Transport Policy 188 (2026) 104385



Contents lists available at ScienceDirect

Transport Policy

journal homepage: www.elsevier.com/locate/tranpol



What makes Innovative Air Mobility visually pollutant?

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ARTICLE INFO

Keywords:
Visual pollution
Innovative Air Mobility
Drones
Urban Air Mobility
Virtual reality
Mobility experiment
IAM policies
Drone policies

ABSTRACT

Innovative Air Mobility (IAM) has the potential to assist the amelioration of several mobility and logistics issues. Several barriers have been identified to its implementation and any potential negative impacts need to be minimized before the deployment of IAM services. Visual pollution has been designated as one of these barriers with potential negative impacts. This study aims to explore the concept of visual pollution in the IAM context and identify its determinant aspects. Data was collected through focus groups and a thematic analysis was conducted. The key aspects that arose as components of visual pollution in the context of IAM were related to three main areas (drone properties, human-drone interactions, dynamic visual effects) and specifically concerned the colour, the size, the design of the drone, the noise it produces, the drone's altitude, distance from people, type of flight area, shadows, drone quantity, flight schedule and air space structure. The most frequently mentioned topics among the participants were the type of flight area, the colour of a drone, its noise, the altitude it flies, the drone density, the structure of U-space and the purpose of the flight. The results provide insights that can assist policy makers and regulators with the definition of U-space characteristics, measures that can enhance social acceptance and policies to be formulated in the framework of mobility plans.

1. Introduction

Innovative Air Mobility (IAM) envisages a safe and environmentally sustainable air transport system for both passengers and cargo, integrated into multimodal transport systems, with potential to relieve ground traffic, provide safer, faster and cleaner mobility and have a positive impact on the economy (European Union Aviation Safety Agency, 2025). Despite IAM's potential benefits, the implementation of its technologies face significant barriers such as social acceptance and its determinants. While much of the existing IAM research has focused on technical, operational and infrastructural challenges, such as system performance, airspace integration, safety and network optimisation (Jin et al., 2024; Pons-Prats et al., 2022; Straubinger et al., 2020), less emphasis has been placed on citizen concerns such as visual pollution, which may significantly influence public perception and social acceptance (Al Haddad et al., 2020; EASA, 2021; Kalakou et al., 2023; Santos et al., 2025).

Conceptually, visual pollution is perceived as the degradation of the visual environment through intrusive, excessive or visually discordant elements that disrupt landscape harmony and visual comfort (Chmielewski et al., 2016; Jana and De, 2015; Wakil et al., 2019). In the context of IAM, visual pollution extends to the airspace, where the presence, movement and spatial organisation of aerial vehicles may alter how citizens perceive and experience their surroundings. In the context of this study, visual pollution is defined as the negative perceptual response generated when airspace becomes visually overloaded, aesthetically discordant, or disorganized due to the presence, quantity, movement or arrangement of IAM vehicles. This includes conditions that reduce visual harmony, diminish landscape coherence, or disrupt an observer's ability to appreciate or interpret the surrounding environment.

The intrinsically subjective nature of visual pollution stands for its greatest challenge, since individual and collective perceptions of what constitutes visual pollution in a given landscape may vary and there is no wide application in the society yet to capture the views of citizens. In this sense, recent studies looking at this concept and its nuances show that drones can be perceived as intrusive or aesthetically disturbing (Thomas and Granberg, 2023) but limited attention has been given to how the visual characteristics of IAM operations may contribute to perceived visual pollution. There is a lack of empirical understanding of

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https://doi.org/10.1016/j.tranpol.2026.104385
Received 7 December 2025; Received in revised form 23 August 2026; Accepted 23 August 2026
Available online 24 August 2026
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which visual factors (related to drones as vehicles, their interactions with humans and their visual effects) are perceived as visually disturbing, and how these perceptions can inform operational design and policy decisions. Given that visual pollution is part of social acceptance, a crucial factor when implementing new technologies with the capacity to impact citizens' daily lives (Lee et al., 2023), it is important that citizens' opinions are considered so that negative impacts are minimized and successful implementation is enhanced.

To fill this gap in literature, this study uses a virtual reality environment as a way of developing an immersive experience that can respond to the lack of real-world data on visual pollution's social implications and, through focus group discussions, it aims to identify how visual pollution can be depicted and defined in the context of IAM, identify key determinants of visual pollution and connect user perceptions to specific IAM design and policy topics, such as acceptable flight altitude, traffic density and airspace structure.

To address this gap, this study pursues the following research objectives:

(1) To identify the key visual determinants that contribute to perceived visual pollution in IAM operations, including drone properties (e.g., colour, size, noise), human-drone spatial interactions (e.g., altitude, distance from people), and dynamic visual effects (e.g., drone quantity, shadows, flight schedules).
(2) To examine how these determinants vary across operational contexts by comparing immersive Virtual Reality (VR) scenarios representing urban and rural environments and different levels of U-space activity.
(3) To explore how user perceptions of visual pollution can be translated into IAM design and policy levers, such as altitude bands, density thresholds and structured airspace configurations.

The contributions of this study are summarised below:

- It explores and describes the concept of visual pollution for the first time in the fields of mobility and logistics, as current studies focus on other fields and technologies related to marketing studies and energy.
- It captures the contributors to IAM visual pollution as revealed by citizens after have an immersive experience with IAM applications.
- It provides a set of policy requirements for IAM to be socially acceptable with regards to visual pollution impacts. The study contributes to the development of reliable assessment frameworks and informed decision-making in the design of the drones by the manufacturers and regulation of this technology by urban planners and policymakers, thus maximising the potential for successful implementation.

The rest of this paper is organised as follows: Section 2 presents the literature review. Section 3 outlines the methodology used throughout the study. Section 4 details the results and discusses the findings. Finally, Section 5 concludes with final remarks and directions for future research.

2. Literature review

2.1. Visual pollution and social acceptance of IAM

Throughout the years many types of pollution such as air, water and soil pollution have been widely studied. However, there are other types of pollution being less studied in the urban context, such as visual pollution (Wakil et al., 2019). In the context of IAM, few studies have explored the correlation between IAM and visual pollution. There is however already evidence that visual pollution is a significant barrier in citizen acceptance (Thomas and Granberg, 2023).

A recent study by the EASA (2021) on the social acceptance of IAM argues that user trust in this technology innovation will be essential for the successful implementation of IAM in Europe, and the development of a regulatory framework. After consulting around 4000 participants from 6 major cities, the results not only showed that citizens had an initially positive attitude towards the implementation of IAM, but also some of their concerns, which include visual pollution (EASA, 2021). Al Haddad et al. (2020) also revealed this issue as one of the citizens' major concerns regarding IAM. Beyond its mobility implications, IAM can also be understood as part of a broader process of technological digitalisation within transport and logistics systems. Recent reviews suggest that the adoption of emerging transport technologies is often constrained not only by economic and operational factors, but also by societal acceptance and public perceptions (Sardarabady and Durst, 2024). In the context of IAM, this highlights the importance of understanding non-technical barriers, such as visual pollution, that may influence citizens' willingness to accept these technologies.

In addition, Yedavall and Mooberry (2019), through a market study on public acceptance, point out that among the variables related to visual pollution that most affect public acceptance of IAM are the aircraft's altitude, flight schedule, flight frequency and whether you can see the aircraft or not. The study showed that to achieve the highest positive public perception of IAM, drones should fly at a very high altitude, fly only once an hour and fly early in the morning (Yedavall and Mooberry, 2019). Although flight times have not proved to be as relevant as initially expected, flights during the day were viewed more positively (Yedavall and Mooberry, 2019). Recent research has also highlighted the growing importance of operational design decisions in drone logistics systems, particularly regarding routing, scheduling and the organisation of aerial movements (Du et al., 2026). Although examined from a logistics perspective, these operational parameters overlap with several factors previously associated with public acceptance and perceived visual impacts of IAM, including flight frequency, operational timing and flight organisation (Thomas and Granberg, 2023; Yedavall and Mooberry, 2019).

Thomas and Granberg (2023) focused on quantifying visual pollution derived from IAM using the Analytical Hierarchy Process (AHP) methodology, to identify factors that may contribute to visual pollution and concluded that it increases with the number of drones in the environment and decreases with the distance in a non-linear way indicating that, from a planning perspective, flight corridors may be less visually polluting (Thomas and Granberg, 2023). This goes along with other research that identified non recognizable flight paths and unforeseeable manoeuvres as disruptive factors in IAM VR simulations (Stolz et al., 2025) So, initially, it is believed that it would be beneficial for drones to operate on helicopter routes, taking advantage of naturally noisy areas, such as highways, to mitigate the noise impact. A gradual introduction is advocated, prioritising flights peripheral to urban areas over routes through residential areas. This gradual approach could facilitate the integration of IAM by promoting greater acceptance by communities when they witness safe and controlled passenger transport operations (Yedavall and Mooberry, 2019).

2.2. Context, purpose and environmental setting

Even though the use of Emergency Medical Services (EMS) Unmanned Aerial Vehicles (UAVs) may not decrease the perceived visual pollution, people tend to be more willing to tolerate a higher level of visual pollution caused by IAM in emergency scenarios (Thomas and Granberg, 2023). This was also confirmed by the Airmour Project research, whose focuses is on research and innovation to support IAM through emergency medical services (AiRMOUR, 2023). This tendency is also reflected in logistics applications of UAVs within healthcare settings, where drones are increasingly viewed as a viable complement to conventional transport systems due to their ability to improve responsiveness and service delivery (Grote et al., 2024). Such findings further support the notion that socially beneficial and medically oriented

applications may generate higher levels of public acceptance despite potential concerns regarding their visual presence.However, while the use of IAM for emergency scenarios is more acceptable, this is not the case for other purposes such as transporting people, photography, parcel delivery and hobby usage (Stolz et al., 2025; Tan et al., 2021). This shows that the purpose for which drones are used has an impact on the level of acceptance by the population, and there may be purposes whose visual presence becomes more acceptable than others (AiRMOUR, 2023; Thomas and Granberg, 2023).

The environment in which the drones fly and where the citizens are also seem to have an impact on the perceived level of visual pollution and acceptance. However, the results on this subject seem to vary somewhat. The study conducted by Thomas and Granberg (2023) concluded that people seem to be more accepting of visual pollution in urban environments than in rural environments, even without significant differences in the level of visual pollution. On the other hand, Yedavall and Mooberry (2019) present evidence about citizens' share of concern. The study registered a higher percentage of concern about IAM among those living in urban areas than among those living in rural areas. This comes despite urban citizens being more interested in IAM than rural citizens (Yedavall and Mooberry, 2019).

There are, however, differences in the level of acceptance of IAM within urban environments. An investigation on the public acceptance level of drones in a city centre, a residential area, an industrial area and a park concluded that within these urban environments, the one with the most positive responses was the industrial area. In turn, the residential area registered negative responses to the presence of drones in all the parameters asked (Stolz et al., 2025). This reinforces the idea that the population may initially be more favourable to IAM when flying over less populated areas (Yedavall and Mooberry, 2019). Therefore, the environment in which the drones are flying might also have an impact on the accepted visual density (Stolz et al., 2025).

Literature also suggests that it is important to improve the public opinion about this technology and to advertise it to successfully implement IAM, raising awareness on this subject, as people with a negative opinion about UAVs tend to register higher levels of visual pollution (Thomas and Granberg, 2023; Yedavall and Mooberry, 2019). This might be done, for example, by implementing IAM gradually starting of with cases with higher public acceptability, such as emergency ones (Thomas and Granberg, 2023). Similar patterns have been observed in research on emerging mobility services, which highlights the existence of different user profiles ranging from enthusiastic adopters to resistant users, with familiarity, perceived usefulness and knowledge significantly influencing adoption intentions (Gan and Li, 2025). This reinforces the importance of communication, awareness and gradual implementation strategies in fostering public acceptance of IAM. Furthermore, research on transport information systems suggests that users value timely and accessible information regarding transport operations and safety-related events (Karolemeas et al., 2024). This finding is particularly relevant for IAM implementation, given that previous studies have highlighted the importance of increasing public awareness and understanding of drone operations, their intended purposes and their potential societal benefits (EASA, 2021; Yedavall and Mooberry, 2019).

As summarised in Table 1, previous research on visual pollution has focused predominantly on static elements of the built environment, such as urban clutter or energy infrastructure, and on public acceptance of IAM mainly through survey-based approaches. Whilst these studies have identified important factors related to aesthetics, infrastructure density and social acceptance, visual pollution has rarely been examined as thoroughly as a concept within IAM airspace. Existing IAM research has either addressed visual impacts through analytical modelling or treated visual disturbance as a secondary component of broader acceptance studies. In contrast, the present study adopts an immersive virtual reality approach combined with qualitative focus groups to capture experiential perceptions of visual pollution under controlled operational scenarios. By explicitly linking these perceptions to measurable IAM parameters, such as flight altitude, drone density, spatial organisation and environmental context, this study bridges the gap between perceptual insights and IAM design and policy considerations, extending the current literature beyond descriptive acceptance metrics.

