

Urban air mobility infrastructure design: Using virtual reality to capture user experience within the world's first urban airport

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ABSTRACT

Human factors research can play an important role in the successful design of infrastructure to support future mobility. Through engaging users and stakeholders early in the design process we can gain insights before the physical environments are built. This paper presents data from a truly novel application of Virtual Reality (VR), where user experience and wayfinding were evaluated within an emerging future transport infrastructure to support urban air mobility (UAM) – the urban airport (aka vertiports). Urban airports are located in city centres where drones or ‘flying cars’ would land and take off from. Previous quantitative studies have investigated passenger experience in traditional airports using field observation and surveys, but this paper is the first to present qualitative research on user experience in this emerging mobility infrastructure using an immersive VR environment. Twenty participants completed a series of six scenarios aimed at understanding customer ‘exciters’ and ‘pain points’ within an urban airport. Results and recommendations from this empirical research will help inform the design of all future mobility infrastructure solutions, through improving user experience before the infrastructure is physically deployed. Finally, this paper highlights the benefits of engaging users at an early stage of the design process to ensure that future transport infrastructure will be accessible, easy to navigate and a pleasure to use.

1. Introduction

1.1. Background

Urban Air Mobility (UAM) is one of the fastest emerging domains in future transport and mobility. UAM is defined as “safe and efficient air traffic operations in a metropolitan area for manned aircraft and unmanned aircraft systems” (Thipphavong et al., 2018). It consists of passenger or cargo-carrying air transportation services as a solution in dense urban environments. This includes journeys to and from city centres and suburban areas. Along with drones, electrically powered Vertical Take-Off and Landing (eVTOL) aircraft can take to the skies utilising considerably smaller infrastructure footprints compared to traditional airports. Indeed, eVTOLs have the capabilities to quietly transport not only goods, but also a small number of passengers for short journeys up to 180 km, at a cruise speed ranging from 130 to 370 kph (Thipphavong et al., 2018). This air transportation service could help improve fast, efficient (Antcliff et al., 2016) and sustainable mobility in comparison to congested road networks and infrastructures (Federal

Highway Administration, 2016). Furthermore, flying in and out of busy urban centres may also have the positive effects of increasing conventional mass transit services (Hunt, 2021), such as mainline train routes, as completing the ‘last-mile’ of the journey could be achieved quickly and sustainably. The feasibility and development of UAM rely on a dedicated infrastructure allowing the safe and efficient operations of aircraft when taking off and landing vertically. This is only possible with new, ultra-compact infrastructure named “vertiports” or “urban airports” where drones and eVTOLs can operate.

1.2. Urban and traditional airports

An urban airport (aka vertiport) is a portable, space-efficient and rapidly deployable structure that can be deployed to many locations in urban areas and cities. Compared to traditional international and regional airports, it is smaller as it does not need runways and usually consists of one building unit (Fig. 1). These urban airports can be used for drone logistics, or passenger journeys. Specifically for passenger operations, there is no baggage delivery area as individuals will only be

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able to carry hand luggage on board the eVTOLs. They remain similar to traditional airports in that passengers need to proceed through check-in and security procedures at both take-off and landing areas. They also bear resemblances as they both have boarding/disembarking 'Gates' as well as retail and waiting areas. This is where it is challenging to design urban airports as they are not as big as traditional airports but need nonetheless to ensure a fast, efficient and pleasurable journey through the building, as otherwise defeating the purpose of UAM.

1.3. Evaluating passenger experience within transport infrastructure

UAM is a novel transportation service whose infrastructure has yet to be examined from a user perspective. Indeed, this novelty and lack of familiarity to the user, means that during the design and development of the infrastructure there is an acute need to carefully consider public acceptance in order for it to be successful (Thipphavong et al., 2018). More specifically, how travellers navigate through an urban airport needs to be investigated in terms of user experience, usability and accessibility. One crucial question pertaining to the development of urban air mobility infrastructure is how they should be designed to ensure a positive traveller experience?

There is limited literature on passenger experience in traditional airports (Chonsalasin et al., 2021; see Popovic et al., 2009 for a review) and on how urban airport layouts (e.g. Preis, 2021) or eVTOLs (e.g. Palaia et al., 2021; Serrano, 2018) should be designed. However, there is very little qualitative research on travellers' experience and navigation in urban airports in an immersive environment (Zdanowicz et al., 2021). The main benefits provided by a qualitative approach, as adopted in this paper, are (a) providing insight into users' experience within novel UAM infrastructure with both flight and non-flight related services; (b) generating an understanding of navigation within an urban airport from a traveller perspective and (c) the capacity to focus on subjective aspects of boarding an eVTOL and leaving an urban airport. This present research aims at bridging the gap in the UAM and user experience qualitative knowledge base, by evaluating user experience and the customer journey within a virtual environment. To this end, participants were administered closed and open-ended questions after experiencing a simulated urban airport in Virtual Reality (VR). The verbal data collected was analysed using inductive content analysis, a method deemed suitable when the topic investigated has not been yet examined (Elo and Kyngäs, 2008). In this instance, this type of content analysis allows unveiling the multifaceted experience of exploring a novel transport infrastructure, including users' comments on their perception, comprehension and evaluation of the environment.

1.4. Using VR for user evaluations

A recent systemic review of multimodal human-computer interaction has been conducted by Azofeifa and colleagues in 2022, this highlighted how different technologies (including VR) have been used in different domains to collect user-centred data. Domains covered range from medicine to cultural heritage, with limited research within the transportation domain (Azofeifa et al., 2022). Transport research using VR as a tool for user engagement has mainly focused on driver interaction with human machine interfaces (HMI) within a vehicle (see Riegler et al., 2021 for a review) or how pedestrians interact with automated vehicles (Burns et al., 2020; Hübner et al., 2022). Within the aviation domain VR and flight simulation for training (see Xie et al., 2021 for a review) and evaluation of cockpits designs are just as prevalent. Virtual reality has been increasing used to understand passenger flow and wayfinding within buildings and infrastructure, particularly within emergency scenarios (Fu et al., 2021). However, gaps in the research literature when considering the use of VR or studying pedestrian wayfinding behaviour include evaluations taking place in simplified virtual scenarios which present an unrealistic representation of the real world (Feng et al., 2022). This gap is addressed in this current study as the virtual environment is very high fidelity and interactive, while also depicting a future transport hub for urban air mobility that we be realised physically in Coventry, UK. In addition, the novelty of this paper lies – not in the fact that VR was used as a tool to engage end users – but in the application of VR to evaluate UAM infrastructure. Therefore, this paper is the first application (published to the authors knowledge) where VR is used to better understand user experience within emerging UAM infrastructure.

