# What you see is (not necessarily) what I see—Pervasive AR for Public Displays

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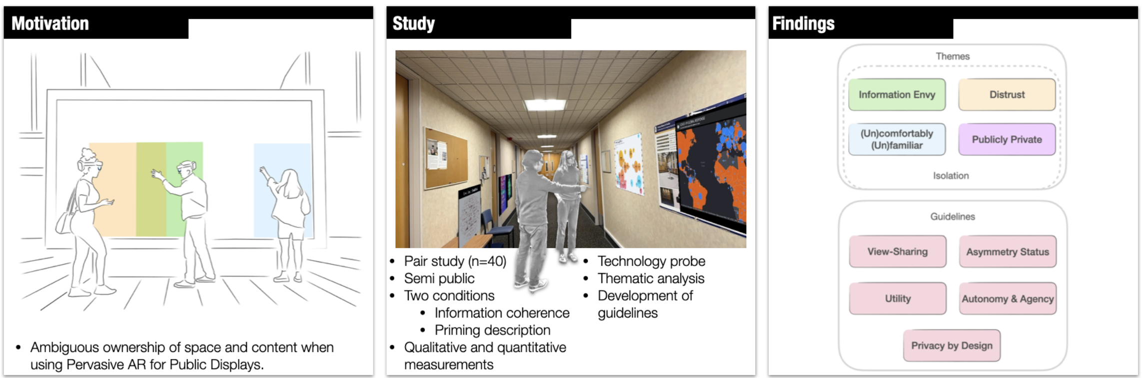


Fig. 1. Visual abstract summarising our research on Pervasive AR for enhancing public displays. This study provides design guidelines for future Pervasive AR systems, helping designers proactively address concerns related to delivering tailored information to users in public spaces, particularly issues such as isolation.

Augmented Reality shows the potential to emerge as the next step of wearable computing, with AR headsets turning into an everyday casual commodity. Thus, evolving to Pervasive AR as an omnipresent and continuous augmentation of our environment. We exposed 40 participants in pairs to a near-future scenario, displaying augmented public displays with a purpose-built Pervasive AR technology probe, and explored behavioural changes that arise from using Pervasive AR with symmetric and asymmetric information overlays. We developed four themes which we call Information Envy, Distrust, (Un)comfortably (Un)familiar, and Publicly Private. Among the various concerns raised, the isolation and divide that tailored content could create was identified as the most pressing issue. This needs to be addressed in the design of future Pervasive AR systems. Therefore, we recommend implementing a reliable view-sharing mechanism, ensuring users are always informed about system status, prioritising utility over novelty, maintaining users' autonomy and agency, and practising privacy by design.

CCS Concepts: • **Human-centered computing → User studies**.

Additional Key Words and Phrases: Human-centered computing, Interaction paradigms, Mixed/ augmented reality, Ethics

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## 1 INTRODUCTION

Over the last couple of years, we have seen a rise in interest in Augmented Reality (AR) [13, 39, 40]. AR devices and technology were initially explored as a future display technology [45] but, more recently, have been imagined as the next evolution of mobile and wearable technology [13, 17, 39, 40]. While mobile phones are typically in our pockets and require us to actively engage with the information by taking the phone out of our pocket, future AR interfaces are envisioned to have a form factor closer to traditional glasses that can be worn continuously, providing a permanent hands-free information display. Grubert, Langlotz, Zollman and Regenbrecht (2017) [17] coined this trend towards an omnipresent and continuous augmentation of our environment as Pervasive Augmented Reality (Pervasive AR).