2.3. Visual pollution studies in all contexts

Even though the aforementioned studies give us some important insights into visual pollution and its measurement in this context, given that IAM is still a recent subject and it hasn't been deeply studied, it is necessary to seek information regarding visual pollution and its assessment in other areas. This contributes not only to the better understanding of this specific type of pollution in this context, but also to the development of a consistent and reliable tool for evaluating it.

Globally, visual pollution is becoming more important in society (Yilmaz & Sağ;söz, 2011) and as a result, several studies have appeared recently using different definitions for the term of visual pollution, emphasising the complexity of this subject and alluding to the fact that there is a lack of consensus. It has been defined as (1) a term used broadly to cover limits on the ability to view distant objects, subjective issue of visual clutter, intruding structures on beautiful scenes, and other

Table 1
Comparative summary of related studies and the present work.

Domain	Methods	Key variables considered	Main Contribution	Representative studies
Urban visual pollution	Spatial analysis, AHP, GIS, surveys	Visual clutter, aesthetics, density of elements, landscape disruption	Conceptualisation and measurement of visual pollution in urban settings	Wakil et al. (2019); Chmielewski et al. (2016); Borowiak et al. (2024);
Energy & infrastructure visual impact	Visual preference surveys, landscape evaluation, modelling	Height, number of elements, distance, visual harmony	Demonstrated how infrastructure quantity, altitude and spacing affect perceived visual impact	Molnarova et al. (2012); Betakova et al. (2015); Kirchhoff et al. (2022); Salak et al. (2021)
Public acceptance of IAM	Surveys, questionnaires, market studies	Trust, safety, noise, general acceptance	Identified acceptance barriers and enablers for IAM adoption	EASA (2021); Al Haddad et al. (2020); Lee et al. (2023); Tan et al. (2021)
IAM Visual pollution	Analytical modelling, AHP, simulation-based analysis	Drone number, distance, flight organisation	Quantification of visual pollution linked to drone density and spatial separation	Thomas and Granberg (2023); Yedavall and Mooberry (2019)
VR based IAM and environmental perception studies	Immersive VR experiments	Presence, realism, environmental interaction	Validated VR as a tool to study user experience	Birrell et al. (2022); Stolz et al. (2025); Kuliga et al. (2015); Newman et al. (2022)
Visual pollution determinants and implications in IAM airspace	Immersive virtual reality (VR) experiment combined with online focus groups and thematic analysis	Flight altitude, drone density, colour, size, noise, shadows, spatial organisation of airspace, urban versus rural context	Links user perceptions of visual pollution determinants to measurable IAM operational design and policy parameters.	This study

visual defacement (Sumartono, 2009), (2) the result of a combination of clutter, disorder and the excess of objects and designs in the landscape (Chmielewski et al., 2016), for instance, media devices and advertisements (billboards, posts, signs, and works in addition to flags), vehicles passages (Allahyari et al., 2017), lightning features and street furniture (Chalkias et al., 2006; Falchi et al., 2011), (3) the unbridled and uncoordinated diversity of colours, forms, light and materials along with the accumulation of heterogeneous visual elements that make the environment ugly and unattractive (Nami et al., 2016) and (4) a set of irregular formations, which may consist of anything modified by human activities that are unattractive and affects people's ability to enjoy the view and vista (Jana and De, 2015); (5) negative visual impact of visual pollution object on a landscape (Kamičaitytė-Virbašienė et al., 2015). Despite the differences in the definitions, it is possible to perceive that they do have some elements in common, namely that they are disruptive, with a negative impact that disturbs the normal/natural environment or landscape.

With the accelerated urban growth, cities are seeing more and more unwanted visual elements, which are defined as visual pollutants (Titu et al., 2024). These include billboards, tangles of electric wires, graffiti, street litter, and all elements that are aesthetically displeasing and intrusive to the observer (Titu et al., 2024). As concerns about the aspects of quality of life grow, several studies have examined different aspects of visual pollution, exploring how and from which objects it can arise. For instance, studies have been conducted to assess public perception of the introduction of wind farms (Kirchhoff et al., 2022). Kirchhoff et al. (2022) through an online survey deploying photographs and photomontages concluded that the beauty evaluation of the landscapes provided (which included wind turbines) was significantly influenced by moral associations and judgements associated with the different mast-like structures presented (Kirchhoff et al., 2022).

However, there are other findings that contribute to the perceived scenic landscape quality in this context that may be relevant to other scenarios. Research suggests that the landscape attributes and structural factors are more decisive than sociodemographic factors (Molnarova et al., 2012). Additionally, the more beautiful a landscape is deemed to be in its natural state, the greater the perceived impact and deterioration caused by these structures. On the other hand, in less-attractive landscapes, these structures are considered to have less of an impact and in some cases can even be seen as an improvement (Betakova et al., 2015; de Vries et al., 2012; Lothian, 2008; Molnarova et al., 2012; Salak et al., 2021). Furthermore, the impact of wind turbines on the landscape diminishes over the first kilometres, and beyond that range, research reveal varying and inconsistent results (Betakova et al., 2015; de Vries et al., 2012; Lothian, 2008). Regarding the number of these visual pollutants, research shows contradictory results, with studies where it had impact, and others where it did not have much. According to Betakova et al. (2015) and Salak et al. (2021), the number is a significant variable since the greater the number of turbines, the greater the impact resulting from their presence. On the other hand, de Vries et al. (2012) and Lothian (2008) concluded that there was no evidence that the number had a significant impact on people and the perceived quality of the landscape. As for colour, research in this field also showed inconclusive results, as de Vries et al. (2012) point out that colour did not emerge as an important factor and Lothian (2008) highlighted the necessity for more in-depth research on the subject. Nevertheless, previous research has suggested that the use of different colours on vehicles can have impacts on citizens (Bayley et al., 2004; Teodoru-Stanciu, 2024).

Visual pollution resulting from billboards in different scenarios has also been discussed, as over the years these have been described as "*junk mail of the highway*", "*litter on a stick*", "*visual kudzu*" or "*urban blight*" (McMahon, 2011). Rangel-Buitrago et al. (2023) examined how excessive political advertising worsens visual pollution and leads to public health issues like stress, sociocultural impacts by weakening community bonds, and economic losses due to reduced tourism while also highlighting the ineffective regulations and the need for better mitigation measures (Rangel-Buitrago et al., 2023). Furthermore, as billboards are one of people's main complaints when it comes to visual pollution (Borowiak et al., 2024), tools such as spatial decision support systems (SDSS) have also been developed to support stakeholders, including local authorities, billboard owners and the public in making informed decisions aimed at reducing the perceived level of visual pollution. Utilising established open-source geospatial technologies, SDSS adopts a decision-making framework inspired by the AHP methodology for spatial analysis. Thus, it is possible to optimise where billboards should be positioned in order to mitigate visual pollution (Wakil et al., 2021). Additionally, Titu et al., 2024 developed a piece of hardware capable of identifying visual pollution and achieved a detection accuracy of 98%, which reflects the progress in this area and the possibility of successfully adopting innovative methods for its evaluation (Titu et al., 2024).

However, the main challenge associated with visual pollution remains its subjectivity due to the lack of robust and reliable methods for the quantification of this aspect (Wakil et al., 2019). While noise pollution has both physiological (physically measurable causes and effects) and psychological (subjective) elements, visual pollution is purely psychological (AiRMOUR, 2023). Hence, it is crucial to understand how people perceive the visual pollutants in question. This will not only contribute to effective planning, development and acceptance of these visual pollutants and technologies, but also help informing the decision-making, addressing concerns, and promoting effective communication strategies (Caporale et al., 2024).

2.4. Determinant aspects of visual pollution

From the above review it can be understood that when it comes to visual pollution, there is a strong need to use specific and adequate vocabulary. The vocabulary in question is used to cover and describe precisely everything that could be the cause of or be related to the existence of visual pollution in a given context. Therefore, literature suggests that this vocabulary should be considered and is extremely important in order to develop a reliable tool for the assessment and measurement of visual pollution in the context of IAM. Some keywords are present in multiple studies regarding visual pollution, namely integration into surroundings (Samavatekbatan et al., 2016) and spatial and visual compatibility (Lucchi, 2022; Lucchi and Schito, 2022). These are used to describe how well the object in question integrates with its surroundings without causing visual disruption and considering various factors such as shape, size, colour, concealment, and others (Lucchi, 2022; Lucchi and Schito, 2022). Still regarding spatial issues, locational concentration (Wakil et al., 2021) and density (Rangel-Buitrago et al., 2023) are commonly used to address the number of visual pollutants in the environment and the spacing between them. The visibility of the visual pollutant is also a factor pointed out as capable of influencing the visual pollution level (Gao et al., 2024) and it refers to how clearly the pollutant can be seen and the extent of unobstructed view in a given area (Birrell et al., 2022).

The terms disorder, clutter (Chmielewski et al., 2016) and messiness (Borowiak et al., 2024) have been used in visual pollution definitions to portray and describe the landscape under analysis in terms of organization and cleanliness. Visual blight can also be used to refer to anything that spoils the appearance of the landscape, making it unattractive or unpleasant, such as dazzling billboards, power lines or ugly buildings (Jana and De, 2015). Words like unattractive and unpleasant (Jana and De, 2015) are used to describe negatively the general perception about these environments or visual pollutants. These visual pollutants can even end up causing a feeling of disturbance on people, which captures the negative impact of human interventions and man-made elements (Tveit et al., 2006). This can be caused by variations in size, pattern, shape, texture or colour (Hernández et al., 2004). The impacts can be referred to as negative impacts (Thomas and Granberg, 2023), or also, depending on the context, visual impacts (Caporale et al., 2024).

3. Methodology

Since IAM has not yet been applied and integrated into society, this study uses virtual reality (VR) as a methodological tool due to its ability to simulate urban and rural environments in a controlled and immersive way. VR makes it possible to recreate realistic scenarios in which participants can interact with elements of the environment, including the presence of drones, without the logistical challenges and limitations inherent in testing in real environments (Newman et al., 2022).

In this sense, the use of VR in this study has numerous advantages, such as providing a high degree of control over the experimental variables (Kuliga et al., 2015), which facilitates the standardisation and replicability of the stimuli to which the participants are subjected, giving greater rigour to the data collected. Additionally, the more the virtual environment resembles a real one, the more the participants' responses also resemble what they would respond to the environment itself (Freeman et al., 2000). Thus, VR makes it possible to collect highly detailed data relevant to the study, such as where participants look most, pause, for how long, etc. (Kuliga et al., 2015), which can provide relevant insights for decision-makers.

3.1. Recruitment of participants, procedure and data collection

Fig. 1 provides a visual overview of the study procedure, illustrating how participants moved through each stage of the VR experiment and qualitative data collection. First, participants concluded an experiment comprised of 6 parts in which participants were exposed to different IAM operations deploying three vehicle types (a small sensing drone, a cargo drone and a passenger drone) in two types of environments, an urban and a rural one. Across the different experiments, simulations of low, medium and higher levels of U-space activity (Table 2) corresponding to the presence of different aerial vehicles (Fig. 4) in two types of environment, urban (Fig. 2) and rural (Fig. 3), were represented. Drone and ambient noise were used in the VR (people and urban/rural sounds) environment where the drone noise was as d as imported by the software itself. Each experiment had an approximate duration of 1 h. After the experiment, the participants were invited to a focus group session through which visual pollution was explored as perceived by the participants during the experiment. Focus groups were the chosen technique because they are an extremely suitable and robust method when the aim is to gather information on a new, complex topic on which there is not much information, and it is also pertinent to use focus groups when exploring new subjects with implications for social settings, allowing to gather a wide range of perspectives and opinions (Breen, 2006; Kitzinger, 2005). Five online focus groups were conducted between July and November 2024 via Microsoft Teams.

All participants completed the same VR protocol and were exposed to

Table 2
VR Settings specification (altitude and speed according to EASA).

Drone Type	Altitude	Speed	Path placement
Sensing	30m	20 m/s	Above participant, to the side, on top of buildings
Cargo	120m	30 m/s	
Passenger	120m	30 m/s	



Fig. 2. VR urban environment scenario.