1.5. Rationale and purpose of the present study

The epistemological stance adopted for this study is pragmatism, which means inevitably the authors have some knowledge on the topic examined. Therefore, they could be considered to not be entirely objective when analysing and interpreting the data, which could be reflected in the findings (Bryant, 2009; Corbin and Strauss, 2015). In this instance, all the authors have a background in human factors and transportation, including some experience in UAM, and were eminently aware of the user experience aims of the study. Considering that this study is inductive, no priori hypotheses were formulated relating to likely user experience within the six identified scenarios.

The purpose of the current research as presented in this paper is to better understand the user experience specifically related to a better understanding of the customer journey and wayfinding within this novel infrastructure of an urban airport to support future transport via urban air mobility. To achieve this, an inductive content analysis was



Fig. 1. An example of an urban airport (aka vertiport), as realised in the UK funded AirOne project, designed and constructed by Urban-Air Port Ltd (<https://www.urbanairport.com/>), for which the authors are collaborative partners.

conducted on answers given to the open-ended questions asked at the end of the VR trials. The signs to support wayfinding were designed by Coventry University specifically for this project and followed best practice for signage contrast ratios, font used, readability and size at fixed distances, and height above at key locations (see [Federal Aviation Administration, 2013](#)). This user study was conducted in VR before any physical build of an urban airport has been completed, meaning that user feedback from this VR trial can be used to improve future iterations (see [Fig. 1](#)).

2. Methods

2.1. Material

The experiment took place in a large design studio, using retractable barrier posts and hazard tape to define the area where participants would be using the VR headset (see [Fig. 2](#)). A HTC VIVE Pro Eye wireless headset and two handheld controllers with lanyards were used for the experiment. The controllers allowed participants to wirelessly interact with the virtual world, by pressing grip buttons on the side of each controller, participants' virtually grabbed specific objects such as coffee cup or a magazine in their hands. The multifunction trackpad allowed them to navigate within the environment, while still allowing for accurate positioning movements to be completed physically by taking smaller steps or turning the body or head. General background conversational sounds were also presented to the participant via the VIVE headset within the virtual environment in order to increase realism and immersion of, and into the scenario. The base stations sensors' tracking determined the optimal size of the area (i.e. 5×5 m) to navigate around the scene in a seamless and immersive fashion. As the user trials were conducted during the 2021 during the Covid-19 pandemic, additional measures were taken to ensure participant and researcher safety, including UV sterilisation (using Cleanbox UX1) of the VR headset and the controllers before each trial.

The urban airport Computer Aided Design (CAD) model was built in-house using Rhino 3D and 3Ds Max, which is compatible with the Unity real-time 3D game engine used to generate the environment. The model was then populated with static avatars, furnishings and recreating realistic lighting. The novel UAM infrastructure, as realised in this paper, was developed through the UK Future Flight Challenge funded AirOne project, where the world's first operational vertiport which was demonstrated in Coventry, UK in May 2022. AirOne (as designed by Urban-Air Port Ltd) has a circular shape with central 17m landing pad

(or FATO) for eVTOLs and drones, has a total diameter of 43m, and the highest ceiling point reaches 7m ([Fig. 3](#)). It has one main entrance and exit, and two emergency exits.

The infrastructure consists of the passenger terminal, as well as the eVTOL maintenance hangar at the back of the building (see [Fig. 4](#)). There are two security checkpoints with Gate A and B where passengers embark and disembark the eVTOL via the landing pad. Firstly, they must use a facial recognition system to check-in, and then to get through full-body and baggage security scanners to finally board the aircraft. There is also a variety of non-flight related facilities, including retail areas, two coffee shops, a recreational area and a working space.

All user trial sessions were audio recorded using two Zoom H1 Digital Recorders. One researcher was responsible for the transcription of the recordings. All participants gave written consent to be audio recorded after being issued information about the purposes of the study. The research was granted ethical approval by Coventry University Research Ethics Committee and was GDPR compliant.

2.2. Participants

Volunteer participants comprised of a convenience and snowball sample of 20 adults, with 10 women and 10 men. Ten participants were young adults aged 18–29, eight were aged 30–39 and two individuals were middle-aged adult 40–49. Participants were recruited via email, promotional posters and internal social media posts. Participants had to report two inclusion criteria: (a) be aged above 18 years old, and (b) not be prone to motion sickness, either in the form of VR, or car sickness.

2.3. Experimental procedure

Participants were compensated £10 in vouchers for taking part in the user trial, which lasted approximately 60 min. At the start of their session, they were asked to complete a demographics questionnaire. Participants were also described in detail the aim of the user study during an initial briefing, during this it was highlighted that the experimenters were primarily interested in aspects related to 'user experience' of the urban airport, and that it was their perceptions on the experience that would be the focus of the interviews following the VR scenarios. Then they were given instructions on how to use a VR headset and two controllers while being placed in the test environment. Participants were then asked to complete six different scenarios where they would be navigating in the urban airport virtual environment using the controllers to navigate.



Fig. 2. Experimental setup with a participant using the VR headset.

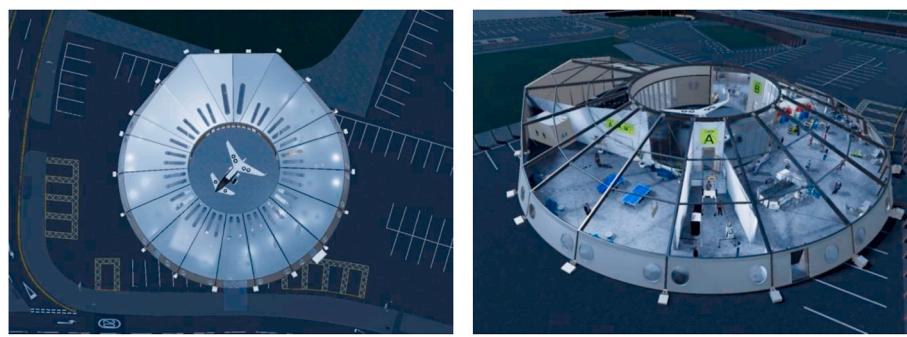


Fig. 3. The top (left) and perspective (right) views of the Urban Airport within the VR environment.