If realised, the vision of Pervasive AR opens many new applications and can potentially change how we interact with digital information and our physical environment. Many examples of research explore Pervasive AR from a technical point of view (e.g., focusing on large-scale tracking and adaptivity [30]), from an interface point of view (focusing on adaptive interfaces [32]), and from an ethical point of view [6, 13, 17, 40]. However, only a few approaches look into the challenges that arise when Pervasive AR becomes a reality and is increasingly used in public contexts. For example, using Pervasive AR allows us to put information displays almost everywhere—which is a vision shared with the interactive public displays research community [2]. Interactive displays are typically physical information displays that are embedded in our everyday environment, including our homes and public spaces. They draw the user's attention by displaying certain information. As the user engages more with the displays, the display recognises this engagement and then adapts the information display accordingly (e.g., by showing additional details or even more personalised information). Engagement levels are typically distinguished by the distance between the user and the display (see Figure 2 A) and generally range from public to private. Pervasive AR has the potential to implement this vision using wearable displays that are used to overlay graphical content, thus making physical displays obsolete. However, this transition from traditional interactive displays to Pervasive AR enhanced public displays introduces several challenges. For example, with traditional interactive displays in a public context, if the display switches to a more personalised information display owing to user engagement, this is usually clear to bystanders even if they might not immediately see the information displayed itself (e.g. because it is blocked by the user standing in front of the display). This relationship is less understood and noticeable in Pervasive AR, potentially affecting trust in the displayed information and used technology in general (see Figure 2 B).

In this work, we aim to understand better the effect of using Pervasive AR when implementing the concept of interactive public displays. Specifically, we investigate the ethical implications of tailored information delivered on Pervasive AR-enhanced Public Displays. For our studies, we prototypically implemented a Pervasive AR scenario that demonstrates the usage of Pervasive AR-enhanced public displays in a public setting. Within a mainly qualitative study, participants explored our study environment together, using current-generation head-mounted displays. Similar to traditional interactive public display approaches, we differentiate between engagement levels with the displayed information by adapting the displayed information based on user proximity. However, in contrast to interactive public displays, we investigated the perception of displaying the same information to all the users vs. showing different information to each user. Through an inductive thematic analysis [5, 7, 46], we agreed on four main themes outlining the implications of information privilege, and thereby, the divide it causes, the critical factors that would affect the acceptability of Pervasive AR specifically in public spaces, and the attitudes towards receiving tailored content.

Overall, our work has the following contributions. We A) provide feedback from a qualitative study exploring the potential challenges when using Pervasive AR to realise the vision of interactive public displays in public environments. We also B) discuss the results and design recommendations for future research on mitigating some of the identified issues. To the best of our knowledge, this is the first exploration of Pervasive AR to implement the concept of interactive public displays, particularly emphasising the differences between the traditional models of user engagement and usage patterns used in the interactive public display community.

## 2 RELATED WORK

AR technology is steadily moving away from one-off, single-purpose applications to be more ubiquitous and versatile; thus pervasive [39]. Grubert, Langlotz, Zollman and Regenbrecht (2017) defined Pervasive Augmented Reality (Pervasive AR) as,

"*... a continuous and pervasive user interface that augments the physical world with digital information registered in 3D, while being aware of and responsive to the user's context.*" [17]

Another notable difference is that the use of AR systems is more generic, while Pervasive AR systems tend to be more tailored towards the user. Pervasive AR systems focus on delivering value to their users by overlaying meaningful information that is relevant to the user in a timely manner. Therefore, Pervasive AR systems are required to understand and adapt to the user's context regarding user requirements and situation [17]. Therein lies the most vital difference between traditional AR and Pervasive AR.

However, as Pervasive AR systems become commonplace, it is essential to look into how they will be adapted into society and the ethical concerns that may arise with them. Pervasive AR, along with other wearables, has been extensively investigated for its social acceptability, with valuable insights into the discussion on ethics and Pervasive AR.

### 2.1 Social Acceptability of Pervasive AR

These studies on the social acceptability of Pervasive AR have favoured themes such as how different gestures and overlays would be perceived by the users of the devices, how the use of these devices will affect social interactions, and how the devices will impact bystanders. Kelly and Gilbert (2016) [26], in developing a scale predicting social acceptability, define the social acceptability of a wearable as the *absence of negative reactions or judgements from others*. Schwind, Deierlein, Poguntke, and Henze (2019) [43] and Schwind and Henze (2020) [44] taking a different approach, explore the ability of stereotypes as defined by the Stereotype Content Model (SCM) to determine the acceptability of wearables.