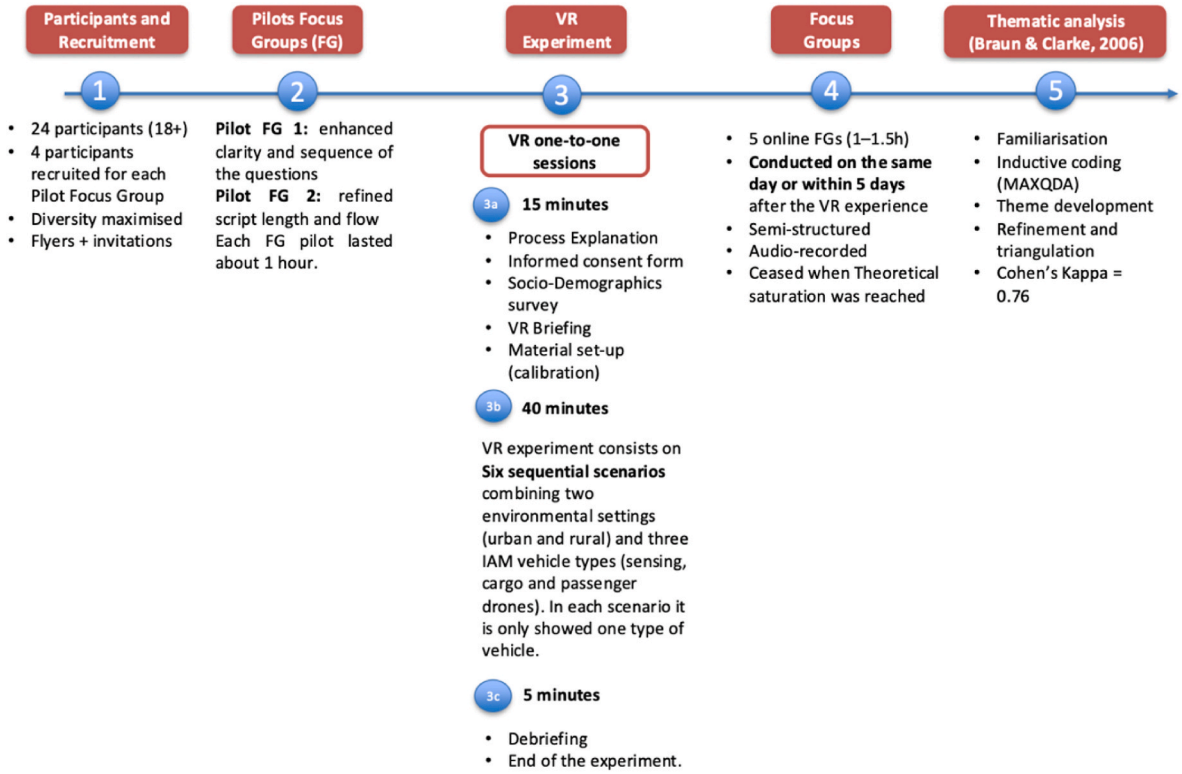


Fig. 1. Sequential study procedure and timeline.



Fig. 3. VR Rural environment scenario.

the same operational scenarios. The experiment consisted of six sequential scenarios combining two environmental settings (urban and rural) and three IAM vehicle types (sensing, cargo and passenger drones), with predefined activity levels, flight paths, altitudes and operational characteristics (mentioned in Table 2). This ensured that all participants were exposed to the same visual stimuli and experimental conditions, thereby supporting comparability and reproducibility of the results. To minimise potential order effects, two mirrored scenario sequences were used (Brooks, 2012). Half of the participants (n = 12) experienced the scenarios in the following order: Urban-Sensing, Rural-Sensing, Urban-Cargo, Rural-Cargo, Urban-Passenger and Rural-Passenger. The remaining participants (n = 12) followed the reverse sequence: Rural-Sensing, Urban- Sensing, Rural - Cargo, Urban - Cargo, Rural - Passenger, and Urban - Passenger. This counterbalanced design helped minimise potential learning effects, habituation to repeated drone exposure, participant fatigue, and biases associated with consistently evaluating one environment before the other (Brooks, 2012). By distributing the presentation order across participants, the influence of scenario order on the results was reduced (Brooks, 2012).

Due to participant availability and the voluntary nature of participation, focus groups could not always be conducted immediately after the VR exposure. Nevertheless, all sessions were scheduled as close as possible to the VR experiment and always within a maximum period of five days. Previous studies have demonstrated that VR memories are reliably retained for a week after the experience (Jespersen et al., 2025) and retention of spatial memory declines two weeks after the experience (Buttussi and Chittato, 2023) with detailed studies indicating a decline from 90% from week 0 to 87%, approximately in week 1 and 84% in week 2 after the experiment (Menzemer et al., 2026). To assess whether the timing of the focus groups influenced the findings, a comparison was conducted between participants who completed the focus group on the same day as the VR experience and those who participated after a short delay of one to five days. No noticeable differences were identified in the themes generated, the breadth of topics discussed, or participants' ability to recall and reflect upon the VR scenarios. Additionally, all themes identified in the study emerged in both groups, suggesting that the short delay did not substantially influence the thematic structure of the findings. Therefore, all participants reported clearly remembering the simulation and the scenarios experienced in VR. As an additional measure to support recall, the FG moderator displayed static images of the urban and rural VR environments and the IAM vehicles (corresponding to Figs. 2–4) at the beginning of each session. These visuals represented exactly what participants had seen during the VR experiment and ensured consistent memory retrieval across participants.

Participants were recruited through flyers displayed on campus and invitations issued by the researchers, the only restriction being that they had to be aged 18 or over. This resulted in a total of 24 participants, aged between 18 and 62, of whom 19 were male and five female. Of these, 13 were aged between 18 and 24. Once the VR session, which was one-to-one, had been completed, the online focus group session was scheduled. Additionally, each FG session lasted between 1 h and 1 h and a half. The recruitment of participants was based on maximising the diversity obtained, both in the depth of information provided and in maximising points of view and perspectives. The sessions were audio-recorded with the written consent of all the participants, whose approval was also obtained from the ethics committee. The number of focus groups in this study was determined based on the concept of theoretical saturation. According to Glaser and Strauss (1967), saturation occurs when no additional data emerges that contributes to the development of the category by finding similar instances, which gave empirical confidence that the themes were saturated and resulted in a rich data set. Besides, five focus groups is deemed an adequate number to achieve relevant insights about a topic.

3.2. Focus groups design

Two pilot studies were carried out to help refine the final version of the script used. In the first pilot study, the sequence of some questions was changed and the clarity of some questions, which could have been difficult to understand, was revised. In the second pilot study, all the amendments made to the script were tested and adjusted so that it would not become too long and time-consuming, which could lead to fatigue effects. Although the script has set questions, which helps to maintain consistency between focus groups, a semi-structured approach was followed to enable participants to speak freely, and raised new issues on the topics, being very flexible, allowing for engaging with the subject and rich discussions.

First, the facilitator began by introducing himself and the aim of the session, leaving the participants free to ask questions, and ask questions. Then, participants introduced themselves in order to get comfortable with each other. The following table (Table 3) shows the questions that introduced the discussion, in the sequence in which they were presented to the participants. At the end of each session, it was always ensured that the participants' questions were answered and that there were no other topics they wanted to discuss.

3.3. Data analysis

To analyse the collected data, a thematic analysis was conducted, following the approach outlined by Braun and Clarke (2006). This



Fig. 4. Illustration of Sensing, Cargo and Passenger drones used in the VR scenarios.

Table 3
Script questions.

Questions
1. Visually disruptive definition: Is anything that impacts the ability to clearly view the visual quality of public and community spaces which includes regularity, order, beauty, symmetry, and simplicity?
What would be, for you, more characteristics of a visually disruptive space?
2. How would you describe the VR environments we showed you?
3. Was there anything in the specific scenarios we showed you that you identified as a visual pollutant?
4. Were there any elements that drew your attention excessively? Can you clearly identify these elements? that is, were there any visual elements that you found particularly unattractive or unpleasant?
5. Do you think the use of drones in the environment(s) you saw is appropriate? Do you think that drones "fit in" this environment?
6. What do you think about the drones flying above you (in the VR)?
7. How would you react if you saw them in a city (in real life)?
8. What would make a drone flight be more tolerable, reduce its level of visual disturbance?
9. Do you think the drones are creating visual disruption?
10. How would you describe visual pollution for drones?

method enables the identification of patterns or themes within the dataset while also facilitating the interpretation of their underlying meanings (Maguire and Delahunt, 2017). After the Focus Groups (FG), the analytical process began with the familiarisation with the data. This began with the transcription of the FGs; after a first version obtained, careful revisions were made against the audio to check for flaws in the transcription and, if necessary, the absence of any potentially important keywords. This process made it possible to explore the data and identify some relevant patterns that were worked on in the coding phase.

Since the FGs were carried out in a semi-structured way, the coding was done following an inductive (or bottom-up) approach, so the codes originated from the data and not from a pre-existing coding framework (Braun and Clarke, 2006). The coding was carried out using *MAXQDA 24* software. According to Braun and Clarke (2006), semantic themes are identified directly from the explicit content of the data without deeper interpretation of what the participant has said or written. On the other hand, latent themes go beyond the explicit content and explore underlying ideas, assumptions, conceptualizations and ideologies and therefore require interpretation and analysis to uncover deeper connections between concepts. During this process, whenever possible, the participants' own words were used to name the codes. However, there were cases in which this was not possible, and it was necessary to identify underlying ideas on data that were relevant to the research question and that would give the codes a name. The coding was reviewed as this phase was important for correcting inconsistencies, such as joining codes with the same meaning.

Once the coding was completed, the next step involved searching for themes, where the codes were organised into meaningful groups to identify patterns and relationships (Naeem et al., 2023) forming the initial themes. In the following stages, these themes were refined, as some of the themes identified overlapped and collapsed into each other and were given names. To ensure the consistency of the coding, triangulation was applied by involving one more researcher in the process. In addition, Cohen's Kappa was used to calculate the inter-rater agreement between these two researchers. The resulting score of 0.76, according to the Landis and Koch (1977) interpretation scale, indicates a substantial level of agreement between coders which suggests the reliability of the resulting codes. The analytical process ends with a reporting phase, where the results were analysed on the basis of evidence, namely participants' statements, and the themes were analysed according to the research objectives. To ensure transparency and rigour in the qualitative process, a saturation grid (shown in Table 4) was composed to track the reference of each code across focus groups. The marked "X" means that the code was mentioned by one or more participants within the FGs. The grid showed that from the third focus group onward no new themes emerged, with the remaining focus group sessions reinforced, rather than extended, the thematic structure. This pattern demonstrates that thematic saturation had been achieved (Hennink and Kaiser, 2022; Morgan, 1996).

Table 4
Saturation Grid Across focus Groups.

	FG1	FG2	FG3	FG4	FG5
Theme: Huma-Drone spatial interactions					
Type of flight area	X	X	X	X	X
Altitude	X	X	X	X	X
Distance From People		X	X		
Theme: Dynamic Visual Effects					
Drone quantity	X	X	X	X	X
Air Space Structure	X	X	X		X
Shadows	X		X		
Flight Schedules	X	X			X
Theme: Drone Properties					
Noise	X	X	X	X	X
Colour	X	X	X	X	X
Design	X	X	X	X	X
Size	X	X	X		X
Theme: Flight Purpose					
Emergency	X	X	X	X	X
Others	X	X	X	X	X
Theme: Concerns					
Social Concerns		X		X	X
Environmental Concerns	X		X		
Safety Concerns	X		X	X	X
Theme: Familiarity					
Gradual Introduction to drones	X	X	X		X
Technology familiarity		X		X	
Time effect to familiarity		X	X	X	X
Theme: Citizens knowledge/information					
Previous knowledge	X	X	X	X	X
Real time information sharing	X	X			

4. Results

Annex A provides an overview of the thematic analysis, presenting the main themes and associated codes alongside their frequency counts. These frequencies indicate how often each theme and code was mentioned across the focus groups. This overview helps to highlight the relative importance of different aspects shaping participants' perceptions of IAM.

4.1. Visual pollution definition

One of the themes that was highlighted in the discussions was the participants' definition of visual pollution, where they had the

opportunity to express what, for them, is characterised as a visually polluted and disturbing space. In this way, it was possible to identify factors and characteristics that contribute to this definition, which are identified below as codes.

4.1.1. Lack of beauty

It was possible to identify this code in which participants highlighted the lack of beauty in the surrounding environment as one of the points that contributed to the increase in visual pollution they felt. Thus, this code represents the participants' negative aesthetic perception of the environment in question, where the presence of elements such as drones can result in an unsightly and aesthetically unpleasant setting. This aspect is directly associated with the aesthetic dissonance of these elements, a common factor in the literature on visual pollution (Nami et al., 2016; Sumartono, 2009).

> *"The airspace was visually disturbing and with a certain lack of beauty due to the fact that all those drones were passing by simultaneously."* - Participant #6

> *"If it was a very ugly place, dirty, and, again, full of objects or people."* - Participant #8

Beyond a subjective aesthetic judgement, the notion of "lack of beauty" reflects a perceived disruption of visual harmony between IAM operations and the surrounding environment. In line with visual landscape theory, aesthetic appreciation is influenced not only by the object itself but by its coherence with the broader visual context (de Vries et al., 2012; Tveit et al., 2006). In this sense, perceived visual pollution emerges when IAM vehicles are seen as visually incongruent or intrusive within a given setting, rather than from their mere presence. This finding suggests that visual integration and contextual sensitivity play a critical role in shaping citizens' tolerance of IAM operations (Chmielewski et al., 2016; Nami et al., 2016).

