h. Figure 2 visualizes the process of the study.

## 4.2 Method 1: simulation

### 4.2.1 Scenario design

**4.2.1.1 Independent variables** The study included a baseline scenario without drones and a one-factorial design for visual density and flight altitude. Each of these contained three scenarios with different factor manifestations. In-flight altitude scenarios, drones flew on a single trajectory at 10, 15, and 20 m. These categories are based on a question from the telephone survey DLR conducted in 2018 [23]. Participants were asked which minimum flight altitude drones should obtain for different use cases.

The number of drone trajectories used in the scenarios ranges from two to four, with variations in visual density. In the flight altitude conditions, drones were only flying on trajectory 2. In the visual density scenarios, drones flew at an altitude of 10 m on trajectories 3 and 4 and 20 m on trajectories 1 and 2. An overview of the different flight altitudes and visual density conditions is presented in Table 4.

**4.2.1.2 Dependent variables** Four items from the Technical Acceptance Questionnaire adapted to video surveillance (TAM-VIS) [10] were used to measure perceived risk. The items were rephrased according to our research topic. Moreover, a 5-point Likert scale (1 = “totally agree,” 5 = “totally disagree”) was used instead of a 4-point scale to provide participants with a response option for neutral or undecided votes. The items were formulated as follows:

- Item 1: I did not feel constrained in my actions.
- Item 2: I felt disturbed by the drones flying around.
- Item 3: I was at ease in the situation.
- Item 4: I had the feeling that I was being observed.

**Table 4** Conditions of the flight altitude and visual density scenarios

Flight altitude	Visual density
10 m	Drones flying on two trajectories
15 m	Drones flying on three trajectories
20 m	Drones flying on four trajectories

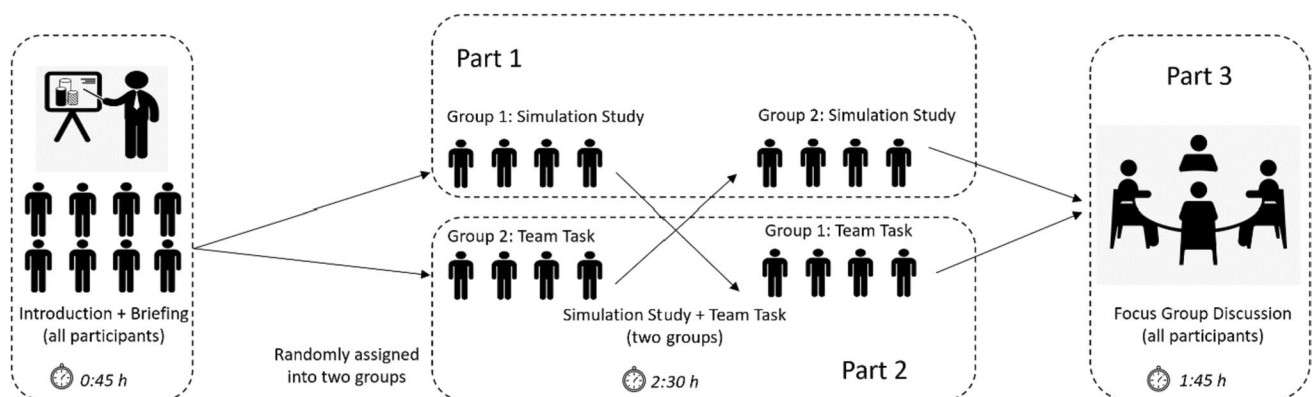
### 4.2.2 Apparatus

**4.2.2.1 VR-Lab** The urban scenery is simulated using DLR’s Virtual Reality Lab (VR-Lab) of the Institute of Transportation Systems. The Virtual Reality Lab is a highly dynamic and scalable simulation environment. It can show a 360° representation of the virtual world through a 360°-front-projection visualization. The VR-Lab has a resolution of 1200 × 1920 pixels per each 30° projection angle, summing up to a resolution of 14 400 × 1920 pixels.

A shared software framework makes it possible to link with other simulators and infrastructures within the institute, such as an augmented reality device (AR device).

The 360°-wall of the VR-Lab visualized the forecourt of the central station of Brunswick and its surroundings. The picture of the scenery was static, meaning there were no moving automobiles or passengers around. The only moving elements in the scenarios were the flying drones visualized on an AR headset.

**4.2.2.2 Drone traffic simulation in augmented reality** We used a Microsoft HoloLens [45] to show the participants four different drone models in predefined trajectories. The Microsoft HoloLens is an augmented reality headset with optical see-through displays that adds virtual content into the actual or simulated environment, e.g., as in [46, 47].



**Fig. 2** The procedure of the mixed-method approach study

Furthermore, it runs four environment understanding cameras, a depth camera, a photo/video camera, and an inertial measurement unit (IMU) to track its position and orientation in 3D space. Due to optical waveguide technology [48], 3D-generated drone models can be seen through glasses.

The four models were a Maritime Robotics PX-31, an Alpha Unmanned Alpha 800, a DJI Phantom 4, and the Dex Pro X8, a drone constructed and owned by DLR. They were chosen because they represent different types of drones, such as fixed-wing and rotating-wing drones. Moreover, they depict several drone sizes. The participants could gain a variety of impressions about drones in this way.

The virtual drones are moving in total on four implemented trajectories (see Fig. 3) with a predefined distance from each other. The trajectories were developed regarding actual GPS coordinates to match the correct position of the city in the VR Lab. The Holograms of the drones were visualized on the HoloLens, and in combination with the surrounding in the VR Lab, the impression was created that the drones were flying in the sky (see Fig. 4). Due to the weather conditions at the actual central station in Brunswick, we combined VR- and AR technology to get a controlled, weather- and time-independent environment.