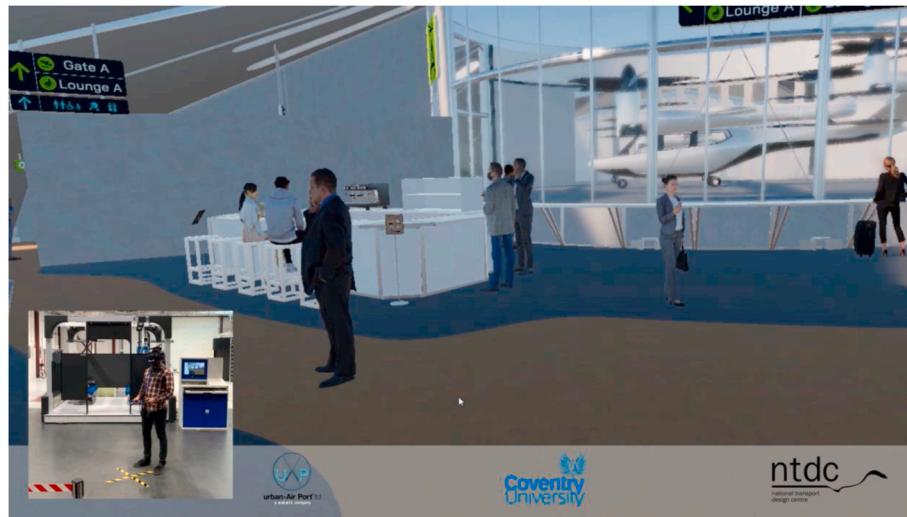


Fig. 4. First person VR view of the Urban Airport infrastructure, insert shows the experimental setup.

2.4. Customer journey scenarios presented in VR

The six scenarios were based on ‘exciters’ or ‘pain points’ identified in previous research (Jankovec, 2014; Kraal et al., 2009; Popovic et al., 2010; Zdanowicz et al., 2021). ‘Pain points’ are points of increase stress and lower satisfaction, for instance arrival at the airport and passing security procedures. Whereas exciters are points of enjoyment, and can be related to retail (shopping or cafes) or exciting design features. The Latin Square design (Keedwell and Dénes, 2015) was implemented to choose and assign scenarios to each person, the exception was scenario S1 which was always administered first as it was timed.

The six customer journey scenarios were developed with the core principle of accurately replicating ‘exciters’ and ‘pain points’ in existing air travel. The scenarios were also informed by previous research by the authors that investigated different personas for air travellers, with storyboards to illustrate their respective customer journeys (Zdanowicz et al., 2021).

Based on this previous research the six customer journey scenarios developed were:

- (S1) Pain point, frequent traveller: *You have got 10 min to get to Gate A, check-in using a facial scanner and to board your eVTOL.*
- (S2) Exciters, less frequent traveller: *Go and pick a magazine, get a coffee and go to your Gate B.*
- (S3) Exciters, working while travelling: *Go and pick a coffee and find a quiet spot in a designated area to work on your laptop.*
- (S4) Exciter and pain point, travelling with a child: *You are travelling with your child. Get them a hot chocolate and play a game. Before you board your eVTOL, find the toilets and nappy changing facilities.*

(S5) Exciter and pain point, exit task 1: *You have landed at the urban airport. Your taxi is waiting for you. Leave the building as soon as possible.*

(S6) Exciter and pain point, exit task 2: *You have landed at the urban airport. Get a coffee and magazine and leave the building.*

After experiencing each scenario participants were asked one open-ended question and two closed questions to get insights on their experience with the urban airport. All the questionnaires and forms were in paper form. The full experimental procedure timeline is presented in Fig. 5.

2.5. Measures

The following open-ended question was asked after each of the six scenarios to investigate participants’ opinions relating to the user experience of the scenario they just completed in the urban airport:

- Q1: *What do you think about the scenario you have just completed?*

Participants were then asked to answer the following two 5-point Likert scale questions (ranging from 1: *not at all* to 5: *a lot*):

- Q2: *How easy did you find it to navigate through the environment?*
- Q3: *How easy did you find it to complete the scenario?*

In order to assess the participants’ level of immersion and presence within the virtual environment, an adapted and shortened version of the Witmer and Singer (1998) Presence in Virtual Environments

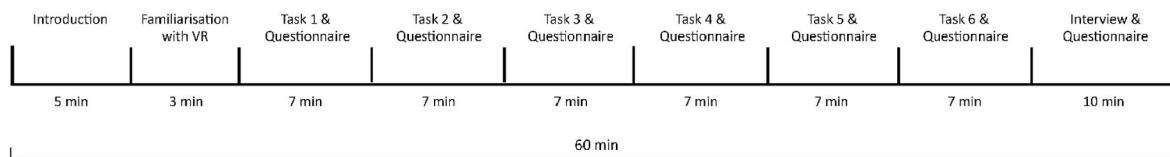


Fig. 5. Experimental procedure timeline.

questionnaire was administered. Four relevant questions were asked once, after all scenarios had been completed, and scored on a 5-point Likert scale (ranging from 1: not at all to 5: a lot):

- Q4: How realistic did you find the proposed virtual environment?
- Q5: How responsive was the environment to actions that you initiated or performed?
- Q6: How involved were you in the virtual environment experience?
- Q7: How quickly did you adjust to the virtual environment experience?

3. Analytical strategy

Inductive content analysis is an open approach (Kyngäs, 2020) used to explain the meaning of qualitative data and generate knowledge (Hsieh and Shannon, 2005; Schreier, 2012). It consists of determining a unit of analysis to identify open codes in the data. These open codes are compared according to their differences and similarities and subsequently classified in sub-themes. These sub-themes are then organised into first-order themes, which are further combined into second-order themes. Depending on the nature of the data and the concepts elicited by individuals, second-order themes can be organised into broader categories, namely general dimensions. All the themes and dimensions identified are named using content-characteristic words.