4.1.2. Disorder (or without patterns)

The lack of visual patterns or organisation in the environment in question, in this case airspace, was described as one of the factors that can form visual pollution. These statements by the participants are in line with the work of Chmielewski et al. (2016) where he refers to the relationship between visual pollution and visual clutter and disorder. According to the participants, the perception of order and pattern helps to create predictability, making IAM movements less noticeable and more acceptable.

> *"I think things working in a pattern also helps. If everything is a bit out of order without a pattern it's easy to notice. It also takes away a bit of the regularity and order that you're talking about."* - Participant #7

> *"So, I think that, for example, you can have a lot going on, but everything happening in order, like in a pattern, looks nice. If it's all in chaos, all separated from each other, then it's not so beautiful."* - Participant #10

These findings indicate that visual disorder and the absence of recognizable patterns amplify perceptions of visual pollution by reducing predictability within the airspace. This aligns with prior research linking visual clutter and disorganization to increased perceptual disturbance (Chmielewski et al., 2016; Gao et al., 2024). The results suggest that structured and predictable flight paths may mitigate visual pollution by allowing IAM traffic to blend into the visual background more easily.

4.1.3. Unpleasant

Throughout the discussions, the presence of what was coded as unpleasant was also noticeable. This code refers to the perception of visual and emotional discomfort caused by the presence of visual elements that stand out negatively in the environment. In this sense, the participants not only used this perception to describe the issue of visual pollution in general, but also what could result in this sensation, such as something that is out of tune with the environment, and then ends up being unpleasant, or even being more specific, mentioning elements such as skyscrapers where there are none. The participants' statements are in line with the literature where terms such as visual blight (Jana and De, 2015) are used, showing how these elements can make the landscape unpleasant and unattractive.

> *"I think that a visually disruptive space for me is a space that has elements that are either out of place or that do not make much sense given the environment we are in. In other words, something that looks like it should not be there or that creates some visual confusion"* - Participant #16

> *"For me, it is when you have sort of like a view of a landscape and there is a huge tower in the middle."* - Participant #23

> *"Irregularity is something that I would consider disruptive."* - Participant #23

> *"I think that depending on the place, something that can be visually disruptive is something that can interfere with normal vision and therefore our interpretation, for example, of a landscape."* - Participant #17

The perception of IAM as "unpleasant" reflects an emotional response to visual incongruity, where elements are perceived as out of place within a given landscape. This corresponds with the concept of visual blight described in the literature, where visually intrusive elements disrupt environmental coherence and negatively affect landscape appreciation (de Vries et al., 2012; Jana and De, 2015). In this sense, unpleasantness emerges when IAM is perceived as interfering with the interpretability and meaning of the surrounding environment.

4.1.4. Lots of things simultaneously

It was also noted that many of the participants mentioned that the presence of too many elements in the environment, and therefore any visual overload, can actively contribute to damaging the aesthetics and sense of tranquillity of a given place, as advocated by Rangel-Buitrago et al. (2023). They pointed out that when there are too many elements in a given environment, visual information is not processed in a positive way.

> *"A place very full of things, a lot going on at the same time."* - Participant #8

> *"I was thinking of a place with a lot of people. Like, completely full. That, for example, is not visually pleasing."* - Participant #16

> "When there are a lot of drones passing overhead, I am not necessarily looking at the sky, but what I see is a lot of shadows passing by me and next to me, and that is what can compromise order and regularity and the normal."

> *"It is not their existence that is disturbing. What might disturb you is seeing the amount of drones passing by"* - Participant #6

Participants' emphasis on visual overload highlights the role of simultaneous visual stimuli in shaping perceptions of visual pollution. Consistent with studies on visual saturation, an excessive number of elements can overwhelm perceptual processing and reduce visual comfort (Betakova et al., 2015; Rangel-Buitrago et al., 2023).

4.1.5. IAM visual pollution definition

The participants were also asked to vote for a definition of IAM as given in the literature. Table 5 presents the results of the analysis and demonstrates that there is agreement that the most suitable definition is "Visual Pollution of IAM is the excess of vehicles (drones), their visual disorganization in the space and their disruption of the existing landscape's harmony."

The selected definition reflects participants' emphasis on excess, disorganization and disruption of visual harmony, reinforcing the multidimensional nature of visual pollution identified in previous research (Chmielewski et al., 2016; Wakil et al., 2019). This shared

Table 5
IAM Visual Pollution definition.

IAM Visual Pollution Definition	Votes/ Participants	Based on
Visual Pollution of IAM is the effect of disorder, excess number of physical elements (drones) that limits the ability to view distant objects.	2/2	Wakil et al. (2019)
Visual Pollution of IAM is the negative impact that the view of drones (visual pollutants) and its movement might have on a person.	2/1	Sumartono, 2009
Visual Pollution of IAM is defined as everything altered by human activities that are unattractive and that affects people's ability to enjoy or appreciate the view or vista.	7/6	Thomas and Granberg (2023)
Visual Pollution of IAM is the muddled impact of messiness, disorganization and existence of different drones and designs in the landscape.	0/0	Jana and De (2015)
Visual Pollution of IAM is the excess of vehicles (drones), their visual disorganization in the space and their disruption of the existing landscape's harmony.	20/7	Borowiak et al. (2024)

understanding supports the framing of IAM visual pollution as a phenomenon shaped by both spatial arrangement and the cumulative presence of aerial vehicles.

4.2. Drone properties

At the centre of citizens' perception of visual pollution related to the implementation of IAM in society are the characteristics of the drones themselves. These can end up playing a fundamental role in the acceptance or otherwise of this technology.

4.2.1. Colour of drones

Within the drone properties, one of the factors that showed significant weight was the colour of the drones, which was addressed in different ways. Not only was this factor highlighted as being disturbing or not, but there was also a strong tendency to prefer softer, more neutral colours, as they were perceived as being less disturbing and more likely to go unnoticed in the environment. However, the possibility of having a set of colours for the drones as a way of identifying the different purposes was also raised, and some considered this identification capacity to be fundamental, contributing to greater acceptance.

> *"I really notice it when it's black, when it is white, not really. I know it looks bigger, but I don't know why, somehow, I did not feel as disturbed as when I saw the black drones flying. So, I think colour and the similarly to the background will be very useful."*. - Participant #12

> *"I think there should be some kind of rule or something. For example, white drones are for people, black drones are for goods."*. - Participant #16

> "I agree with being able to discriminate between colors and to understand which colors are meant to some specific things." – Participant #11

> *"Maybe if the black was in white, I would prefer white because you could confuse it with the clouds."*. - Participant #9

> *"(…) if the colour is softer in the sky, it does not shock the issue of beauty"*. - Participant #1

The colours of drones have not been previously researched, however there are studies in the transport sector that designate this characteristic as significant for the experiences of people. In fact, the results of the current study are not totally aligned with insights from previous research on vehicles' colours and their impact on passenger and citizen perceptions. Modern cars are intended to be eye-catching, leading to the use of bright colours (Wright and Curtis, 2002), which are more conspicuous and thus more easily seen by pedestrians waiting to cross the road, which can be helpful from a safety standpoint (Bayley et al., 2004). This study also concluded that, from a pedestrian point of view, people are less concerned with the superficial appearance of vehicles than with what they saw as the physics of collision (Bayley et al., 2004). However, with regard to having a set of colours, the results are in line with literature, as Teodoru-Stanciu (2024) studied the importance and role of colour schemes in public means of transport and highlighted that the duration of trips, the purpose, the scenery and the area of operation can influence the choosing of the colour scheme. This is important because the colour scheme can create feelings and sensations not only in passengers but also in people in traffic, (Teodoru-Stanciu, 2024) and it is important that these are as positive as possible.

4.2.2. Size and design of drones

In addition to colour, size and design were points raised in the discussions, and the responses were diverse. There were those who favoured a smaller size of drone than the one presented in VR, and there were also those who pointed out that they hadn't even noticed this factor. Opinions were also divided on design, with some pointing out their preferences when it came to the design of the drones, while others said that design was not a key factor when it came to their acceptance. This reflects the subjectivity associated with both factors, making it difficult to reach a consensus.

- *"The smaller the better"*. - Participant #9
- *"(…) you are also talking about size, and, for me, I don't think it's a factor that bothers me much to be bigger or smaller."*. - Participant #19
- *"(…) if there were some lights on the drones, sometimes it would be more pleasant to look at."*. - Participant #7
- *"In terms of colour and design, of course there are differences, but I do not think they are the factors, in my opinion, that have the most impact on fitting in an environment or not."*. - Participant #16

From a pedestrian point of view, people are less concerned with the superficial appearance of vehicles than with the physics of collision (Bayley et al., 2004), which may be attributed to the importance of design and size in pedestrian acceptance. Therefore, although the results were inconclusive, they show that these themes can play a relevant role in perceived visual pollution while demonstrating and emphasising the subjective nature of it.

4.2.3. Noise of drones

One of the points that was raised on which most participants agreed was the issue of noise. The importance of noise in visual acceptance was mentioned, which demonstrates the correlation between the two types of pollution. Some participants pointed out the ability of noise to make the presence of drones more visually disturbing, but also some even addressed the sequential nature of the phenomenon, saying that before noticing the drones, they noticed the noise coming from them and that this led them to look. In this sense, it is possible to realize the importance of the auditory issue in visual pollution and the need to reduce the noise produced by drones as much as possible to also reduce visual pollution.

- *"More of an auditory pollutant than a visual one for me."* - Participant #10
- *"(…) not making noise would be a wonderful upgrade."*- Participant #7
- *"I think that in my specific case, first, in general, you listen and then you look. You are looking ahead and as the drone is overhead, you're not looking at the sky. So, I think the first impact is audible and then it's the visual impact."*. Participant #16

Since the research done on visual pollution on IAM was mostly done

through questionnaires and other methods in which the participants based their answers on 2D visualisations, this experiment allowed us to delve deeper into topics that were left out of those studies, namely sound.

4.3. Human-drone spatial interactions

4.3.1. Altitude

The altitude to which drone flew was one of the most mentioned factors throughout the FGs, and according to the participants, was too low. There was a consensus that the drones should fly higher and that this could help reduce the perceived level of visual pollution. Some participants also pointed out the possibility of altitude also affecting other factors such as noise, which can also, as mentioned above, affect acceptance and the level of visual pollution. Except for a few participants, it was argued that the more invisible they are, the better and flying at a higher altitude could help to this direction and to making them less noisy.

- *"The low altitude makes drones more noticeable, more conspicuous and noisier. So, I think the more invisible they are, the better."* - Participant #7
- *"(…) if the drones can be that low it would be good, if they are noiseless. Much less noise. Because for them to work very well within the city area and using several of them at the same time I think having a way to reduce their noise drastically will help their acceptance."* - Participant #14
- *"(…) the altitude influences the drone being a visual pollutant or not."*. - Participant #8
- *"I think I even mentioned it when I was in virtual reality, that the drones passed by at a certain height which was visually disturbing."* - Participant #17

These findings reinforce the role of altitude as a key perceptual factor of visual pollution, confirming that higher flight levels reduce conspicuity and perceived disturbance. This aligns with research showing a negative relationship between distance and visual impact, whereby increased separation diminishes visual dominance and enhances comfort (Betakova et al., 2015; de Vries et al., 2012). In the context of IAM, altitude emerges not only as a safety and operational parameter, but also as a critical determinant of perceived visual acceptance.

4.3.2. Distance from people

This also leads to the point made about the distance participants were from the drones. Participants highlighted the proximity of the drones to people as a relevant factor for visual and emotional discomfort. This concern refers not only to their altitude, but also to their position in relation to the space occupied by individuals, such as flying directly over someone or groups of people. Drones' presence in these areas was described by some participants as uncomfortable, pointing out their preference for passing through areas where there were not many people on the ground and the people-drone distance was longer.

- *"I hate seeing them on top of people. So, for me it's way, way easier to see a drone on top of a mountain or something if no one is there, than on top of a beach that's full of people. No. That's way more stressful for me."*. - Participant #20
- *"So, especially in the case that there were the bigger ones, and they are passing relatively close it would be something that would cause me some discomfort."*. - Participant #15

Perceived discomfort associated with proximity to drones reflects the importance of personal space in shaping visual and emotional responses. The further the observer is from the object, the lower the level of impact resulting in greater visual comfort (Betakova et al., 2015; de Vries et al., 2012; Lothian, 2008). Prior studies have also shown that closer visual intrusion intensifies perceived risk and discomfort, even when objective safety is not compromised (Lothian, 2008; Molnarova et al., 2012). These results suggest that horizontal and vertical separation from people plays a significant role in visual pollution perceptions, particularly when drones operate directly above individuals.