To create flight paths where drones fly under realistic conditions, we used an algorithm based on Catmull–Rom splines [49]. Furthermore, the position and orientation of

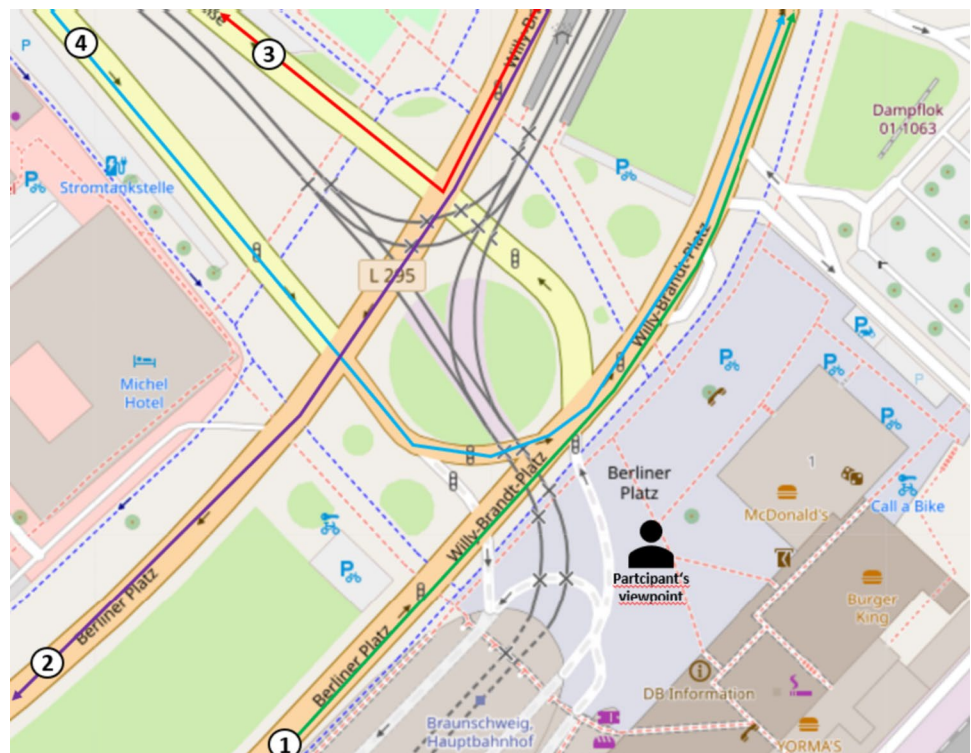
a reference image, also known as the image target, serve as a reference point to connect the VR-Lab and the HoloLens. Herein, the integrated photo camera of the HoloLens detects the placed image with its position and orientation, and we used the Vuforia library [50] to compare the camera picture against a predefined target. Afterward, the implemented virtual content can be augmented seamlessly into the natural surroundings. The initialization and transition between different scenarios of the study are controlled from a separate application in a remote computer, avoiding any unnecessary distraction for the participants or reducing time expenditure during the survey.

The simulation did not include drone noises, as the focus was only on visual perception.

#### 4.2.3 Procedure

During the experiment, participants stood in the center of the VR Lab and wore HoloLens glasses. Each participant was presented with seven scenarios, including the reference scenario, and each three scenarios of the factors of flight altitude and visual density. The sequence of the seven scenarios was randomized, and participants did not know which scenario they were watching. Each scenario lasted one minute. After each scenario, participants were asked to answer the

**Fig. 3** The graphic illustrates the trajectories the drones flew in the simulation, numbered from 1 to 4. The black manikin indicates the viewpoint of the participants in the VR Lab





**Fig. 4** Participant watches the scenario through the HoloLens in the VR Lab. The red square highlights the visualized drones seen through the AR-headset



post-run questionnaire comprising the four items for assessing perceived risk.

#### 4.2.4 Analysis

For each  $2 \times 3 + 1$  (7) scenario, medium values and standard deviations of all participants' ratings for the four items were calculated. Furthermore, a Friedman test was conducted for flight altitude and visual density to determine whether there were statistically significant differences in the ratings of the related scenarios.

### 4.3 Method 2: team task

#### 4.3.1 Apparatus

To accomplish the team task, the participants used a large touchscreen installed on a table to sketch their ideas. The applied touchscreen Multisync X651UHD-2 from NEC has a 65" display with a resolution of  $3840 \times 2160$  pixels.

Moreover, the software *paint.net* was used on the touchscreen, which has various drawing and image editing functions. *Paint.net* depicted a map of the city of Brunswick. The teams were instructed to outline their ideas and concepts on the map. The teams gathered detailed descriptions of their elaborated concepts on a flip chart.

#### 4.3.2 Procedure

Each team worked on the task individually. The teams were instructed to assume that drones are designed, secure, and

certified for use in urban and suburban regions. Thus, a comprehensive concept must be developed to integrate drones into urban traffic successfully. A team of experts will be needed for this task. The groups were instructed to imagine themselves as the expert team and to create a model for integrating various drone operations—such as air taxis, deliveries, rescue missions, etc.—into current traffic and infrastructure. In doing so, participants were asked to consider necessary regulations, flight routes, possible landing spots, operators, and responsibilities. The teams illustrated their ideas on the map of Brunswick and the flip charts. At the end of the study, the teams then presented their concepts within the group discussion. The researchers took notes during their presentations to record the results.

#### 4.3.3 Analysis

Flip charts, drawings on the map, and researchers' notes were used for the analysis. The teams' respective contents were initially recorded in a single document. Second, content categories were extracted from the text file using an inductive methodology. All statements that appeared repeatedly in the results were combined, and all pieces of text containing content were categorized appropriately.

### 4.4 Method 3: group discussion

#### 4.4.1 Procedure

Participants in the focus group discussion were instructed to vote on several drone use cases before the debate began.

They were asked about their opinions on using drones to transport packages, serve as air taxis, conduct research, provide protection to the public, use them for a hobby, and to take pictures and films. Participants were told to cast their votes using their thumbs. Thumbs were held up or down to indicate a positive or negative attitude and horizontally to indicate a neutral opinion. When voting, participants were instructed to close their eyes to prevent group dynamics from influencing the results. The results were documented in a table. The various drone applications were discussed more thoroughly about perceived benefits and drawbacks and associated attitudes, beliefs, and concerns. During the group discussion, researchers paid particular attention to the applications that received controversial or negative votes from the participants.

#### 4.4.2 Analysis

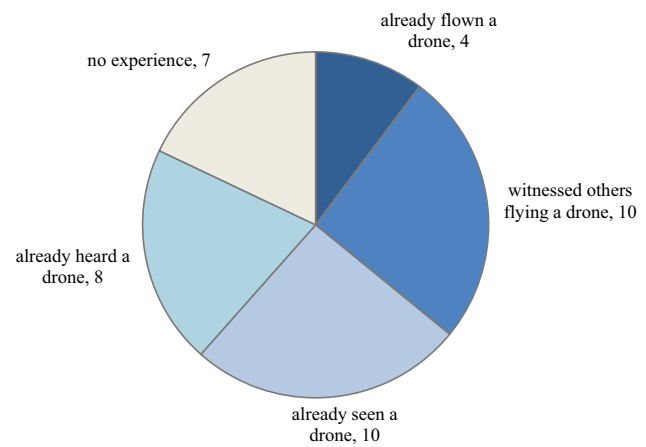
In the initial stage of the analysis, all relevant statements from the audio recordings that linked to the participants' opinions on different drone applications were noted in a table. The voting assignment used drone applications as the topic categories at the beginning of each group discussion. On this basis, all relevant information from the records was categorized accordingly. Redundant statements were combined.