Two researchers initiated the inductive content analysis by familiarising themselves with the data, as this is of paramount importance to allow a broader understanding of the transcripts to emerge (Gale et al., 2013). Through an iterative process, the two researchers who coded the participants' responses returned to the original transcripts several times to make sure that the results were linked to the data that they analysed. Then, each researcher peer debriefed each other's coding to strengthen the validity of the results. The VR nature of the research, rather than physical interaction with an existing piece of transport infrastructure, was acknowledged to better understand the meaning of the responses and interpret accordingly. Finally, the researchers tested the coding frame to assess its validity (i.e., the extent to which the categories describe the material) and consistency (i.e., categories do not overlap with one another) for each themes and associated sub-categories. After applying a few minor changes, the researchers agreed on the final-version of the coding frame that was utilised for analysis.

4. Results

The first section of the results will present participants' responses to closed questions, whereas the following sections describe the inductive content analysis in the following order: (1) raw data themes, (2) first-order themes, (3) second-order themes, and (4) general dimensions. One participant dropped out from the study and did not answer the questions in four instances (i.e. missing data).

4.1. Responses to closed questions

The scores for Q2 (easy to navigate through the environment) and Q3 (ease to complete the scenario) for the six scenarios participants experienced are summarised in Table 1. Generally, they have found it easy to navigate in the environment and complete the scenarios based on a scale ranging from 1 (not at all) to 5 (very).

Table 1

Quantitative results from Questions 2 to 7. Questions 2 and 3 asked at the end of each scenario; Q4-7 asked at the end of all scenarios.

Questions	Mean	SD
Q2:S1 (easy to navigate)	4.70	0.66
Q2:S2	4.80	0.52
Q2:S3	4.47	0.51
Q2:S4	4.25	1.02
Q2:S5	4.60	0.60
Q2:S6	4.11	0.74
Q3:S1 (easy to complete)	4.90	0.31
Q3:S2	4.90	0.31
Q3:S3	4.58	0.61
Q3:S4	4.30	0.98
Q3:S5	4.80	0.41
Q3:S6	4.37	0.68
Q4 (Realistic virtual environment)	4.35	0.75
Q5 (Responsive)	4.40	0.60
Q6 (Involved)	4.85	0.37
Q7 (Quickly adapted)	4.75	0.44

Note. There are missing values for Q2:S3, Q2:S6, Q3:S3 and Q3:S6 because the participant dropped out from the study.

4.2. Inductive content analysis – raw data

A total of 118 relevant transcripts were extracted from the corpus, including 20 transcripts for Scenario one, two, four and five, and 19 transcripts for Scenarios three and six. Similar transcripts were combined into 23 raw data themes. Table 2 shows the raw data classified into raw data themes, first-order themes, second-order themes and general dimensions with the associated frequencies.

Two transcripts were not related to any of these themes and were excluded from the analysis, as they were not deemed relevant in terms of the questions posed (e.g. "I feel a bit queasy", Participant 3 [P3]). These transcripts mentioned the instructions provided to the participants ("the instructions were easy to follow", P3) and the simulation environment ("it was an interesting environment", P20). Importantly, data saturation was achieved while processing the transcripts from the final scenario (i.e. S6, and within the final 19 transcripts of the 118 collected) as no new codes were identified within the data, they were either redundant or already collected.

4.3. First-order themes

The raw data themes were examined to identify those linked with the user experience in the urban airport. Those not linked were removed from the analysis. Subsequently, one or more first-order themes were extracted for each transcript, leading to the compilation of nine first-order themes (see Table 2). These first-order themes were related to the layout of the building (e.g. arrival & departure, dimension and facility) and, at a granular level of scrutiny, the elements within the layout that affected the users' navigation (e.g. wayfinding, comprehension and visibility). The definitions of each first-order theme is provided in Table 3.

4.4. Second-order themes

The nine first-order themes were merged into four second-order themes that were related in terms of topic, but also suggested broader

categories (see Table 2). In general, these second-order themes referred to the layout of the urban airport ('it is a small airport and there are only two gates', P2) and the attributes of the objects and areas within ('The Gate A sign is really big, which is good. It isn't pretty but it's required', P9).