4.3.3. Type of flight area

The environment the individuals find themselves in also showed to affect their perceived level of visual pollution and therefore general acceptance of IAM, reinforcing the importance that the contextual issue can play in the implementation of this technology. The overwhelming majority of participants argued that the presence of drones in an urban context would be more appropriate and acceptable than in a rural context, since the latter can clash with the idea of tranquillity and calm that these environments can provide. Their presence in rural environments is not always ruled out, but the acceptable quantity appears to be significantly lower than in urban environments.

- *"I thought that in a rural environment it certainly influences and affects you a lot more, because in the city you're generally used to more noise, traffic, cars passing by, horns honking, airplanes passing by all the time, you name it. But in rural areas you certainly want more peace and quiet."*. - Participant #8
- *"In a rural environment, I don't think it makes much sense. It would only make sense for emergency situations, perhaps."*. - Participant #8
- "*In the city I do not know why I feel like it is more suitable." – Participant #12*
- *"In the city I think it can be perfectly something that people can get used to. In smaller towns, with a different type of population, I think it might be a bit more shocking to start introducing this new type of air mobility."*. - Participant #9
- *"In the countryside IAM was a bit more suffocating for me. It didn't really belong there"*. - Participant #9

In some cases, this may seem contradictory, since some of the participants who said they found the presence of drones in rural and, therefore, less populated areas, more disturbing said they felt uncomfortable when they flew over them or other people. The key point here turns out to be the context in which this is addressed. When individuals express a preference for drones not to fly directly overhead but instead at a greater distance, this is often due to the visual presence of the drone eliciting discomfort associated with perceived insecurity and fear of potential adverse events. On the other hand, when discussing the lower level of acceptance related to the context in which IAM is inserted, this factor was not considered, as this is just considering the visual fit to the environment.

Although most of the participants pointed out that IAM did not fit into the rural context and that its presence could result in a significant level of visual pollution, the importance of drones for isolated areas was also discussed. The participants argued that even though it was more visually disruptive, the presence of this technology in these types of areas with poorer access could be important and relevant to consider, which could also affect its acceptance.

- *"(…) for example, in those more isolated villages, I think it would be excellent. When it comes to taking medicines, supplies, I do not know, I have no idea. In winter, with the snow, villages become isolated. So, I think that is extraordinary, is it not?"*. - Participant #1
- *"However, where it can really make impact is in the rural areas where there is a lot of interest, there are a lot of things that are needed. There are a lot of relief supplies that need to be delivered to people who live in those communities in distant areas and so on."*. - Participant #14
- *"I'm thinking over a scenario. For example, if you have an old couple that lives in the fields in a place that is 30 min away from the closest village and you ask them "I can bring your groceries for the month in a drone. Would you like that?". Maybe the people are like, oh, ok then maybe that is nice. That is a nice way for the drones to work."*. - Participant #22

In addition, the participants were also challenged to imagine an IAM in their area of residence and the responses were noteworthy. These can be divided into two groups, those who would be bothered, and those who said it would not be a big problem. However, a relevant factor emerged during the analysis: most of the participants who argued that it would cause discomfort, live in a rural area or one with less movement, while, on the other hand, the participants who said they could imagine it live in urban areas. This is in line with what they had previously argued when asked whether drones would fit into the environments presented in virtual reality, and they pointed out that their presence would cause more discomfort and that they were not as contextualised in rural environments as in urban ones.

- *"I live in the city, so for me it is acceptable."* #21
- *"I live in the city, and I also think it is ok."* - Participant #24
- *"It was a bit disturbing for me too. At least at the beginning, when you are not used to it. In virtual reality, when you realize you are in the countryside, everything is quiet and suddenly you start hearing drones, it is a bit disturbing. In the city it might be a bit better but living in the country I do not know."* - Participant #17
- *"For me it was disturbing. I live in the countryside; I am used to a quieter place and the noise and the amount of drones is something that would immediately change it."* - Participant #18

The results are in line with previous research (Lothian, 2008; Molnarova et al., 2012; Salak et al., 2021) that has pointed to the possibility that the context in which the visual pollutant is located may have an impact on the level of visual impact. This aspect has also been considered in the study carried out by Thomas and Granberg (2023), which concluded that the environment had no major impact on the perceived level of visual pollution. However, our findings indicate that it is important to acknowledge that this is a crucial factor, which can have a major impact on the way people perceive drones, so it is essential to respect their preferences to minimise the visual impact and boost acceptance.

4.4. Dynamic visual effects

During the discussions about how drones can affect and visually pollute space, dynamic factors associated with the use/presence of drones were brought up numerous times, such as shadows, quantity, flight times and the structure of the airspace.

4.4.1. Shadows

Some participants seemed to feel disturbed by the vehicles' shadows, even saying that they acted almost as a reminder that there was something above them, and some mentioned that the environment in which the drones are located can affect their tolerance of shadows. This was a new element that had not been seen in the literature before.

- *"It always reminds me that something is passing right over me."*. - Participant #2
- *"What bothers you is that you are not looking at the sky, and what always reminds me of the existence of drones is the shadows."*. - Participant #2
- *"(…) the shadows were more disturbing in the rural environment because, as it is a more open environment, we see the shadows for longer, especially when they come down from the mountain."*. - Participant #3
- *"In the urban environment the shadow did not bother me, but the little ones worked almost like flashes in the eyes in the rural, where there were mountains. (…) They made more of an impression on me."* - Participant #1
- *"Depending on the height of the buildings, the shadow passed at the same height as the windows. This can also disturb people at home. Not only in rural areas, but also in cities. It can be disturbing."*. - Participant #17

4.4.2. Drone quantity

The quantity of drones circulating also seemed to affect the level of visual pollution perceived by the participants and, therefore, their acceptability of IAM. On this point, the statements were quite coherent, as the main conclusions were that vehicle quantity and visusal pollution show a positive correlation and that, therefore, the fewer the drones circulating, the less visual pollution they cause. The possibility was also raised that the quantity could be related to the environment in which the drones circulate, since it was mentioned that in a rural environment the acceptable quantity would be lower and therefore more likely to become visually polluting. On the other hand, the acceptable quantity of drones in an urban environment would be higher in comparison, and therefore more drones would be tolerated until it became visually polluting.

- *"But it is all about the amount of it. A few of them is ok, but not too many. Even in the city."*. - Participant #21
- *"The higher the flow, I think the more confusing and the more disturbing it is."*. - Participant #16
- *"The quantity of drones can make them a visual pollutant, definitely."*. - Participant #9
- "*I think the number of drones for me also depends on where we are. At least my VR experience was very affected by whether I was in the countryside or in the city."*. - Participant #9
- "*People in the city are going to be affected by the drone routes, but I think that those in the countryside or other smaller towns also will be affected … but perhaps less frequently, because they won't need to be, traffic will be lower*" - Participant #9

The quantity seemed to be one of the main aspects capable of influencing the peoples' perceived level of visual pollution. This is consistent with existing research not only on visual pollution in different scenarios (Betakova et al., 2015; Rangel-Buitrago et al., 2023; Salak et al., 2021), but also in the context of IAM (Thomas and Granberg, 2023), where there is a positive correlation between the number of visual pollutant objects and visual pollution. Although it is one of the most mentioned factors not only in the discussion, but also in the rest of literature, this study provides a new view of it, given that past studies were mostly based on questionnaires and images, leaving aside potentially relevant issues that could influence the perception of the quantity factor, such as the movement of drones.

4.4.3. Flight schedule

An interesting point discussed was the possibility of flight schedules, where the majority argued that this could help to increase acceptance. Participants raised ideas about whether there should be flight schedules and what times would be most suitable. Although there were many different suggestions and ideas on the subject, the main point of agreement was that, in case of an emergency, the drone should be able to fly regardless of the time. There should not be any restrictions on the use of IAM in an emergency because it would be for an acceptable purpose, showing a correlation between the purpose and the tolerable flight times.

- *"If I had to do this exercise, I would say that I would be receptive to the idea of drones only on a pre-defined schedule."*. - Participant #9
- *"I think the schedule depends on the type of the drone and the place where they will be. For example, emergency drones can always fly and maybe this transportation drones can only fly from 1 h to another. Also, with delivery there should be some schedule, but depends on the type and the place."*. - Participant #21
- *"Drones flying at night would not be so acceptable, compared to the day."* #18
- *"It makes more sense to me to see a lower amount of drones in the morning or no drones in the morning. And then, during the peak hours of activity like at 3:00 p.m. and then it goes down at night again. Or maybe the reverse. Maybe if there is absolutely no noise, all the drones working at*

night in order that I cannot see the drones, so they only work at night. But in that case, they would have to make no noise." - Participant #23

Participants' support for flight schedules highlights the temporal dimension of visual pollution, suggesting that predictability over time may reduce perceived disturbance. This finding aligns with acceptance studies indicating that controllability and expectation play a role in tolerating technological presence (Yedavall and Mooberry, 2019).

4.4.4. Air space structure

Air space structure also influenced the level of visual pollution perceived by the participants with the majority reporting they prefer the drones to have flight paths. They indicated that having a more organised structure would be better and defended their preference for different reasons, namely the fact that it conveys a sense of ease, that it is more organised and therefore less visually disruptive, avoiding the feeling of chaos, as well as the fact that drones are expected to fly in that area and can therefore be more easily ignored, avoiding them being aware all the time. The fact that there are flying paths can give citizens more confidence, which would make it easier to accept. This theme and the insights from the discussion are in line with what Thomas and Granberg (2023) concluded when it was argued that the use of flight corridors for drones would be less visually polluting in comparison to allowing free path planning.

"Everything that is standardized ends up being more visually pleasing. Because if you don't have a pattern that you can identify, you go straight to the definition of confusion and chaos.". - Participant #7

- *"I think that if it is done in a standardized way, like we saw a straight line, it does not necessarily cause confusion or disorganization."*. - Participant #8
- *"If they were passing by in, kind of a chaos, one going one way or the other, without a clear order, I think it would be stranger. If they were organized in lines, I think it would be more pleasant."*. - Participant #7
- "I have this feeling of chaos and discomfort by seeing them flying without any specified route." – Participant #11

Even though the flying paths convey more trust, some participants raised the point of where these paths will pass, with some saying that they would prefer that they did not follow the path of the roads. These kinds of preferences reflect that it is not only important to define that drones circulate on these flying paths, but also where the paths pass through, serving as a possible insight into the logistical aspect of implementing this technology in society.

- *"It might not be a good idea to follow the roads. Maybe it would be better to take alternative routes. It wouldn't be so confusing, and people wouldn't be distracted."* - Participant #19
- "*There should be other routes that do not go right over the roads."* - Participant #18
- "(…) *like a highway in the air, and maybe it could be smartly placed, for example, if it is above a highway, you have always cars going below it. But if it is above a train line, trains only go there occasionally, so you minimise the time where people are below it, so, maybe something smart like that."* - Participant #20

Overall, preferences for structured airspace reflect the importance of visual order and predictability in reducing perceived chaos. This supports findings that organised movement patterns and designated corridors can reduce visual intrusion by creating expectations and facilitating visual habituation (Chmielewski et al., 2016; Thomas and Granberg, 2023). However, participants' concerns regarding corridor placement suggest that structure alone is insufficient, and that spatial alignment with existing infrastructure may further influence visual acceptance.

4.5. Flight purpose

A relevant point regarding the implementation of the technology, and one that the participants said greatly affected its acceptance, was the flight purpose. This can have a major impact on the level of visual pollution and acceptance felt by the participants, since not all purposes are equally tolerable. Even though not all purposes are acceptable, the feedback on the use of IAM for medical emergencies was positive and consensual, being acceptable in the various contexts and environments. This corroborates the literature on IAM, where it has been shown that, although it does not necessarily translate into a lower level of visual pollution, there is a greater tolerance for the presence of drones for the purposes of medical emergencies (AiRMOUR, 2023; Thomas and Granberg, 2023). However, during the discussion it emerged that, for other purposes, the level of visual pollution and acceptance changed depending on the environment in which the drones were located.