## 5 Results

### 5.1 Sample

The study included 21 individuals from Brunswick and the surrounding area (14 men and seven women). Six to eight individuals took part in each trial. They were recruited via local social media like Ebay and Facebook groups. One participant's test had to be stopped during the simulation because the person could not see the drones and was therefore excluded from the simulation's analysis.

The participants were 38 years old on average ( $sd = 11.93$ ) and ranged in age from 18 to 58. Regarding their educational backgrounds, three people have attained the matriculation level, seven have received a vocational education, four have a polytechnic degree, six have graduated from a university, and one has a doctorate.



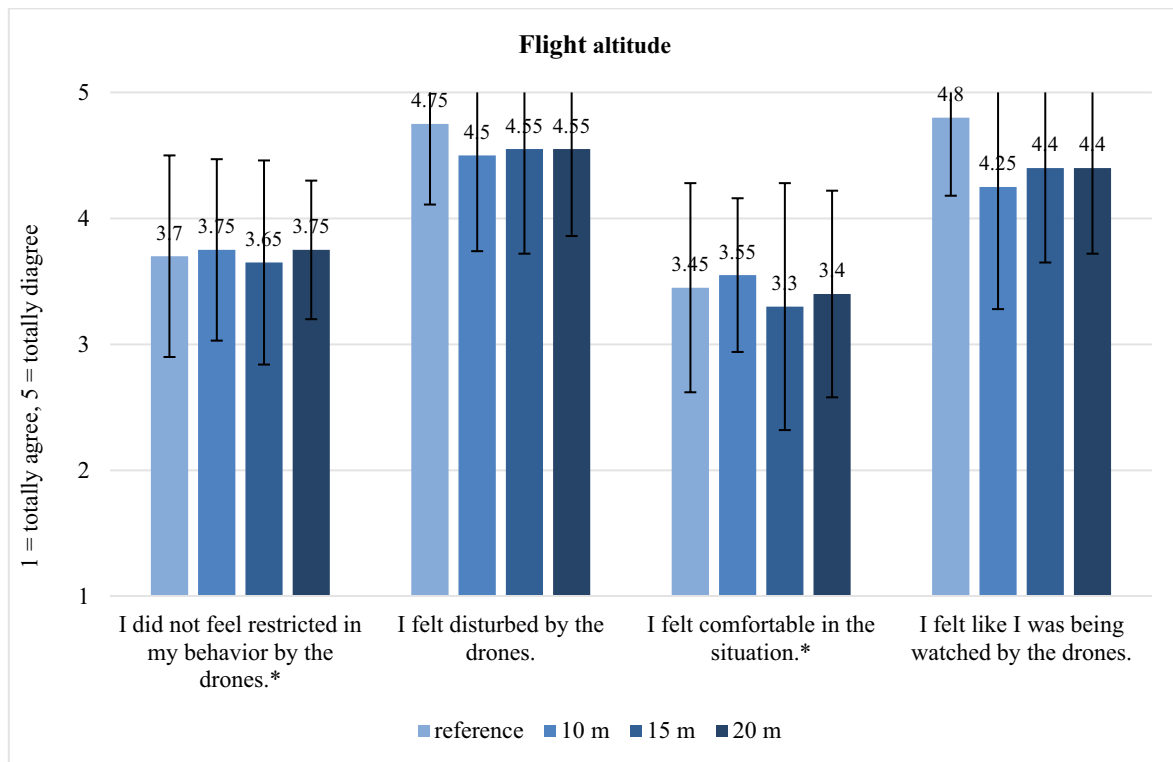
**Fig. 5** The pie chart presents participants' experiences with drones in total numbers (multiple choices were possible)

Eleven participants are full-time employees, two are unemployed, two are in retirement, and six reported a different type of employment status. The participants were further asked about their experiences with drones. The results are presented in Fig. 5, whereby multiple answers were possible.