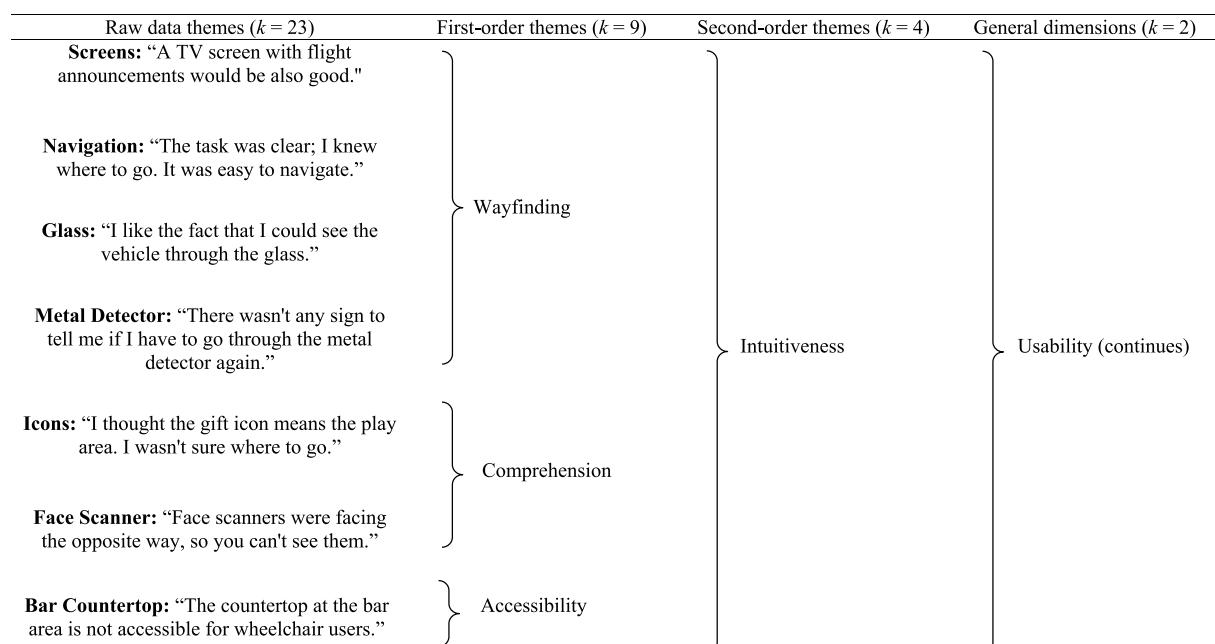
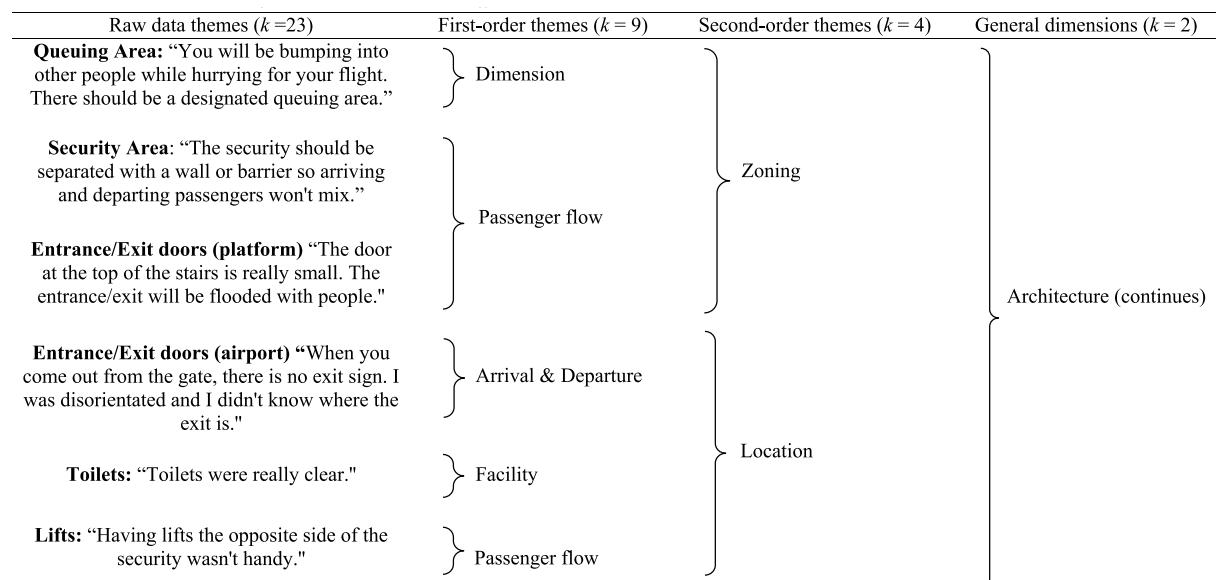
The first set of second-order themes elicited by the participants were grouped into two categories: 1) *Zoning* and 2) *Location*. *Zoning* referred to the separation of the urban airport in areas depending on their function, purpose and characteristics ('the security area should be separated with a wall or barrier so arriving and departing passengers won't mix', P13). *Location* was related to the position of a room, service or area within the general arrangement of the building ('face scanners were facing the opposite way', P9). In terms of user experience, these second-order themes could either be positive ('it was easy to leave the building', P5) or negative ('having lifts the opposite side of the security area was

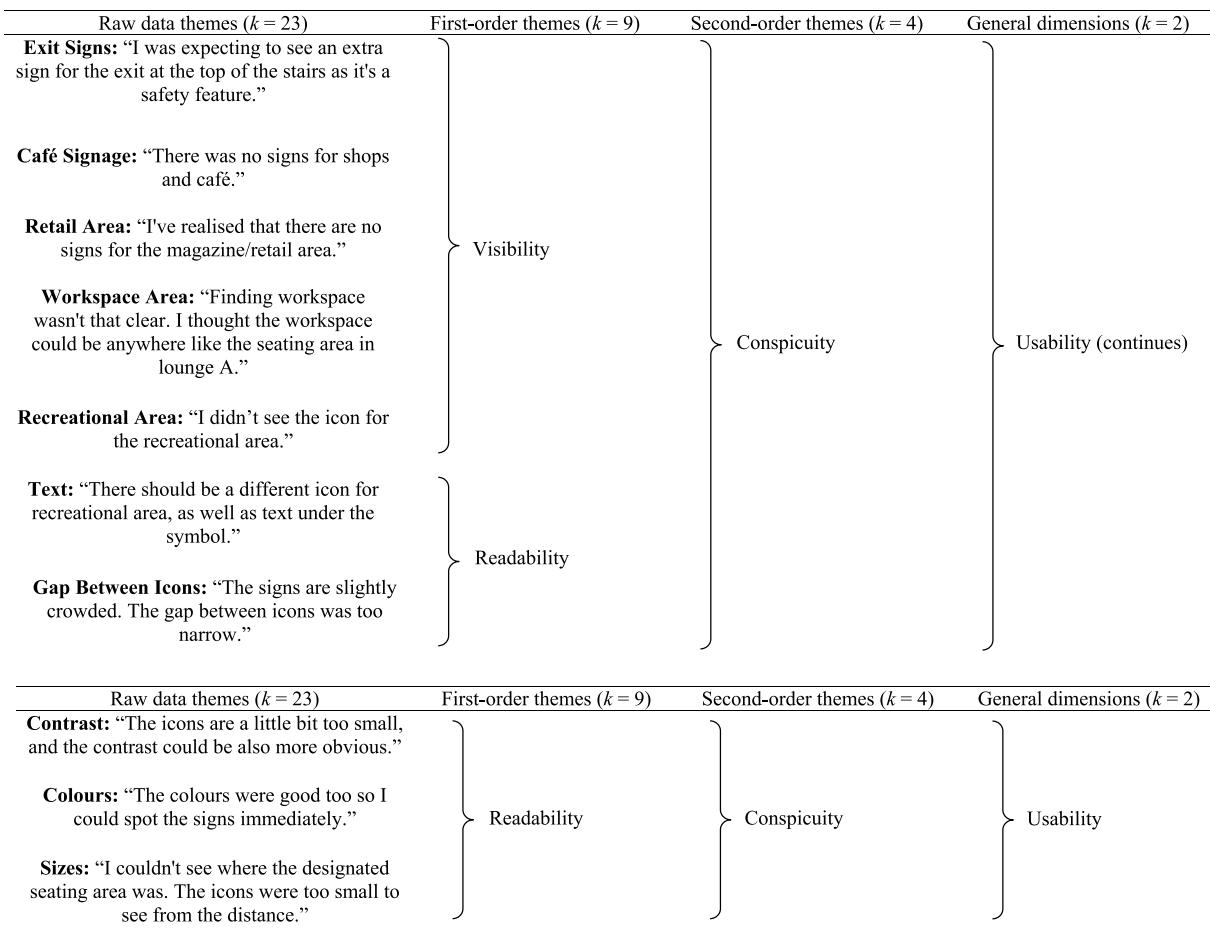
not handy', P6).