- *"If it is an emergency, they can come at any time."* - Participant #6
- "*It would only make sense for emergency situations, perhaps. Even more so in rural areas, which are generally more difficult to get to.*" - Participant #8
- "*In case of emergency it would be acceptable 24 h a day, seven days a week."* - Participant #10
- *"For me the purpose would also affect my acceptance of it. (…) For example, I would not mind drones as mentioned in an agricultural setting as an improvement on current technologies (…) But if it is Mount Everest and suddenly there is a whole series of drones just transporting people just across the space that I am supposed to enjoy, it would ruin the setting. (…) I would not feel it is a good justification to have drones used in tourist means if it means ruining the view for other people.*" - Participant #23
- "*I think that for those who are going to need it, medicine, help from the hospital, yes, but things that we do not really need, I don't think it is worth visually polluting the sky which is a place that people sometimes look at and it is also a place of distraction or a point of calm."* - Participant #9

The increased acceptance of IAM in emergency situations confirms that perceived usefulness can outweigh negative visual impacts. This is consistent with previous studies showing greater acceptance of visually intrusive technologies when societal benefits are clear and immediate (AiRMOUR, 2023; Thomas and Granberg, 2023). Conversely, the lower acceptability of non-essential uses suggests that visual pollution is evaluated not only through aesthetic criteria, but also through normative judgements regarding necessity and proportionality.

4.6. Concerns

Participants raised three different types of concerns during the discussions: social, environmental and safety concerns. The range of concerns expressed by participants suggests that visual pollution is closely linked to broader social, environmental and safety considerations. Rather than being assessed in isolation, visual discomfort appears to be exacerbated by perceived risks, ethical considerations and fears associated with the deployment of IAM. This is consistent with existing research, which demonstrates that the acceptance of emerging mobility technologies is shaped by a combination of perceptual and normative factors, with concerns about safety, environmental impact and social equity intensifying negative visual responses (Al Haddad et al., 2020; Lee et al., 2023). As such, perceived visual pollution can be understood as part of a broader set of acceptance related concerns.

4.6.1. Social concerns

Social concerns also emerged during focus group discussions, where participants raised several social concerns related to IAM, particularly regarding its acceptance, potential impacts on different population groups, and the role of individual and contextual factors in shaping these perceptions. The equal access to technology was also noted by some

participants, pointing out the fact that not having IAM in rural areas could contribute to increasing the disparity between urban and rural areas, and it is important to find a balance, even though its presence may seem more decontextualised in this environment, as mentioned above.

- "*I think that one of the main factors related to drones is the social acceptance of it. I think it will take a lot of years for people to accept it, there is still a lot of work to do regarding that specific case.*" - Participant #22
- *"It may cause public concern and confusion, if people are unable to understand what is going on.*". - Participant #14
- *"I think that if we exclude drones from these smaller or remote locations, we will also be increasing the disparity between access to technologies and means in locations that are much more reserved and without access to many things that people in the city have. So, we also have to pay attention to this and aim to achieve a balance*". - Participant #9

4.6.2. Environmental concerns

Environmental aspects also arose as concerns. Questions were raised about the possible impacts on wildlife resulting from the introduction of this technology and how this might or might not affect its acceptance. If there were significant impacts, acceptance would be reduced.

- *"Also, in the rural area and on the countryside that there are a lot more wildlife that we can't explain what a drone is to them. They just have to live with it. They have to adapt to it and every being has the right to be left alone, and we want to make sure that in a rural area, for example, no matter how useful it is, it should still be only applicable in a very specific time window and a very specific purpose.*". - Participant #12
- *"For isolated areas, I think it would be excellent when it comes to taking medicines, supplies … but constantly? I do not know because I don't know about the flora and fauna and if it has any impact afterwards.*". - Participant #1

4.6.3. Safety concerns

The participants safety concerns and their link to how uncomfortable they might be were clear in these discussions. Several times the participants mentioned that the presence of the drones alone could make them afraid of them falling on them or even hitting other people. Not only this, but also numerous other factors that appear to affect the feeling of safety were mentioned throughout the interviews, such as the lack of legislation, the fact of having a flying path and how this can convey safety, the size, the distance from the drones and the space between them.

- *"It has to do, perhaps, with future legislation that they are thinking of making. I think there must be a way of making sure that not just anyone can use it for superfluous means.*" - Participant #1
- *"I do not know, I am just scared of it falling on top of people. As long as it falls where there is no one. Like on top of a roof, that is ok. But on top of a concert? No, that is not ok for me.*". - Participant #20
- *"I am going to imagine there are a lot of things that are going to go down and hit me. So, I think they need to have space between them.*". - Participant #13
- *"Despite the fact that maybe if we are talking about the size and the dimension of the drone in the future, maybe it will be bigger. If there is something, maybe the casualties will be much larger.*". - Participant #12

4.7. Citizen knowledge/information

Information also influenced participant's perceptions of drones and how visually pollutant these can turn out to be. This point is also related to the social acceptance mentioned earlier in the sense that it was addressed by several participants that social acceptance can be directly related to the information presented to citizens and that the presence or lack of it can directly affect their confidence and level of discomfort regarding the technology. This aligns with the existing literature on the acceptance of IAM, which highlights public knowledge and prior knowledge as factors that can influence the acceptance of this technology (Jana and De, 2015; Melo et al., 2023). Therefore, this also supports previous research conclusions that the lack of knowledge on the topic might lead to the rejection of IAM even though there may be a positive attitude towards it (AiRMOUR, 2023). This highlights the concerns that participants have about knowledge related to this topic. They point out that with proper knowledge about the innovation, not only possible concerns will be reduced, but also, even though people may not have a positive opinion of it, they can more easily tolerate and accept its presence in the environment.

4.7.1. Previous knowledge

In this sense, it was stated several times that before the technology is implemented, there should be clear communication of factors such as the purposes, locations, functionalities, and objectives of the drones and that this could make a significant contribution to reducing the level of discomfort felt when introducing IAM, causing less visual impact.

- *"If they do want to let other people know, it is very important to then communicate it to us so that maybe it will lessen the uncomfortableness a little bit. Knowing that it is fine, they are helping people.*". - Participant #12
- *"I think that anything that has a real impact on society as a whole has to be clearly presented to people so that they understand what their openness to the topic is. Otherwise, when a drone appears unexpectedly, people may think it is something alarming. So, people need to know what they are going to start seeing.*" - Participant #9
- *"When people know what drones are used for and how they can help, that will make it easier to accept their use.*" - Participant #21

4.7.2. Real-time information sharing

Still in this topic, the importance of real-time information was also addressed. As with information prior to the introduction of the technology into society, the participants emphasised the impact that the information they can obtain when looking at drones can have on their level of comfort, perceived level of visual pollution and consequent acceptance. As mentioned earlier, one of the suggestions discussed to make this possible would be to implement a colour code for the drones and their respective functions.

- *"I think is actually one of the most important things because, if you tell someone "this drone is being used to transport some organs to a hospital nearby so people can have a surgery" maybe the social acceptance of it will be more smooth and easier*". - Participant #22
- *"I would like to understand more what is the specific purpose that each drone is serving while flying. For example, why it is used in the city or in the in the fields. I think that is important.*" - Participant #22
- *"I think colour is important. (…) it is important to distinguish what they are used for, and colour is the best way. From a distance (…) you cannot tell how big they are, but if they are red, you already know that they are for an emergency, or if they are white, they are carrying something, some kind of merchandise.*". - Participant #17

4.8. Familiarity

Familiarity seemed to be a relevant factor to some in the sense that this in the long term can influence how the society feels towards this technology.

Overall, "Familiarity" emerged as a temporal factor shaping perceptions of visual pollution, with participants suggesting that repeated exposure may reduce initial visual disturbance over time. This aligns with findings from environmental perception research indicating that habituation can lower sensitivity to visually intrusive elements, particularly in urban settings (Lothian, 2008; Molnarova et al., 2012). However, the persistence of discomfort in rural contexts suggests that

familiarity alone may be insufficient to offset visual pollution when expectations of tranquillity dominate. These results reinforce the notion that visual pollution is context-dependent and shaped by both exposure and environmental meaning.

4.8.1. Gradual introduction of drones

Some participants argued that the introduction should be gradual and not sudden. In this way it wouldn't be so disruptive and unpleasant for the general public and it would allow possible initial mistakes to be corrected, preserving not only people's safety but also the success of the introduction in society. In addition, the possibility has been raised that, during this gradual introduction, the first drones to be used would only be for emergencies, which would possibly not cause such a visual impact since they argue that the population's tolerance for these scenarios would be greater. The possibility of the first drones to be implemented in society having medical purposes had also already been suggested by the existing literature on visual pollution in the context of IAM (Thomas and Granberg, 2023) since these drones have a higher rate of acceptance and tolerance (AiRMOUR, 2023; Thomas and Granberg, 2023). Therefore, this consistency in the gradual implementation of this technology in society further emphasises the importance of its purpose in people's tolerance of the visual pollution resulting from it.

- *"For me, it would have to be something very gradual, because although we are already a very technological society, we are increasingly more immediate. I think that something so new must be gradually inserted into society."* - Participant #9
- *"It really must be done carefully and gradually with plans like this to repair the damage if it goes wrong."* - Participant #7
- *"If we do not start with the urgent ones, I do not know what the criteria is. If it is something very trivial, what is the criteria then? I think that urgent and extreme situations are smaller, so the quantity is smaller. Then, yes, move on to the rest."*. - Participant #19

4.8.2. Time effect to familiarity

Another factor to consider is the time effect to familiarity, as this was mentioned in the discussions in the sense that, with the passage of time and greater exposure to the presence of drones, the population will eventually get used to it and it will no longer be considered as visual pollution. While some argued that human beings are creatures of habit and would therefore end up getting used to them, others defended their view based on their own experience of virtual reality in which, according to them, as it progressed, their presence no longer shocked as much as it did at the beginning. Therefore, this reinforces the idea that visual pollution is a psychological concept, as previously mentioned.

- *"Obviously they will get used to it. This would be an initial problem, but as the days, months, years go by, people will get used to it. That is why people easily get used to anything and routines. Then it would become a routine like the airplanes that fly over us every day."* - Participant #6
- *"Then, little by little, I started to get used to it. So, I think it is a matter of habit too, especially if they fly high."* - Participant #8
- *"Eventually they will be like cars passing on the road where there is the visual background noise. People know they're there; it is expected."*. - Participant #3

Furthermore, some argued that this hypothesis would only be valid for urban environments, as drones would not be suitable for rural environments regardless of the time.

- *"In the city I think it can be perfectly something that people can get used to. In smaller towns, with a different type of population, I think it might be a bit more shocking to start introducing this new type of air mobility."* - Participant #9
- *"I think people can get used to drones and, in this case, this visual disruption will stop being visual pollution in urban environments, but not in rural environments."* - Participant #3

4.8.3. Technology familiarity

Another factor related to familiarity that was highlighted was technology familiarity, where it was possible to observe two interesting perspectives. On one hand, there were those participants who pointed out that in their home area that is not a large urban centre, as soon as people come across new technologies, they tend to get excited and feel positive about it. On the other hand, there were also those participants who, even though they have worked with drones and are in favour of them, said that they don't feel comfortable with drones flying over people because they have seen some of them falling down.

This shows that greater technological familiarity, although it can contribute positively in many ways to the successful implementation of IAM in society, is not necessarily synonymous with a lower level of perceived visual pollution.

- *A lot of people there, especially where I come from, because I come from a very small city where if there are new things, people will actually be very excited about it."*. - Participant #12
- *"I am super scared of having a drone on top of me. Even though I am super pro drones, they can be very useful, they can use them for agricultural and stuff, but as long as they are not on top of me. Maybe it is because I have seen those things crash or something, But I am very stressed out when I see a drone above a concert. I hate that."* - Participant #20

5. Discussion

5.1. Summary of IAM visual pollution determinants and theme comparative analysis

A summary of the obtained results is presented in Fig. 5 that presents a prioritisation of the key determining factors that shape public perceptions of Innovative Air Mobility (IAM), based on frequency counts derived from thematic qualitative analysis and Fig. 6 that depicts the themes that arose through the thematic analysis and the frequency with which the contents of each category were mentioned during the focus groups.