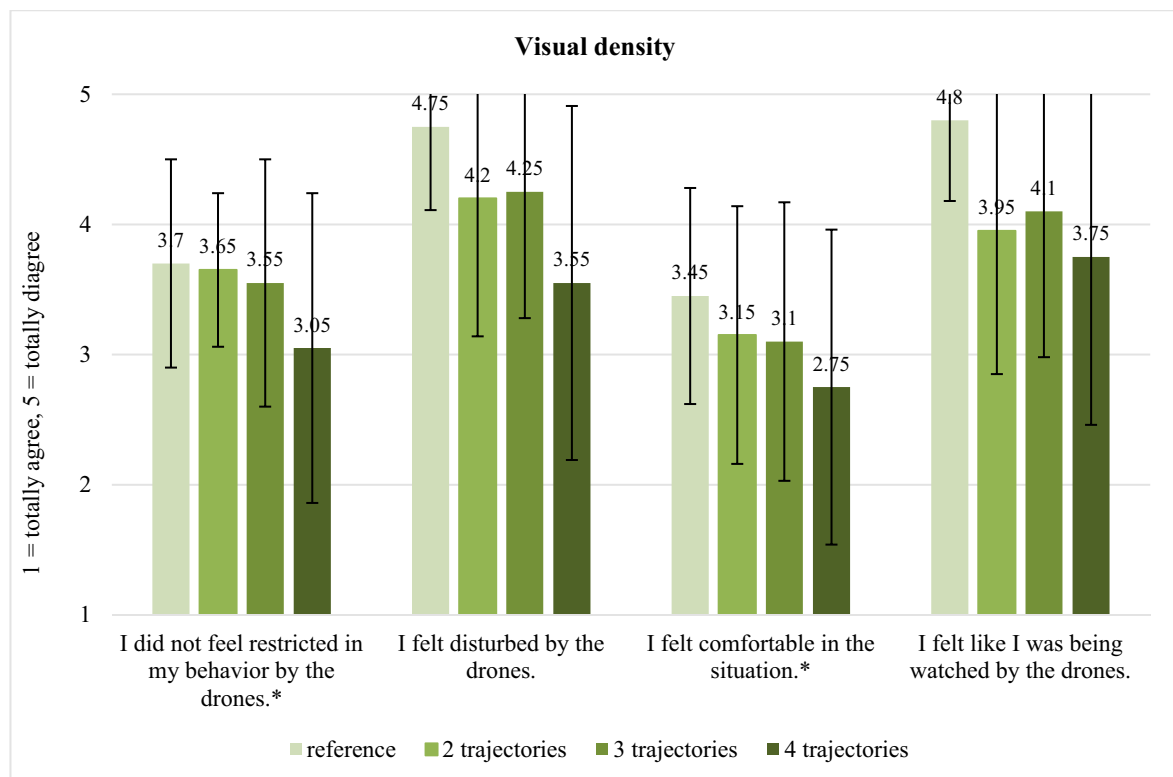
## 5.2 Simulation

### 5.2.1 Flight altitude

The mean values and standard deviations of the participants' ratings of the acceptance items are presented in Fig. 6. Relating to the feeling of being disturbed and being watched by drones, the bar chart indicates that participants disagreed with these statements. They were rated most favorable in the reference scenario and slightly more negative in the scenarios with drones flying. Overall, the responses to all scenarios do not indicate that participants felt negatively about drones at any time. As the items related to not being restricted in one's behavior by drones and feeling comfortable in the situation are formulated positively, their mean values have been reversed. The responses show that participants were not restricted or uncomfortable in any scenarios. However, these are rated slightly more negatively than the other two items.



**Fig. 6** Bar chart of means of the acceptance items for the factor flight altitude (whiskers show standard deviation,  $n=20$ ). Items highlighted with a \* have been reversed



**Fig. 7** Bar chart of means of the acceptance items for the factor visual density (whiskers show standard deviation,  $n=20$ ). Items highlighted with a \* have been reversed

A Friedman test explored whether the responses significantly differ between the scenarios. The test was overall significant in the feeling of being watched by drones ( $\chi^2(3) = 12.49, p = 0.006, n = 20$ ), but no significant differences were found in the post hoc tests according to Dunn–Bonferroni.

### 5.2.2 Visual density

The mean values and standard deviations of the participants' ratings of the acceptance items are presented in Fig. 7. The bar chart indicates that for all items, the responses tend to be more negative the more drones were flying in the scenario. Similar to flight altitude, more favorable responses are given regarding the feeling of being watched and disturbed by drones compared to the other two items. The findings indicate that the participants never really felt unpleasant, but there is evidence of a little decline with increasing visual density.

A Friedman test explored whether the responses significantly differ between the scenarios. The test turned overall significant for all items (not restricted:  $\chi^2(3) = 11.75, p = 0.008, n = 20$ ; disturbed:  $\chi^2(3) = 21.23, p < 0.001, n = 20$ ; comfortable:  $\chi^2(3) = 14.97, p = 0.002, n = 20$ ; watched:  $\chi^2(3) = 22.43, p < 0.001, n = 20$ ). However, only in the case of the items referring to feeling disturbed and being watched Dunn–Bonferroni's post hoc tests also turned significant. For both feeling disturbed  $z = 1.35, p = 0.006, \text{Cohen's } r = 0.30$ ) and being watched  $z = 1.28, p = 0.011, \text{Cohen's } r = 0.29$ ), the test reveals a significant difference between the reference scenario and the scenario, in which drones were flying on all of the four trajectories. Both are moderate effects.

### 5.2.3 Feedback on the simulation

Feedback on the simulation was collected during the group discussion to improve future simulation studies on drone acceptance. An overview of the various comments given by the participants is provided in Table 5.

## 5.3 Team task

The following five general content categories were formed from the concepts and ideas of the teams for integrating drone traffic into the city of Brunswick: necessary regulations and responsibilities, flight routes and flight zones, operators, landing spots, and further recommendations. Preferences and advice for managing future drone traffic elaborated by the teams are presented in Table 6. The table is structured according to the derived content categories.

## 5.4 Group discussion

### 5.4.1 Attitude on drone applications

Figure 8 shows the results of participants' votes on different drone use cases. The results reveal that all participants voted to use drones for civil protection and research. Participants perceive these applications as highly beneficial based on the statements made during the discussion. Most feedback on using drones for taking pictures and films, as a hobby, and as an air taxi was neutral or positive. It is important to note that following the voting, participants said their opinions on filming drones depend on the purpose. For instance, people would judge tobacco advertising images harsher than drone-shot news broadcasts. Participants' views on delivery drones are polarizing. As a result, there are about equal numbers of positive and negative votes.

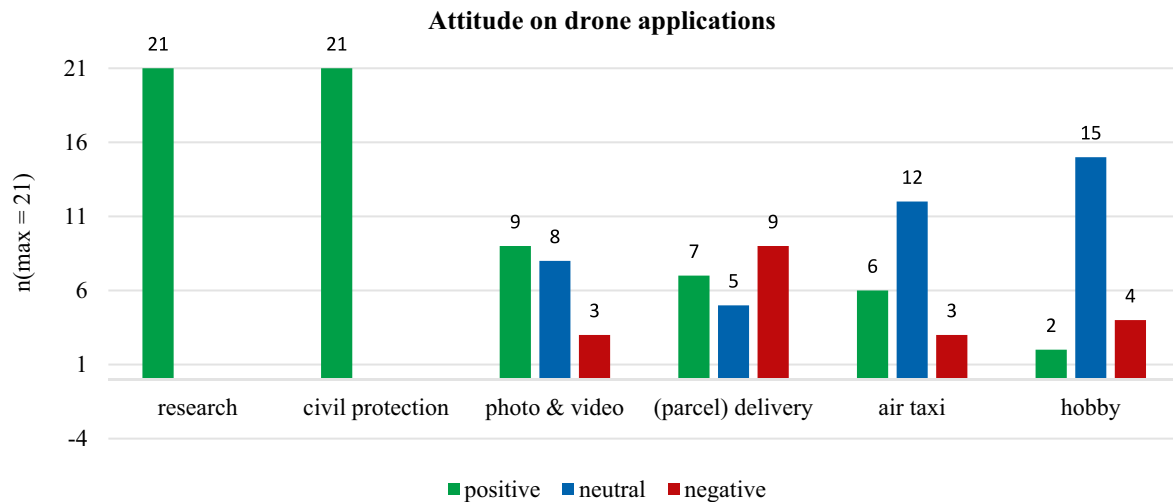
**Table 5** Feedback on the simulation

Participants' comments on the simulation
<ul style="list-style-type: none"> <li>• Integrate drone noise</li> <li>• Better visibility of drones, maybe use also different colors</li> <li>• Integrate other traffic and passengers; this would be more realistic</li> <li>• Include a scenario where a drone lands directly in front of you</li> <li>• Create more selective scenarios (challenging to recognize different flight altitudes)</li> <li>• Test higher visual densities, as the scenarios in the simulation were not threatening</li> <li>• Integrate different drone types, as some seem more menacing than others</li> <li>• Use 360-degree view in simulation; in this simulation, you could not look up at the sky</li> <li>• Include direct overflights as well</li> <li>• 3D simulations would be better</li> <li>• The instruction that drones will be visible in the simulation triggered an expectancy effect; maybe use other instructions in future studies</li> </ul>