The following set of second-order themes (Table 1), were defined as 3) *Intuitiveness* and 4) *Conspicuity*, which also included positive and negative raw themes. It provided more details into specific objects of the urban airport, such as signs ('the signage was clear', P7), devices ('[...] having screens for flight announcements', P11) and material ('I took time to look through the glass', P14). *Intuitiveness* evoked how participants found their way in the urban airport ('I knew where to go. It was easy to navigate', P17), whether they understood where the different areas were ('the icon wasn't clear for the recreational area', P10) and if these areas were accessible ('the countertop at the bar is not accessible for wheelchair users', P6). The level of effort it took a user to comprehend the layout of the urban airport is the core principle of *intuitiveness*. Users' vision and objects appearance were brought to the fore to define the *conspicuity* second-order theme. *Conspicuity* was defined as the

Table 2

Results of the inductive content analysis. The raw themes labels are in bold and examples in quotation marks.





quality of an object or visual element of being visible, discernible and readable (i.e. when textual). It encompassed the size ('the icons were too small to see from the distance', P13), the colours ('the colours were good too so I could spot the signs immediately', P10), and the contrast ('the contrast could be more obvious', P16) of a visual element (i.e., *readability*). *Visibility*, the other component of *conspicuity*, related to how clearly users could see objects and the range of unobstructed vision in a specific area ('there was no sign for shops and café', P20).

4.5. General dimensions

The four second-order themes (see Table 2) were the combined based on their conceptual relevance, and classified under General Dimensions. Consequently, two distinct dimensions were conceived from the verbatim collected in response to the six experimental questions. They were labelled: 1) *Architecture* and 2) *Usability*.

Architecture is formed of the second-order themes *zoning* and *location*. We defined *architecture* as the design of a building including its structure, the location of its areas and the position of its physical access points (e.g. doors, lift, retractable barrier posts etc.). It also encompasses the way people circulate within the building. *Architecture* themes elicited by participants mentioned how the layout of the urban airport had or could affect their journey in terms of progression ('you will be bumping into other people while hurrying for your flight', P13), delimitation ('there should be a designated queuing area', P13) or area position ('I didn't think to go to the lounge as the gates are before that area. Not like at airports where lounges are around the gates', P10).

Of key importance to this paper were participants' insights on the quality of the user experience when interacting with the urban airport facilities and signage. These verbatim were categorised under the *usability* dimension, which is composed of *intuitiveness* and *conspicuity*. *Usability* is about effectiveness, efficiency and the overall satisfaction of the user. For example, some participants made a positive evaluation of the signs ('overall, signs are good', P2) when they helped navigating in the urban airport ('I knew where to go', P3), but other comments were more negative/constructive concerning their design ('this icon wasn't clear for the recreational area', P6) or the lack thereof ('if there could be any signs in front of me saying you need to scan your face first, that would be great.', P18). The *usability* dimension was the micro level of design, whereas *architecture* was the macro level.

To summarise, the quantitative data showed that participants found it easy to navigate in the urban airport and complete the different scenarios they were presented with. Based on 23 raw data themes, the inductive content analysis elicited nine first-order themes, which were then classified into four second-order themes that, in turn, fed into two general dimensions. These dimensions pertained to architecture and usability of a virtual urban airport from a traveller's perspective.

5. Discussion

The main purpose of this research was to examine travellers' experience after navigating a novel urban air mobility (UAM) infrastructure built within a virtual reality (VR) world. Results from the immersion and presence questionnaire revealed that the virtual environment used in

Table 3

First-order themes elicited by participants and their user derived definitions.

First-order theme	User derived definition
Dimension	Size of an area.
Passenger flow	Movement of passengers through the space in order to complete a specific process or function.
Arrival and departure	Gates A and B of the urban airport allowing passengers to enter and exit the building.
Facility	Toilets and restrooms designed for public use.
Wayfinding	The process of identifying and following a path from the origin to the destination.
Comprehension	The extent to which individuals understand where to go based on the signage or area configuration.
Accessibility	How the design of an object allows individuals with various profiles to use it for the purpose it was designed for.
Visibility	Refers to how clearly objects can be seen and the range of unobstructed vision in a specific area.
Readability	How graphics elements improve perception and comprehension of the sign.

this study was rated very positively by the participants, evidencing credibility and validity for the use of VR as tool to better understand user experience and interaction with future transport infrastructure (Table 1). Participants' responses were collected after the completion of six customer journey scenarios. Evidence presented in this paper suggests that travellers had a rich, multi-level user comprehension of the design implications for such an urban airport (aka Vertiport). The results showed that travellers identified the main activities realised in an urban airport as well as the potential sources of satisfaction and limitations. There are two types of activities in an airport (Kraal et al., 2009; Popovic et al., 2010) and, by extension in an urban airport. Firstly, processing activities are related to complying with the requirements for boarding a plane (e.g., checking in, security screening and boarding). Secondly, discretionary activities encompasses everything else, including waiting, refreshments and retail.

From a theoretical perspective there is also considerable value in conducting the user experience study in VR to better understand the concepts that we were assessing. From a spatial processing perspective, Lynch's concepts of legibility and imageability (1960) provide a framework to contextualise our results. Legibility is defined as the capacity of individuals to understand the layout of a given environment. Our participants tended to report that they understood the layout of the urban airport, with its pros ("I knew where to go") and cons ("the security should be separated"). This demonstrates that, from a user perspective, the urban airport was legible, but not without design flaws. Therefore, a legible environment is not necessarily optimal, but desirable. Imageability refers to the extent to which people find it easy to create a mental image of an environment, word or object. Imageability is affected by landmarks, which are memorable man-made or natural objects such as signs or hills. Participants commented on the signs designed for this study, mentioning that they sometimes lacked ("there was no sign") or were not clear "I thought the gift icon means the play area". It seems that signs are useful to guide users, but more distinctive indications, such as dimmed lights for a workspace or blinking LEDs for an entertainment space, could improve imageability and replace suspended traditional signs which are sometimes crowding the visual environment.