An overview of the Figures allows to observe that the bigger categories are those of human-drone interactions, dynamic visual effects and drone properties appear with similar frequencies in the focus groups (approximately 20% of all the statements each). On the other hand, the flight purpose and the expressed concerns were also mentioned several times (10% each) while the familiarity with IAM and the shared knowledge and information was citizens were designated as important aspects but were less discussed (8% and 6%, respectively). It can be

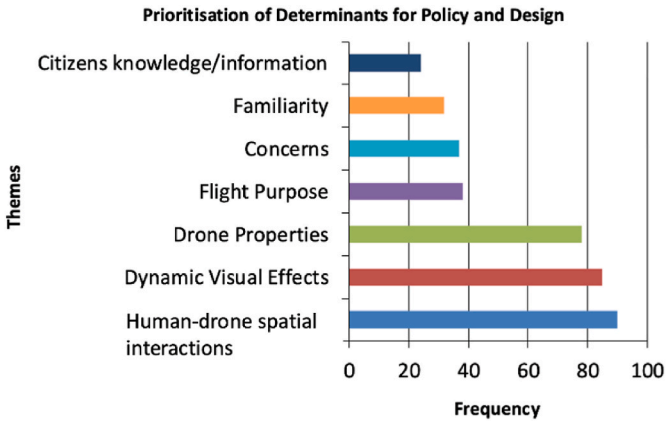


Fig. 5. Prioritisation of determinants for policy and design of IAM

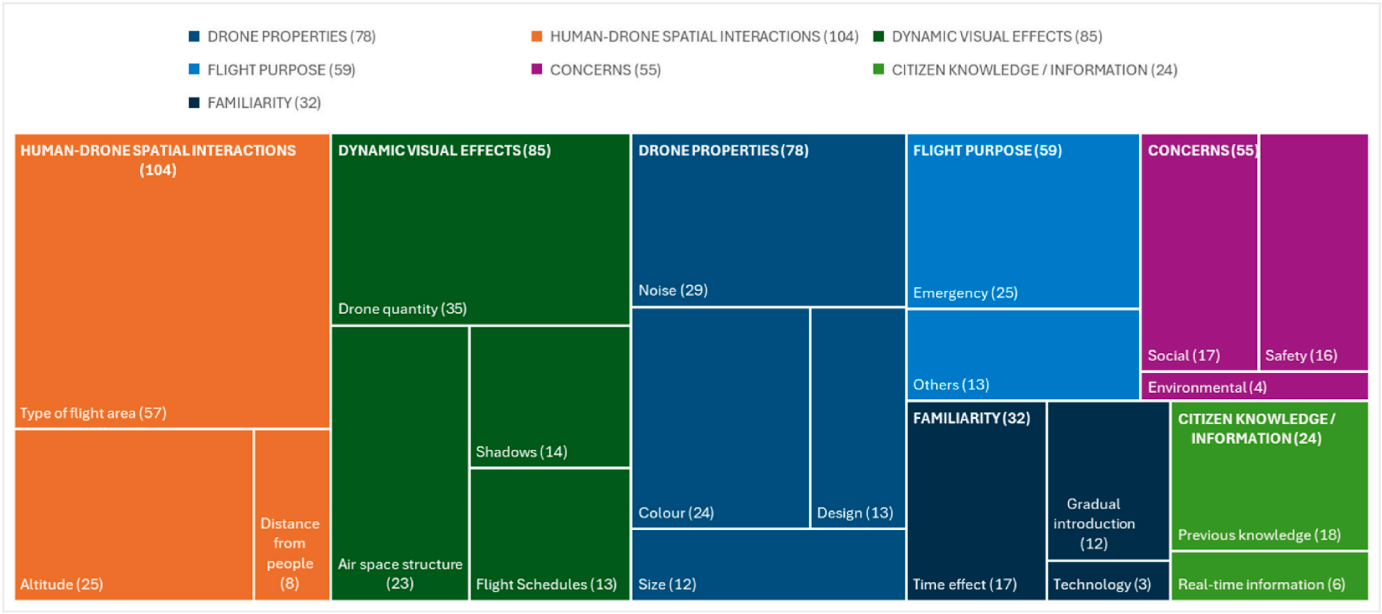


Fig. 6. Overview of thematic analysis results with counts per theme and code.

concluded that Human-Drone Spatial interactions, Dynamic Visual Effects and Drone Properties emerge as the most salient dimensions, suggesting that policy and design efforts should initially focus on these areas. Drone Properties relates to vehicle-level characteristics such as colour, size, form and noise, which directly influence drones' visibility and aesthetic integration. Dynamic Visual Effects map onto traffic-management variables, including drone density, movement patterns, shadows, and flight scheduling. Together, these dimensions articulate how visually polluted airspace can be produced and provide a framework to inform quantifiable thresholds and operational guidelines for IAM deployment. Human–Drone Spatial Interactions correspond to spatial variables such as flight altitude, distance from people, and type of flight area, all of which can be operationalised in airspace rules.

At an aggregated level the top aspects that were more frequently mentioned by the participants indicate that location poses a major weight to the perceived visual pollution with rural environments being more sensitive to urban (57 mentions). The next aspect was drone density (35 mentions) revealing that specific schedules are required so that IAM does not turn into a visual pollutant. Next, of almost equal frequency, were designated the topics of noise (29 mentions), colour (24 mentions), altitude (25 mentions), paths (airspace structure) (23 mentions) and the use for emergency purposes (25 instances). Addressing these elements through regulatory frameworks and design guidelines can therefore increase public acceptance and mitigate potential concerns. The lowest-ranked themes, whilst remaining relevant, may be considered secondary priorities or context-dependent, becoming more prominent as IAM systems mature and operational exposure increases. To enable the translation of these qualitative insights into testable IAM design and policy levers, the themes identified in this study align with measurable parameters of IAM operations.

A more detailed analysis of each category allows to see that the most discussed topic was that of the human-drone spatial interactions with the subcategories of the type of flight area being the most mentioned one (63,3% of all the statements made within this topic), with the altitude following with as the second most discussed topic (27,7%) and finally the distance from people (9%). These aspects express the context within which IAM could appear starting with the possible locations and the relative position of drones with respect to people moving on the ground. The altitude was also found to mark the experience of the participants; since the technically safe altitude was deployed for the execution of the experiments, it can be concluded that operations at higher altitude could improve the level of visual pollution caused by IAM.

On the second most mentioned topic, the dynamic visual effects, drone quantity and the airspace structure are the most noticeable aspects. They both lie on the decisions that U-space providers will make on the organisation of the U-space and the number of flight licenses that will be given at certain time periods of the day.

Regarding the drone properties, the most prominent aspects were noise and the colour of the aerial vehicles that incentivised many comments from the participants. It is noteworthy that while assessing the visual pollution, the participants highlighted the impact of noise leading to the conclusion that IAM is associated to audiovisual pollution which should be further researched. The colour of the vehicles was also determinant for the experiences. There are still several issues on the colour to be explored, and future research could be conducted on the impact of the colour on citizen acceptance and the level of perceived visual pollution. Manufacturers could also benefit from these insights to better understand what options they have for their products and what could make them more acceptable to the public so that they could support the uptake of these services.

It can be observed that perceived visual pollution is fundamentally influenced by two major areas, the operational design of technical aspects that form how IAM is materialised and the way in which IAM is communicated to citizens along with social aspects. The first group includes the elements that comprise operational design, such as - human-drone spatial interactions, dynamic visual effects, drone properties and flight purpose. The other large group includes aspects such as concerns, familiarity and citizens knowledge/information, influencing perceived visual pollution through the form in which IAM is communicated and understood.

The obtained results also allow to form a conceptual framework of the identified aspects that form citizens' views on visual pollution. Fig. 7 presents the framework encompassing the topics designed through the analysis. They can be organised into two main areas, one covering the supply side and the fields that need to be managed to provide socially-acceptable IAM services in terms of visual pollution and the action areas in the side of the demand that need to be considered to manage the external environment of the IAM ecosystem.

In particular, factors such as type of flight area, flight altitude, drone quantity, noise and colour are likely to play a critical role in defining perceived visual and spatial impacts.

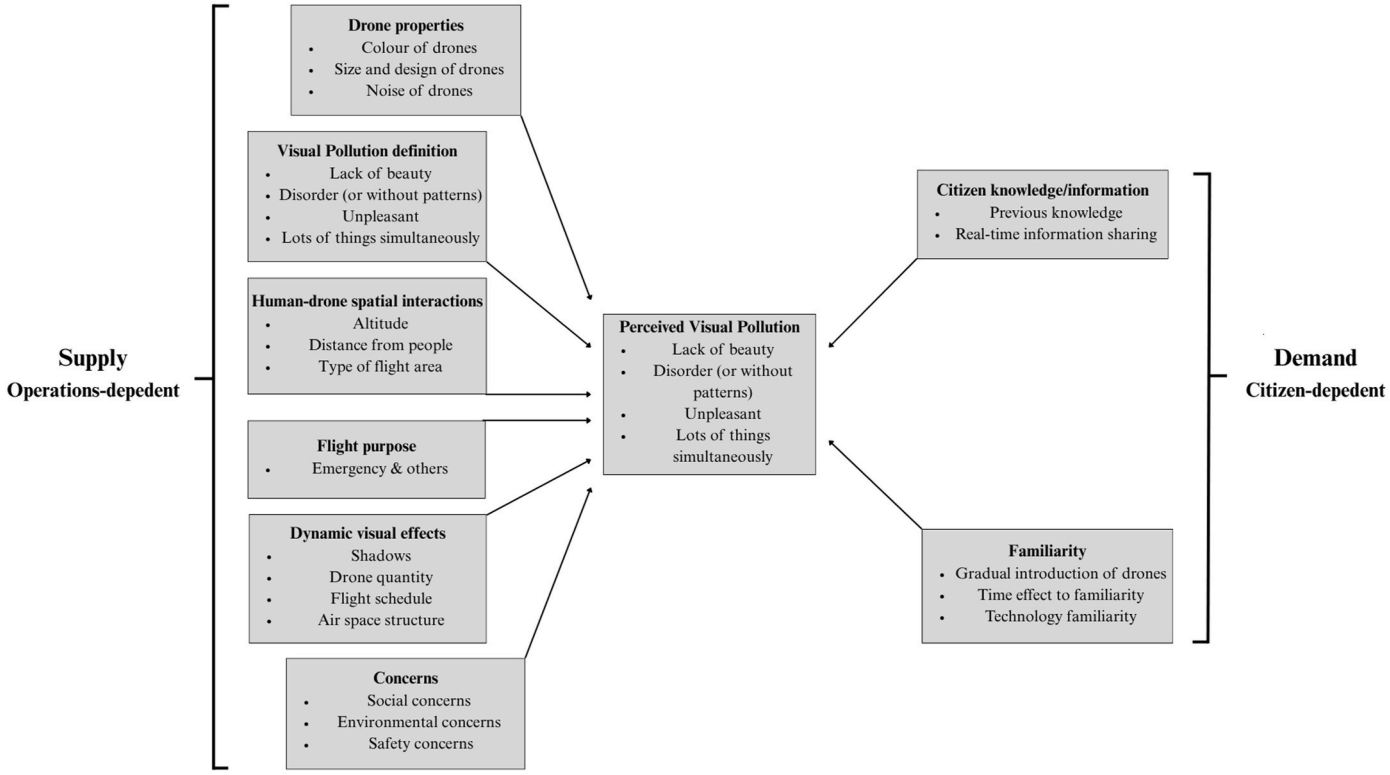


Fig. 7. Perceived IAM visual pollution conceptual framework.

5.2. Suggested actions for policy-makers

During the FGs, the participants provided several suggestions on what could enhance their level of acceptance of drones in inhabited environments and lower the level of visual pollution. Table 6 presents the participants' contributions and the implicit policy actions for IAM management and planning.

A key implication from the participants suggestions was the need for strict user and use case control. In particular, they suggested that pre-authorisation mechanisms include the approval of not only the U-space user profiles as currently required, but also the flight purpose ensuring that drone operations are justified and aligned with defined and socially-acceptable use cases. In terms of operations, several suggestions were given such as (1) control and prohibitions over areas with people's concentration or public gatherings to avoid safety risks and visual pollution, (2) context-dependent restrictions implying different allowed minimum altitudes in rural and natural landscapes and use of allowed altitude as a control measure for emitted noise levels, (3) adoption of standardised flight corridors and possible utilisation of existing noisy transport infrastructure such as railways, (4) establishment of socially acceptable drone density thresholds, (5) establishment of time-slots for drone flights and attribution of time-based operational windows for non-emergency activities to certain time periods such as peak hours for noisy operations or night flights for non-noisy operations and (6) priority attribution to emergency operations because people could tolerate visual pollution for emergencies. From a technical perspective, suggestions for allowed technical design standards were given, including guidelines on colour and size and the implementation of colour or logo codes per type of utilisation. Finally, it was highlighted that citizens should be part of the information chain to ensure policy effectiveness. The provision of real-time information systems (through mobile apps, for example) and a phased implementation roadmap for the gradual introduction of IAM operations were suggested to progressively build citizen familiarity and trust. Collectively, these measures indicate that visual pollution should be treated as a core parameter in drone transport policy, requiring coordination between U-space (airspace) management, urban planning and community governance systems.

5.3. Implications for IAM applications (transport and logistics)

The findings of this study highlight several operational factors that need to be considered for the successful and socially acceptable implementation of IAM. The way the visual pollution resulting from IAM is perceived by citizens has an impact on crucial aspects of transport operations management.

Firstly, in operations management, scheduling is a crucial decision (Heizer et al., 2020) able to influence how resources are allocated to meet demand (Krajewski et al., 2016). For IAM, this is also pivotal as airspace management challenges appear (Jin et al., 2024). The insights provided by the participants demonstrated the importance of considering specific schedules for drone operations in order to minimise the visual pollution experienced, which is why it is necessary to consider social aspects and not just technical capacity. Participants showed a preference for a lower frequency of drones and operations at less intrusive times, such as during the day, suggesting it results in less disturbance. By taking this information into account when developing the deployment strategy, it will be possible to maximise the acceptance of IAM.