**Table 6** Results of the team task structured by content categories

Category	Recommendations of the participants
Necessary regulations and responsibilities	<ul style="list-style-type: none"> <li>• Central agency for monitoring and coordinating drone traffic with the responsibility for safety aspects to interfere in case of violating traffic regulations, and it should be able to take control of drones remotely</li> <li>• Geofences to determine no-fly zones</li> <li>• Use a similar penalty system to that for traffic violations on the road, using penalty points and stripping flight licenses in case of exceeding a certain amount of points</li> <li>• All drones should have registration plates and be registered at a central agency as well as an automated recognition of registration plates should be possible</li> <li>• Different assistance and backup systems for drones and pilots should be developed for traffic safety (e.g., for communication, conflict avoidance, parachutes on board)</li> <li>• Technical Inspection Agency for regular drone checkups</li> <li>• No flights at night; alternatively, flying times should depend on the noise level of a drone</li> </ul>
Flight routes and flight zones	<ul style="list-style-type: none"> <li>• Different air spaces/ flight altitudes for different drone types (e.g., hobby drones: 50 m, delivery drones: 100 m, air taxis: 150 m)</li> <li>• Organize drone traffic by priority: civil protection is the highest priority, followed by other missions like measuring, parcel delivery, air taxis, and hobby drones</li> <li>• Drones could fly on given routes or corridors, e.g., above existing infrastructure like freeways or railways (advantage: those infrastructures are already noisy. Thus, drones would not make a difference; disadvantage: drones might distract car drivers; the benefit of short airways would be obsolete if drones were bound to existing infrastructure)</li> <li>• No-fly zones in areas that need special protection, like parks, nature reserves, airports, jails, graveyards, or open-air baths</li> <li>• Use jamming transmitters to avoid drones intruding on no-fly zones</li> <li>• Only drones used for civil protection are permitted to enter no-fly zones, e.g., via activation codes</li> </ul>
Operators	<ul style="list-style-type: none"> <li>• Obligatory flight license for each drone pilot, also for using hobby drones</li> <li>• Each drone should be assigned to an owner</li> <li>• Private drone users should only have access to a limited selection of drone types, e.g., for autonomous drones, special permission should be mandatory</li> <li>• Many passengers on air taxi rides without a pilot could feel uncomfortable since it is unsettling to hand over control to a system</li> <li>• In autonomous air taxis, passengers should have the opportunity to actively intervene in case of a critical event, e.g., via an emergency button to contact operators on the ground</li> </ul>
Landing spots	<ul style="list-style-type: none"> <li>• Landing spots for air taxis should only be located at central spots, such as train stations and airports, possibly also rooftops and parking garages</li> <li>• Landing spots for delivery drones could be located in gardens, rooftops or cars, nearby parcel stations</li> <li>• Rescue drones should have the highest landing priorities</li> <li>• Landing spots for rescue drones could be located at police stations, hospitals, or fire stations</li> </ul>
Further recommendations	<ul style="list-style-type: none"> <li>• Important to prevent acoustic or visual pollution caused by drones; drones are too noisy</li> <li>• Questions regarding liability and insurance must be addressed, e.g., who will be responsible for damages caused by fully autonomous drones?</li> <li>• Involve society in the whole integration process</li> <li>• Improve education of society (e.g., via reports) as people do not feel well informed about drones</li> <li>• First, integrate drone applications with a high social acceptance. Thus, society becomes accustomed to drones, step by step</li> </ul>



**Fig. 8** Bar chart with absolute frequencies of positive, neutral, and negative votes related to drone applications,  $n = 21$

The following sections present the outcomes of the group talks on parcel delivery, air taxis, and hobby drones (see Tables 7, 8, 9). Since participants had negative or ambiguous feelings about them, the debates focused on these applications. However, the participants' main debate topics across all groups were air taxis and delivery drones. Each table is organized according to content categories, including

perceived benefits and risks, open questions, recommendations for implementing drones, and content-rich quotations from the discussion.

#### 5.4.2 Parcel delivery

See Table 7.

**Table 7** Results of the group discussion related to parcel delivery structured by content categories

Category	Recommendations of the participants
Perceived benefits	<ul style="list-style-type: none"> <li>• Reduce the workload of parcel carriers</li> <li>• Widen time frames for deliveries</li> <li>• Create new jobs</li> <li>• Flexibility</li> <li>• Ecological aspects</li> </ul>
Perceived risks	<ul style="list-style-type: none"> <li>• Weather dependency</li> <li>• Jobs might be endangered</li> </ul>
Open questions	<ul style="list-style-type: none"> <li>• ARE they indispensable in inner cities (inner cities vs. rural areas)?</li> <li>• How will drone delivery exactly happen?</li> <li>• What is the technical feasibility?</li> <li>• What is the capacity of delivery drones, and how many will be necessary?</li> <li>• Ban on night flights vs. flights taking place 24/7?</li> </ul>
Recommendations	<ul style="list-style-type: none"> <li>• Should not replace standard parcel service, but support it</li> <li>• Only apply drones for express delivery or special deliveries like medicines</li> <li>• The service has to be cost beneficial and comfortable compared to conventional parcel delivery. Otherwise, it will not succeed in the market</li> <li>• Suggested landing spots and storage solutions for packages: parcel stations in gardens or on rooftops (rooftops need to be made safer than), use existing parcel stations, delivery by appointment (e.g., delivery times could be set via smartphone)</li> <li>• There should be central warehouses from which packages will be distributed</li> <li>• Different drones could be responsible for different postal districts</li> </ul>
Quotations	<p><i>"How many delivery drones would be needed? How many packages are drones able to carry? And then we have a black sky full of drones."</i></p> <p><i>"How would this whole thing work? Do you have to hold a net out the window when the drone puts the package in?"</i></p>

### 5.4.3 Air taxis

See Table 8.