5.1. Hiding the 'pain points' revealing the 'exciters'

Previous research by the authors and conducted for this project outlined personas and storyboards for users of urban airports (Zdanowicz et al., 2021). In the present research, 'pain points' and 'exciters' were mapped across six customer journey scenarios. In order to deliver an enhanced experience for this new mode of transport, a principle of the design of the urban airport and supported by our research was to make this new infrastructure development a user-friendly place to travel to and from. To demonstrate this, and as illustrated in Fig. 6, the first

thing people saw when they entered the building was the central 180° glass façade that encircled the landing area with the eVTOL on display. Also available in the foyer area were retail and refreshment areas, transforming arrival at the urban airport into an exciting and thrilling experience from what had traditionally been a stressor, as illustrated by participant 18 who observed "I like the fact that I could see the vehicle through the glass". Scenario 2 that was presented in VR was designed to replicate this 'exciter' where a less frequent traveller would use the retail areas then go to their gate. In support of the qualitative data, this scenario was rated highest for ease of navigation (4.90 out of 5) and joint top for ease to complete (4.90). This research highlights that discretionary activities, which could also be considered excitors for customers, should be brought front and centre to enhance the customer experience.

There is an inevitable flip side to this reasoning of the traditional architecture of airports to reveal the excitors, and this was highlighted by participant 13 who said that "The security should be separated with a wall or barrier so arriving and departing passengers won't mix." Further efforts in the design of infrastructure for urban airports could focus on how we optimise passenger flow in smaller spaces to negate the possible side-effects of moving security check-in towards the peripheries of airports. Despite this feedback, within scenario 1 – which is a typical pain point for travellers being a time limited boarding of an aircraft – the data presented in Table 1 suggests that this task was rated as the joint top easiest to complete (with a score of 4.90 out of 5) and second most easy to navigate (4.70).

5.2. The macro to micro dichotomy of design

It was not surprising that participants mentioned processing activities in depth, especially the security screening procedure. What was more unusual were the comments on the arrangement of the area. The main concern was on the delimitation of this area, when participants were concerned about preventing travellers going in opposite directions from bumping into each other. This was a relevant remark in terms of design and demonstrated that travellers not only had certain expectations as regards their travel experience, but also had some expertise in how a security screening area should be organised. These type of comments could be categorised at a macro-level since they elicited concerns on an area or access point rather than on specific objects and devices. On the contrary, comments at the micro-level provided feedback on the signage and icons, which was focused on a single element rather than an area.

The thematic analysis from the VR study revealed that the segregation of Processing (i.e. security and check-in) and Discretionary (i.e. retail) activities did not meet the existing mental models of air travel. Questions were raised around arrivals and departures from the same Gate, a lack of 'one-way' system, and 'where' check-in was located. This expectation of air travel is interesting, as newly redeveloped transport hubs have adopted a mixed approach, and could be seen equally as a social, retail or dining 'destination'. For example, at London Kings Cross St Pancras shopping and dining first greet passengers, with arrivals and departures congregating in the same open spaces. However for air travel this is not the norm. This is where the general dimensions identified within the paper of Architecture and Usability intersect. Whilst it is unlikely that urban airports (as envisaged in this project) will be a 'destination' in itself, the opportunity to redesign the user experience within future UAM infrastructure gives us the opportunity to make them more than just a function transport hub, but spaces that people actually enjoy visiting.

This dichotomous classification of user experience, i.e. macro comments about the design of areas and spaces relating to processing activities, and micro comments relating to singular aspects of the design for discretionary activities, is novel in the area of air mobility and will offer insights to further the design of future mobility infrastructure solutions.



Fig. 6. Illustration of the urban airport foyer from a user perspective in VR.

5.3. Signage levels of abstraction

A core design principle adopted by the authors for designing the signs for wayfinding was based on levels of abstraction of information. Levels of abstraction or abstraction hierarchies (Bisantz and Vicente, 1994) have been used in Computer Science and interface design to categorise information and define the levels of complexity through which a system is viewed. For this paper we have adopted three levels of abstraction, with the highest level being *Purpose*, then *Function* and finally *Form*.

- Purpose: These are the highest levels of abstraction used for the signage. They were used to direct people to the correct general area of the urban airport, in our case away from the foyer/entrance area and towards Gates A or B. Limited details were included within these signs, with the aim to reduce time standing to read lots of information, to move people to the correct area and away the main foyer area and towards the correct zone. This is illustrated by Figs. 6 and 7, which are the first signs people see when they arrive in the foyer.
- Function: Once we have travellers in the right areas and not standing in the foyer, which will be the area with the highest foot flow, we start to provide more detail regarding the functions that people may want to achieve, such as find toilets or working areas.
- Form: These are not directional signs but say what locations you are currently at or entering, for example this is the recreational area.

The unilateral benefit of using VR in this form of user testing was that we could test these design hypothesis with real (albeit surrogate) end users before the physical infrastructure had been built. This process highlighted some positive and negative aspects of the signage designed. Signs that defined the *Purpose* of the visit to the urban airport were well received, with participant 3 saying “The task was clear; I knew where to go. It was easy to navigate”, and the responders giving no negative comments regarding the high level zoning feedback. There were comments around the more traditional airport signage, and the expectations that this would be present within the urban airport. Despite there being a lower number of passenger flights per day from these type of urban airports, and only a limited number of gates for flights to take off and land from, participant 11 highlighted the need for traditional airport signage “A TV screen with flight announcements would be also good”.

An important finding from this study is based around a series of constructive comments from the participants, primarily around the icons related to the signage around *Functions* that people may wish to undertake. The philosophy to reduce complexity of the initial signs that

people are faced with when entering, led to additional support being needed when viewing these secondary, functional signs. In Fig. 7 below, this would be the icons in blue (for toilets, recreation and retail areas) underneath the Gate and Lounge A sign on the upper left of the image. Participant 7 commented that “I thought the gift icon means the play area. I wasn’t sure where to go”, participant 15 “I couldn’t see where the designated seating area was. The icons were too small to see from the distance”, and participant 7 “There should be a different icon for recreational area, as well as text under the symbol”. These subjective responses are supported by the quantitative data which suggest that scenario 4 (travelling with child, get them a drink, find recreational rea and use toilet facilities) was rated lowest in terms of ease to complete (4.30 out of 5) and second lowest for easy to navigate (4.25). These results suggest that we should consider switching the priority order of the list of functions within the sign and have bigger and more prominent icons and wording. This information needs to be viewable from a greater distance than we initially expected to support users finding the functional areas and subsequent activities that they want to achieve while in the urban airport.