Secondly, layout decisions also have a big impact on operations management, since these decisions can directly affect the flow of drones and materials (Heizer et al., 2020). As such, this study provides relevant insights for decision makers regarding the layout of drone operations. Citizens seem to prefer drones to fly in organised paths rather than loose, each on its own route, as previous literature has also shown (Thomas and Granberg, 2023; Stolz et al., 2025). This makes the presence of drones expected, increases the sense of safety and reduces the visual impact, demonstrating the importance of this factor in future drone operations and acceptance. In addition to flying paths, altitude was a factor mentioned by the participants as being able to influence the level of

Table 6
Participants' suggestions for IAM visual pollution policy making.

Code	Participant insight	Suggested Policy Action
Theme: Concerns		
Safety	"It has to do, perhaps, with future legislation that they are thinking of making. I think there must be a way of making sure that not just anyone can use it for superfluous means." - Participant #1	Requirement of flight purpose approval and U-space user and use case approval (requirements for U-space user profile and utilisation)
	" I am just scared of it falling on top of people. As long as it falls where there is no one. Like on top of a roof, that is ok. But on top of a concert? No, that is not ok for me." - Participant #20	Restriction of drone operations over densely populated areas and public gatherings
Social concerns	"I think that one of the main factors related to drones is the social acceptance of it, it will take a lot of years for people to accept it." - Participant #22	Public engagement strategies and gradual implementation policies
Theme: Dynamic Visual Effects		
U-space Structure	"If they were passing by in, kind of a chaos, one going one way or the other, without a clear order, I think it would be stranger. If they were organized in lines, I think it would be more pleasant.". - Participant #7 "if it is above a train line, trains only go there occasionally, so you minimise the time where people are below it, so, maybe something smart like that" - Participant #20	Implementation of standardised and clearly defined flight corridors to reduce visual disruption
Drone Quantity	"It is all about the amount of it. A few of them is ok, but not too many. Even in the city."- Participant #21	Establishment of acceptable drone density thresholds and traffic flow limits in specific areas
Theme: Dynamic Visual Effect		
Flight Schedules	"I would say that I would be receptive to the idea of drones only on a pre-defined schedule.". - Participant #9 "During the peak hours of activity like at 3:00 p.m. and then it goes down at night again. Or maybe the reverse. Maybe if there is absolutely no noise, all the drones working at night in order that I cannot see the drones, so they only work at night. But in that case, they would have to make no noise." - Participant #23	Introduction of time-based operational windows for non-emergency drone activities
Theme: Human-Drone Spatial Interactions		
Altitude	"The low altitude makes drones more noticeable, more conspicuous and noisier. So, I think the more invisible they are, the better."- Participant #7	Definition of minimum altitude bands to reduce visibility and disturbance
Distance from People	"I hate seeing them on top of people. So, for me it's way, way easier to see a drone on top of a mountain or something if no one is there, than on top of a beach that's full of people. No. That's way more stressful for me.". - Participant #20	Enforcement of minimum horizontal separation distances from people
Type of flight area	"In a rural environment, I don't think it makes much sense." - Participant #8 "In the countryside IAM was a bit more suffocating for me. It didn't really belong there". - Participant #9	Context-dependent regulation (stricter controls in rural/ natural areas)
Theme: Drone Properties		
Colour	"Maybe if the black was in white, I would prefer white because you could confuse it with the clouds." - Participant #9 "There should be some kind of rule. For example, white drones are for people, black drones are for goods."- Participant #16	Development of colour guidelines to reduce visual conspicuity, with optional coding for functionality
Noise	"More of an auditory pollutant than a visual one for me." - Participant #10 "First you listen and then you look. So, I think the first impact is audible and then it's the visual impact." – Participant #16	Regulation of noise thresholds and integration of acoustic standards in certification
Size and Design	"The smaller the better." – Participant #9	Development of size guidelines to minimise visual intrusion of IAM vehicles or revision of altitude to which drones can fly to minimise visual pollution
Theme: Flight Purpose		
Emergency and others	"If it is an emergency, they can come at any time."- Participant #6	Priority operational rights for emergency flights and differentiated regulations by purpose
Theme: Citizens Knowledge		
Information	"People have to know what they are going to start seeing." – Participant #9 "If they do want to let other people know, it is very important to then communicate it to us."- Participant #12	Implementation of public communication systems and real-time information sharing tools
Theme: Familiarity		
Gradual Introduction of Drones	"I think that something so new must be gradually inserted into society." - Participant #9 "If we do not start with the urgent ones, I do not know what the criteria is. If it is something very trivial, what is the criteria then? I think that urgent and extreme situations are smaller, so the quantity is smaller. Then, yes, move on to the rest." - Participant #19	Roadmap of a phased and progressive introduction of IAM operations

visual pollution perceived and which is directly related to IAM operations, meaning that the higher the altitude, the greater the level of tolerance.

The density and noise also proved to be significant factors for the participants. The number of drones present in an environment and the noise they produce appears to be directly related to the level of visual pollution, which is why these factors needs to be considered in IAM operations. There are places where a higher density is more acceptable than others, such as in urban versus rural environments, so it is crucial that these aspects are considered when defining a strategy for

implementing this technology, given their ability to influence the perception of it. Acceptable drone density thresholds per area need to be identified to help policy-making in different environments (urban, rural). A recent simulation-based study reinforces this point, showing that increases in fleet size and traffic frequency can reduce user wait times but at the cost of higher aerial density and operational complexity (Onat et al., 2024). Moreover, it is also fundamental to integrate noise-aware management policies – such as limiting flight frequency and minimum flying altitudes (Gao et al., 2024) – that help mitigate community disturbance while maintaining service efficiency. There are also purposes generally more acceptable than others, and this acceptance may vary depending on the flight area. Thus, the perspectives shared by the participants may be relevant to establishing operations that maximise the use of IAM in line with social factors.

Another key point in operations management is the product design. In this case, factors such as colour, size and shape were debated throughout the discussions, thus providing relevant insights into the participants' preferences. In a user-centered study of medical delivery drones, Fink et al. (2024) showed that adjusting visual design based on user feedback significantly improved perceived usability and acceptance. These insights demonstrate that certain characteristics may be preferable, allowing drones to be more tolerable and reflecting the importance of taking user preferences into account when developing technical specifications.

Finally, operations location is also an important factor for IAM operations. During the discussions, it was possible to obtain relevant insights into this factor, given that the participants did not find the same level of acceptance for all zones. Since there was a general preference for the presence of drones in urban areas over rural areas, the strategic importance of location when developing an IAM deployment strategy is clear, and it is crucial that it reflects public perceptions. This will make it possible to cause fewer impacts while seeking to optimise operations, aligning with findings by Jin et al. (2024), highlighting the value of integrating strategic planning with service operations to enhance efficiency and public acceptance in IAM.

6. Conclusion

The present study explored the potential visual pollution associated with Innovative Air Mobility (IAM) operations and how it is perceived by citizens. Using an immersive virtual reality environment combined with focus group discussions, the study adopted a reflexive thematic analysis to identify the determinants of IAM related visual pollution and to contribute to the definition of this concept in the context of IAM. This approach enabled an in-depth understanding of how the presence of IAM vehicles is perceived visually in both urban and rural environments and which factors shape these perceptions.

Overall, the findings reinforce and complement existing literature (flight altitude, purpose, drone quantity, flight paths, schedules) while also providing new insights for both research and practice. The role of drone colour was highlighted as a preference for colours that make drones less visible was revealed. Regarding the application environments, the results point to significant differences in rural and urban environments, with a higher level of visual pollution in rural ones. It was also possible to verify the importance given by people to the need to be properly informed about what is this technology and how it works before its implementation, as well as being able to obtain information about the drone in real time and how these factors can have an impact on the level of acceptance. The gradual introduction of drone flights and for certain purposes was also expressed, as this would result in lower levels of visual pollution and it was pointed out that, over time, citizens will get used to it. Numerous insights were also gained into different types of concerns, namely social, environmental and safety, which demonstrates areas that should not only be considered in the deployment strategy, but also in the communication given to citizens, seeking to enlighten them so that there is a lower level of perceived visual pollution and consequently a higher level of acceptance. Finally, one of the points on which there was the greatest agreement among the participants was the matter of noise and its ability to potentiate visual pollution, demonstrating the urgency of analysing visual and auditory aspects together.

The results highlight the importance of considering multiple operational and contextual factors when assessing visual pollution, as well as the relevance of users' perceptions in shaping acceptance of IAM. These insights underscore the value of integrating visual pollution considerations into IAM planning and deployment strategies. By identifying perceptual drivers of visual pollution and linking them to operational characteristics of IAM, this study contributes to the development of evidence-based policy guidelines that can support decision makers and manufacturers in minimising visual impacts, promoting public acceptance and facilitating the harmonious integration of IAM into society.

6.1. Limitations and future research

Future studies could try to obtain the views of more participants over the age of 30, since most of the participants in this study were below this age. In addition, the study was carried out exclusively in Lisbon, which may limit the generalisability of the results to other geographical and cultural contexts. By taking these two aspects into account, future research, would make it possible to obtain a view that better reflects the different age groups and possible different cultural perspectives in society.

Increasing the number of participants could enhance the diversity of perspectives and contribute to a more robust validation of the insights obtained. It may also be relevant to carry out simulations with environments that simulate suburban areas, as these were not included in this VR experiment. Furthermore, another interesting possibility is mixing different types of drones in the same experiment.

It is also important to note that the implementation of IAM presents a set of cost associated to IAM implementation that can be assessed in parallel to social and environmental. In this regard, it is suggested that future research conduct a cost-benefit analysis capable of relating socially beneficial factors (e.g., improved accessibility to more isolated areas, greater responsiveness in emergency situations, logistical and operational efficiency) and impact factors, namely visual pollution and possible environmental impact in different environments, as demonstrated in the experiments of this study. This will contribute to the creation of more robust indicators to support regulatory decisions, maximising the benefits of IAM while reducing its visual and environmental impacts.

Additionally, it is important to emphasise that qualitative methodologies, as FGs, are always subject to bias, both on the part of the researcher and the participants. Regarding the participants, they were always encouraged to express their convictions openly and spontaneously, but there can always be effects of social desirability and acquiescence bias. Although various procedures were adopted to prevent this from happening, since the researchers who coded the data had expertise in the area, and triangulation was carried out to ensure that there was consensus in the coding, always preserving the contextual meaning, there is still the possibility of researcher bias. In addition, the sessions also had a supervisor to ensure their integrity and that they were conducted with the minimum possible bias. Furthermore, although all focus groups were conducted within five days of the VR exposure and participants demonstrated strong recall of the scenarios, future studies may benefit from conducting all focus groups immediately after the VR experience to further minimise any potential memory effects.

Finally, it is also worth noting that although the study was designed to capture a diversity of perspectives, the distribution of participants in terms of age and gender, as well as area of residence (urban, rural) was not fully balanced. This represents a limitation, since it may have shaped the range of views expressed; however, this is a common feature of qualitative focus group research and does not detract from the exploratory purpose of the study For instance, younger participants were more

likely to accept the presence of drones and their visual disruptions than older participants, and there was also a widespread view that IAM is much more acceptable, including in visual terms, in an urban environment than in a rural, greener setting. Future research could adopt more systematically stratified samples to further examine potential differences across population segments and rollout environments.

CRediT authorship contribution statement

Francisco Rodrigues Aniceto: Writing – original draft, Visualization, Software, Investigation, Formal analysis, Data curation, Conceptualization. **Helena Almeida:** Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Margarida Lopes:** Methodology, Conceptualization. **Sofia Kalakou:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Acknowledgement

This work is co-funded by the European Commission under Grant Agreement No. 101114776 and supported by the SESAR 3 Joint Undertaking and its founding members; it was also partially funded by the Portuguese Foundation for Science and Technology under Grant UIDB/00315/2020). The authors would like to express their gratitude to all contributors and stakeholders involved in the ImAFUSA project.

Annex A

Theme	Code	Codes Frequency	Themes Frequency
	Colour	24	78
Drone Properties	Size	12	
	Design	13	
	Noise	29	
	Altitude	25	90
Human-drone spatial interactions	Distance from people	8	
	Type of flight area	57	
	Shadows	14	85
Dynamic Visual Effects	Drone quantity	35	
	Flight Schedules	13	
	Air space structure	23	
Flight Purpose	Emergency	25	38
	Others	13	
	Social concerns	17	37
Concerns	Environmental concerns	4	
	Safety concerns	16	
Citizens knowledge/information	Previous knowledge	18	24
	Real-time information sharing	6	
	Gradual introduction of drones	12	32
Familiarity	Time effect to familiarity	17	
	Technology familiarity	3	

Data availability

Data will be made available on request.

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