**Table 8** Results of the group discussion related to air taxis structured by content categories

Category	Recommendations of the participants
Perceived benefits	<ul style="list-style-type: none"> <li>• Could connect city centers with suburban regions</li> <li>• Higher comfort for older people (Would they accept and use air taxis?)</li> <li>• Doctors could fly to visit older patients</li> <li>• Ecological aspects</li> <li>• Are not restricted to specific routes</li> </ul>
Perceived risks	<ul style="list-style-type: none"> <li>• High prices (makes population-wide use unlikely)</li> </ul>
Open questions	<ul style="list-style-type: none"> <li>• What are the use cases for air taxis (inner city flights, flights in suburban areas, connecting central points like train stations and airports, connecting larger cities)?</li> <li>• Predetermined routes vs. air taxis are free to fly everywhere? Participants tended to prefer flexible routes</li> </ul>
Recommendations	<ul style="list-style-type: none"> <li>• To make air taxis accessible to the broad public, prices should be similar to those of conventional taxis</li> <li>• For paying for air taxi flights, user-friendly solutions like apps should be offered</li> <li>• Air taxi prices could be included in train or flight tickets</li> <li>• For short distances, other transportation means are more suitable; in most cities, public transport options are sufficient</li> <li>• In the beginning, air taxis could fly in test cities to familiarize the public with the new mode of transport</li> <li>• Air taxis should preferably be used to connect larger cities and to enable transport between central traffic junctions</li> <li>• Suggested landing spots: one per suburb/village, central points like train stations and airports, rooftops, and bus stops (need to be reconstructed accordingly)</li> <li>• The capacity of air taxis should be increased to at least ten seats so that they can compete with minibusses as a viable alternative for avoiding traffic in urban areas</li> <li>• Ban on night flights vs. flights taking place 24/7 → it should depend on the noise caused by air taxis</li> <li>• Safety is a crucial aspect → technology must be as secure as possible to increase public confidence in air taxis</li> <li>• The idea of air taxis flying unmanned might scare people</li> <li>• In critical situations, participants would like to have the possibility to intervene, e.g., via an emergency button actively</li> <li>• Experts on the ground should be able to take over the steering of the taxi in critical situations</li> <li>• There should be emergency equipment like parachutes or separate batteries for a controlled landing on board</li> </ul>
Quotations	<p><i>"If it can be proven that air taxis are as safe as they can be, I am in!"</i></p> <p><i>"I can imagine myself saying, I will just try it out now, fly with it now, just to see how fast it goes, but not for daily use. At least not in Brunswick."</i></p> <p><i>"In case of a critical incident, it would be good to know I can contact someone, and I am not alone somewhere in the sky and have to hope that the system or any person will handle the situation. I think feeling that you can actively do something is important."</i></p>

### 5.4.4 Hobby

See Table 9.

**Table 9** Results of the group discussion related to hobby drones structured by content categories

Category	Recommendations of the participants
Perceived benefits	<ul style="list-style-type: none"> <li>• Fun</li> </ul>
Perceived risks	<ul style="list-style-type: none"> <li>• Produce much waste (environmental pollution)</li> <li>• Batteries contain harmful substances</li> <li>• Drones not registered → potential misuse</li> <li>• Secret filming → high potential to cause conflicts within society</li> <li>• You do not always know who is controlling the drone</li> </ul>
Open questions	<ul style="list-style-type: none"> <li>• Does everyone adhere to the rules?</li> </ul>
Recommendations	<ul style="list-style-type: none"> <li>• Flights should better not take place in urban areas (or maybe only in designated places)</li> <li>• Only in designated areas and at specific times</li> <li>• Hobby pilots should also be obliged to have a drone license</li> <li>• Flight bans in parks, cemeteries, and recreational areas</li> </ul>
Quotations	<p><i>"I think these drones are cool. You are driving through the city center, and the drone is flying behind you the whole time."</i></p> <p><i>"The park is a point of relaxation. Many people are already annoyed by dogs there. Also, having drones next to you could be noisy."</i></p> <p><i>"Some people react kindly to drones; others react very aggressively. This could become critical and cause many irritation or problems within society."</i></p>

## 6 Discussion

### 6.1 Strengths and limitations

#### 6.1.1 Simulation experiment

The simulation test within this study was conducted to provide participants with an impression of what future drone traffic might look like and investigate how the visual presence of drones is perceived in an urban environment. However, the intention of this study was not to experiment on a large sample of participants but rather to explore if the virtual lab provides participants with a realistic impression of drones and to collect some first responses on people's perceptions of different flight altitudes and visual density scenarios. The first experience with this simulative approach and participant feedback suggests that simulations are valuable for giving people an impression of future traffic scenarios. However, the study also reveals some shortcomings and possibilities for improvement. Chapter 7.3 will go into greater depth on this.

Regarding the pre-experimental briefing, participants pointed out that announcing that drones would be featured in the simulation caused an anticipation effect. This led to a focus on drones from the beginning. Therefore, in future studies, consideration could be given to making the pre-study instruction more neutral and revealing less about the subject of the study.

#### 6.1.2 Team task

The methodology of asking participants to work out recommendations for drone traffic within a team task has proven valuable and suitable for identifying citizens' requirements for managing future drone traffic.

Some of the recommendations provided in the U-space concepts, described in the presentation at the beginning of the trial (see chap. 5.1), were also formulated by the participants in the team task. These encompass aspects like drone registration, flight altitudes, and licenses. Consequently, one of the study's limitations might be that the presentation influenced participants' ideas. We counteracted this by emphasizing that we are primarily interested in their subjective wishes and ideas. However, this might have needed to be more consistent with the task instruction, where participants have to imagine being part of an expert team and developing a drone traffic concept for Brunswick. To create an easily relatable setting, we decided to use this story. Another area for improvement is that we cannot determine the amount to which each team member's perspective was considered equally when developing the concepts. When working in groups, it is possible for an unequal dynamic to establish, in which some members contribute much more to the discourse

than others. Therefore, future studies should examine whether the needs discovered in this study are also present in the broader population. This could be accomplished, for instance, by using representative internet surveys.

#### 6.1.3 Group discussion

As mentioned above in the team task, dynamics in a group discussion can also lead to some participants dominating the debate and not all opinions being captured. However, in the discussion, our impression was that many different participants spoke up, and the conversation was varied and lively. Nevertheless, it was noticeable that a few participants were more reserved than others. In further focus groups, incorporating more anonymous survey techniques, such as writing on index cards, could be a solution to engage everyone in the discussion.