Regarding the *Form* signs, or those that state what the locations are and are not directional, participants were positive regarding the signs for the toilets that was said to be really clear, but were less appreciative of the selected icon for the retail area. All of which are constructive comments for future work. One very important consideration for this specific iteration of an urban airport would be adaptive ‘Exit’ signs when leaving the eVTOL, with Participant 9 stating “I was expecting to see an extra sign for the exit at the top of the stairs as it’s a safety feature”. Within this layout either Gate A or B could be used for embarking passengers, meaning we want passengers to disembark from the opposite Gate. There was some confusion as to which Gate exit people should leave the landing platform from, and as this could change from flight to flight, and adaptive exit sign should be considered. This lack of clarity when exiting of the eVTOL was further highlighted by the quantitative data from the closed questions around ease of navigation and scenario completion. Despite being generally rated as positive on the Likert scale, Table 1 indicates that Scenario 6 (landed, exit, get coffee and leave building) was rated lowest for ease of navigation (4.11 out of 5) and second lowest for ease of completion (4.37).

5.4. Limitations and future work

The unique aspects of this VR study also led to some limitations. Firstly, participants used a combination of hand held controllers and smaller positional body movements to move between zones of the urban

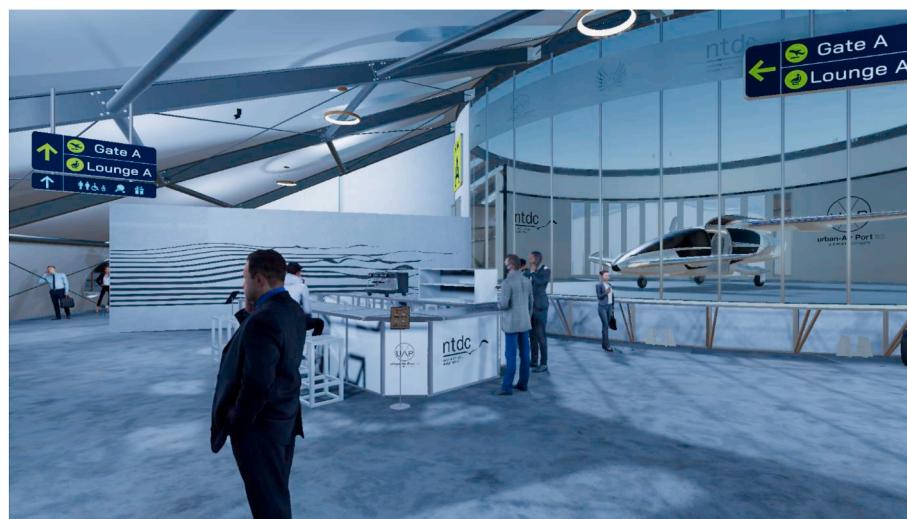


Fig. 7. User point of view of the Purpose signs (top right) and Function signs (top left) that can be seen on entry to the urban airport.

airport, which may have impaired the natural exploration of the infrastructure. Secondly, the aim of this study was to understand user experience with a focus on the customer journey and wayfinding, therefore data around passenger flows and thoroughfares was not considered but highlighted as being important. Thirdly, only one of our participants had mobility impairments (namely a wheelchair user), which limited us in collecting valuable insights on the accessibility of the infrastructure. Additionally, despite the researchers using the HTC VIVE Pro Eye headset (i.e. with eye tracking included) this data has not yet been analysed. However, future research could examine eye glance behaviours to better understand navigation and sign recognition through dwell times or frequencies of glance transitions.

Future research should investigate aspects relating to the sign design within traditional and urban airports. Whilst we followed best practice and guidelines for icon design, signs comprehension might be enhanced if they were designed against compatibility criteria (i.e., spatial, conceptual, movement and modality; [Sanders and McCormick, 1993](#)) and physical representation criterion ([Shinar et al., 2003](#)), as previously illustrated for road traffic signs ([Payre and Diels, 2019](#)). The novelty of this research is that the user experience within this new transport infrastructure was examined using an immersive VR environment.

Furthermore, results showed that users were concerned about the layout of the airport and anticipated what was likely to happen. This illustrates how users not only test mobility, but also facilitates the design of mobility solutions before they even exist, and highlights the importance of adopting user-centred design methods in the design of future transport systems. Future research could expand on this further by investigating users' expectations and experiences on future transport hubs, not only a place of transit, but as a social and retail 'destination', and subsequently how best to design multipurpose spaces.

6. Conclusions and recommendations

Human factors research can play an important role in the successful design of infrastructure to support future mobility. This paper presents data from a truly novel application of Virtual Reality (VR), where user experience and wayfinding were evaluated within an emerging future transport infrastructure to support urban air mobility (UAM). Findings from the inductive content analysis demonstrated firstly that the intelligent design of signage was of paramount importance to support first-time users understand the layout, and secondly that the user experience can be enhanced by carefully considering the pain points and excitors from current air travel. Practical considerations for the design of specific signs and icons are presented to help inform the design of future

mobility infrastructure solutions, through improving user experience before they are physically deployed.

Key recommendations relating to the design of future transport systems identified from this paper are:

- Using high fidelity, immersive virtual environments presented in extended reality are an ideal tool to understand user experience and interaction with built environments.
- Revealing the key 'exciters' for passengers using innovative mobility infrastructure could enhance passenger experience.
- Adopting different levels of abstraction for signage information could be a successful method to improve passenger flow from busy areas, but support needs to be offered for users to facilitate the secondary functional activities within urban airports
- Users' traditional expectations of airports and their information needs should be considered, even in innovative mobility infrastructure solutions. However, this does not have to be delivered by traditional means (i.e. signs on sticks) but could be achieved, for instance, through innovative and interactive flooring or augmented reality (AR) for personalised wayfinding information.
- This paper highlights the benefits of engaging users at an early stage of the design process to ensure that future transport infrastructure will be accessible, easy to navigate and a pleasure to use.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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