### 6.2 RQ 1: How do individuals perceive varied drone flight altitudes and visual densities in urban settings?

In the simulation part of the study, participants experienced different flight altitudes and volumes of urban drone traffic. No substantial differences in the responses to the acceptance items were observed between the distinct flight levels in the flight altitude scenarios. According to participants' feedback, the flight altitudes were not sufficiently distinguishable in the simulation. The reasons are that the scenarios may not have been clear enough. Future research should incorporate a broader range of flight altitudes to address this limitation, encompassing low and high flight levels. In our study, we used response categories of the DLR telephone survey [23], which only includes lower heights, to create the scenarios. We further presumed that drones would be seen as more of an annoyance because they are easier to see at lower altitudes. As professionally operating drones, such as for parcel delivery or reconnaissance, will probably fly at higher levels, future research should consider higher flight altitudes.

Regarding visual density, results indicate that as drone traffic volume increase, responses tend to become more negative, especially in the highest density scenario compared to the reference scenario. However, it is crucial to note that participant responses were consistently within the moderate to positive range of the scale and did not turn entirely negative. The substantial standard deviations imply that perceptions differ significantly among participants. This study involved 20 participants. Further research on larger samples will be required to examine the possible effects of visual density. In 2021, DLR conducted a follow-up study. This also suggests that drone acceptance would decrease as drone traffic volume increase. However, the effects observed in this experiment were also minor, and responses did not turn entirely



negative. In contrast to the initial survey, the study involved drone noises and found that the sound did not significantly impact acceptance. According to the author's explanation of the results, the subjects mostly did not hear the drones, and thus, other traffic noises might have been masked by drone noise [51]. A masking effect of drone noise in an urban environment with many acoustic stimuli was also observed in an experiment conducted by Torija et al. [52].

We emphasize that the simulation was a preliminary simulative approach tested within this study's context. This initial test and participants' comments reveal several enhancements for future simulation experiments. The subsequent chapter will discuss recommendations for further simulation studies in more detail. Because the simulation still has many opportunities for improvement, we will not yet draw specific conclusions from the data. Also related to the perception of drone flights in cities, we will not suggest an acceptance level on the Hofinger scale [9].

### **6.3 RQ 2: Which aspects are important to consider in future simulation experiments related to drone acceptance?**

The testing of our simulative methodology identified various areas for advancement in future studies: the enhancement recommendations concern both the simulation and the scenario design. Since the participants could not glance upward due to the absence of the sky viewpoint in our simulation technique, further experiments might better use VR glasses as they provide a 360-degree view. During the test, some participants looked for drones flying overhead. They proposed that future research should also explore overflight scenarios. A virtual reality study by Aalmoes and Sieben [53] compared the acoustic and visual perception of hovering and overflight maneuvers and found that hovering was perceived as more annoying. Our study only addressed the visual perception of drones. But research indicates that noise significantly impacts the acceptability of drones [25, 34, 52, 54, 55]. For this reason, it is crucial to consider drone noise in future simulation studies. Another area for improvement in the simulation is the visibility of drones. They appeared in bright colors, so some participants had difficulties recognizing them. This is due to the visualization in the HoloLens. The AR glasses perform best in a dark environment. The greater the light in the surroundings, the more transparent and less visible the simulated holograms become. The light from the urban environment simulated on the 360°-wall of the VR lab might have caused the drones to be less visible. A more realistic view might be achieved by simulating all components in VR in future studies. Another interesting approach for creating a highly immersive experience would be letting participants wear the HoloLens in an actual urban situation where drones are simulated. However, this

is currently not feasible due to the aforementioned limited visualization capability in bright light conditions of AR glasses. Although, in theory, AR displays, such as the HoloLens, worn outdoors can show holograms even in bright, sunny conditions, these displays are lacking in contrast to being visible in daylight as they cannot selectively block light from the natural environment [56]. This deficit in pixel-accurate occlusion reduces the difference and makes the virtual objects appear like transparent ghosts. The visibility of drones may also be increased by choosing darker colors. Furthermore, actual drones can come in a variety of colors. This should be represented in subsequent investigations. The findings of a study by Chang et al. imply that people's perceptions of drones may be influenced by their color and shape since study participants perceived dark-colored and "spidery" drones as frightening [34]. Regarding the scenario design, our study reveals the necessity of more selective manifestations, especially regarding the factor of flight altitude. Greater distances between altitude categories and the inclusion of realistic cruise altitudes of drones used by professionals are required. Regarding the issue of the location of drone take-off and landing sites, this is a crucial area of research. It must be assured that drones' visible or audio presence does not disrupt people. It would be interesting to explore how adjacent drones affect peoples' perceptions in future research incorporating drone sound and at which flight levels noise is not considered disruptive. The same applies to visual density. In our study, participants commented that the drone volume was not experienced as menacing. This might change with the inclusion of noise. A last point of criticism is the static character of the urban environment in the simulation. There was no other traffic and pedestrians, so participants perceived the setting as unnatural. Further research should take this into account. Three-dimensional studies where participants can move through the scenario would be more realistic. How drones are experienced in different urban areas could be further explored in this context. There are hints in the literature that people may not tolerate drones in all regions. Flights in business and industrial parks are more acceptable compared to city centers or residential areas [23].

### **6.4 RQ 3: Which attitude do individuals have toward different drone applications? /RQ 4: Can we assume the required minimum acceptance levels on the Hofinger scale within society concerning various drone applications?**

The results obtained from the voting (see Chapter 6.4, Fig. 8) and the discussion show that the acceptance of drones depends on the use case. Participants support the usage of drones in research and civil protection. Using drones for taking pictures and filming is considered neutral or positive. In

contrast, hobby drones and air taxis received more neutral ratings. Acceptance of parcel delivery is polarizing. About half of the individuals in the sample had a positive attitude toward using drones to transport packages, while the other half had a more pessimistic viewpoint. Based on the voting results and the topics raised in the group discussion, we suggest assigning each drone application to a level of acceptance on the Hofinger scale [9], presented in Table 10.

All participants voted in favor of deploying drones for research and civil protection, which indicates a high level of support. This is supported by statements made in the group discussions. Participants assume that civil defense and research are highly accepted in society and believe there are several situations in which these applications may be helpful, such as drones for rescue operations. Participants indicated their support for drones for study and civil protection, but there was no engagement. Due to this, we propose an acceptance level of 7 on the Hofinger scale [9], which indicates people's approval.

We suggest an acceptance level of 6 for drones taking pictures and videos. Most participants voted in favor of this application or were neutral about it. They explained that approval in this situation would depend on the purpose. Participants agreed that using drones to capture images for documentaries and other beneficial purposes would be acceptable. As a result, acceptance of this use case is conditional.

We also propose an acceptance level of 6 for delivery drones and air taxis. In the group discussion, participants noted that they see both benefits and risks in these applications. During the debate, it became clear that people still have many unanswered questions about these use cases. Therefore, the participants paid the most attention to them when discussing. These observations might explain why the voting results largely reflect neutral opinions regarding air axis and polarizing perspectives on delivery drones. The findings reveal that the acceptance of both services strongly depends on how they will be deployed. According to a study by Yedavalli and Mooberry, their perceived convenience mainly affects the willingness to use UAM services. [32].

**Table 10** Results of the group discussion related to hobby drones structured by content categories

Application	Proposed acceptance level	Required minimum level fulfilled?
Civil protection	7 (approval, favor)	Yes
Research	7 (approval, favor)	Yes
Photo and video	6 (conditional acceptance)	No
Air taxis	6 (conditional acceptance)	No
Parcel delivery	6 (conditional acceptance)	No
Hobby and leisure	2–3 (refusal, indifference)	No

We anticipate the lowest level of approval for hobby drones. The majority of the participants had a neutral attitude toward them. But from the debate, it was clear that utilizing drones for recreational purposes offers more risks than other use cases. For this reason, we suggest a lower degree of acceptance for hobby drones and recommend classifying the level of acceptance between 2 and 3, which implies refusal or indifference.

Our proposed classification implies that the minimum acceptable level is met for using drones in research and civil protection, but not for air taxis, delivery drones, and filming drones. This aligns with previous research findings indicating that private and commercial applications are less accepted than public ones [23, 31, 57].

#### 6.5 RQ 4: What are the requirements regarding the coordination and implementation of future drone traffic as proposed by the participants?

Five categories of content were found in the requirements and proposals for future drone traffic developed by the participants in the team task: (I) necessary regulations and responsibilities, (II) flight routes and flight zones, (III) operators, (IV) landing spots, and (V) further recommendations.

The recommendations made by the participants for (I) are notable for having some similarities to norms regulating road traffic, such as a central authority that governs drone traffic and a Technical Inspection Agency to conduct regular checks of the drones. This suggests that operational and technological safety is an essential requirement. Moreover, it is crucial to the participants that drones do not annoy people, which is indicated by their recommendation to limit night flights or to set permitted flight times depending on the noise level of the drones.

Participants' suggestions for segregating the airspace in (II) with lower altitudes for small drones (such as hobby drones) and higher altitudes for large drones (such as air taxis) may also be motivated by noise concerns. No-fly zones were also discussed, particularly in areas that need special protection, such as parks or nature reserves. Previous research also indicates that drone flights are unfavorable in all regions, particularly not close to people [23, 29, 32, 34]. Another suggestion in this category is to prioritize drone traffic, with drones used for civil protection receiving the highest priority. This complements our findings, which show that the highest level of acceptance was observed for drones used for civil protection and research.

Participants suggest that each operator (III) should have a flight license, and each drone should have a designated owner. They further propose limiting hobby pilots' access to certain types of drones. This is in line with the results of the DLR telephone survey [23]. These findings indicate that

safety is a crucial aspect, as is transparency and traceability of pilots and flight missions. Moreover, the topic of fully autonomous air taxis was addressed. Participants asked who would charge critical incidents when no pilot is on board. In such incidents, they would like to have opportunities to act, e.g., by pushing an emergency button to alert ground personnel. This requirement was also detected in a study by Janotta [58].

Regarding landing spots (IV), participants recommend locating them at central locations like train stations or airports. Given the high population density in cities, it is recommended in the existing literature to build landing places on rooftops [59–62], which is also an option suggested by the participants. Further, they propose several places where delivery drones might deposit packages. During the group discussion, the issue of appropriate parcel storage alternatives was addressed in more detail. Analyses of prospective consumers' preferences are advised to increase drone delivery's acceptability. In terms of rescue drones, participants propose providing them priority landing rights.

Further recommendations (V) mainly address society-related aspects. Preventing drone-related potential noise and visual pollution is critical for participants. Drones must not be a nuisance to society as a condition for acceptance. From the participants' viewpoint, including society in the implementation process and better educating the public about drones is vital. Evidence from the literature shows that peoples' acceptance of UAM might increase with more knowledge and experience with drones [23, 25, 29]. Participants suggest integrating drone applications gradually. The idea is to start with those already supported by the general public. This is to familiarize people with drone traffic. There are some parallels when comparing the recommendations of the participants in this study with the recommendations made in the U-space concept in CORUS [5]. Both suggest implementing assistance systems for managing drone traffic (e.g., DAA systems), establishing no-fly zones, and prioritizing rescue drones. However, there are also some differences between the recommendations of the participants and the CORUS concept. In CORUS, for example, drone traffic is managed and controlled by U-space services, whereas participants would like to have a central authority to ensure operators comply with traffic regulations. CORUS uses a density-based approach to airspace and flight routes to enable drones to use the same airspace. According to the concept, distinguishing between a densely populated urban area and a more rural area determines the flight altitudes and zones. On the other hand, participants in this study recommend higher flight altitudes for large drones because concerns were raised about visual and acoustic pollution. This result is supported by the findings of Gwak et al. [63], who detected that perceived annoyance seems to depend on the drone's size.

## 7 Conclusion

This study used a mixed-method approach to investigate the public acceptance of drones. The theoretical basis for this research was a combination of the Hofinger Unacceptability—Acceptance Scale [9] and Krempel's adapted TAM model [10]. The mixed-method approach has proven valuable in capturing different aspects of social acceptance related to drones. The research demonstrates that the combined theoretical model can successfully apply to drone acceptance. The variables perceived risk, control, benefit, and transparency of the TAM model. They have proven a good predictor of the acceptance level on the Hofinger scale [9]. Based on our findings regarding the acceptance level of different drone applications, we suggest a preliminary classification on the scale. It indicates that almost all use cases examined in the study need higher acceptance levels. According to our assumption, an appropriate level is only achieved for public services rather than commercial and private ones. The detailed discussion within the focus groups about parcel delivery and passenger transport reveals that acceptance depends on how these services will be implemented and whether society perceives them as beneficial. Thus, it is important to consider public needs and demands in developing drone services. This research also sheds light on people's expectations for the control and organization of drone traffic. When creating U-space concepts, experts should consider how these demands can be adequately met.

The study's simulative approach has been shown to help provide participants with a picture of future drone traffic. But no definitive conclusions can be drawn concerning the acceptability and perception of flying drones. Reasons for this are the limitations in the simulation, such as the absence of noise and other traffic, and the small sample size. Additional research is required using larger samples and improved simulations and scenario designs.

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## Declarations

**Conflict of interest** The authors have no competing interests to declare relevant to this article's content.

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