Social acceptability is not limited to the device user but also extends to the bystanders. Thus, many studies have explored different dimensions of how social interactions between device users and observers would affect the social acceptability of AR devices. For example, these studies have investigated the influence of the positioning of notifications [42] and different input modalities [1].

A common discussion related to the social acceptability of AR devices focuses on the device's ability to record the user's surroundings and the continuous collection of data [8, 12, 21, 29, 50]. Several studies focused on the indication of the recording status and importance of consent from bystanders and its implications on social acceptability [28, 29].

The potential concerns regarding the upcoming technology are not limited to social acceptability but also to ethics.

### 2.2 Pervasive AR, Ethics and Social Impacts

Ethics in Pervasive AR have only been explored in limited work (eg:[39, 40]). Regenbrecht, Zwanenburg and Langlotz (2022) [40] have investigated how Pervasive AR systems would affect society and the importance of addressing these concerns in advance. Their focus mainly revolves around covert data collection and exploitation.

In a more recent empirical study, Regenbrecht, Knott, Ferreira and Pantidi (2024) [39] explore how users and bystanders would perceive the ethical implications of Pervasive AR. The study revealed the creation of a divide among users and non-users due to privileged access to information. The authors also noted the importance of following an ethics-conscious process throughout Pervasive AR system design and development to mitigate potential issues. Moreover, they emphasise the importance of including the public in the design and development decisions of Pervasive AR systems.

Eghtebas, Klinker, Boll and Koelle [13] explored the malicious and deceptive potential outcomes of Pervasive AR, such as the risks of targeted attacks on persons who are unaware, inappropriate suggestions made via embedded virtual visuals, altering a user's perception of their surrounding, and more. Furthermore, they identified potential remedies for these risks that can be integrated into system design, such as the option to opt out of certain content, focusing on personal rights protection, and the introduction of ephemerality to augmentations to ensure users are always able to distinguish between the augmentations and reality.

In our study, we focus on the information inequity that may be created among users or collaborators in spaces that are otherwise regarded as shared. As identified by Eghtebas, Klinker, Boll and Koelle [13] Pervasive AR has the capability to convert shared experiences to asymmetrical experiences by overlaying different visuals for each user. This issue could be most prevalent in public spaces where we share the sentiment that we all see a common representation. However, Pervasive AR systems alter these spaces with augmentations specific to each user's preference—creating a sense of deception among the users.

Nevertheless, the concept of changing public displays has been explored before, independent of Pervasive AR, especially regarding ownership of the display and the stages of transferring said ownership.

### 2.3 Public Displays and Proxemic Interactions

In this study, we draw inspiration from previous studies in the domain of *interactive public displays*. Proxemics is one of the most discussed ownership transfer mechanisms for interactive public displays. Greenberg, Marquardt, Ballendat, Diaz-Marino and Wang (2011) [16] state that HCI has adopted the term "proxemics" and the four zones of proxemics introduced by the anthropologist Edward Hall. They further state that in ubiquitous computing, proxemics is not solely defined by distance but also by several other factors such as orientation and location. These interactions are made possible with the use of sensors and the context awareness of devices.

Early on, Vogel and Balakrishnan [47] explored the use of implicit interactions (such as proximity and orientation) as well as explicit interactions (such as hand gestures and touch inputs) to transition a display from a public ambient display to a personal display.

Marquardt and Greenberg [33] in their study discuss design challenges in proxemic interactions and how to mitigate them in terms of revealing possible interactions and identifying if an action is intended for a device or not. In addition to distance, much like Greenberg et al. (2011) [16], they too suggest taking into consideration the users' focus, motion trajectories, location and context awareness. They further explore the importance of privacy and security when transferring the ownership of a public display to a specific user.

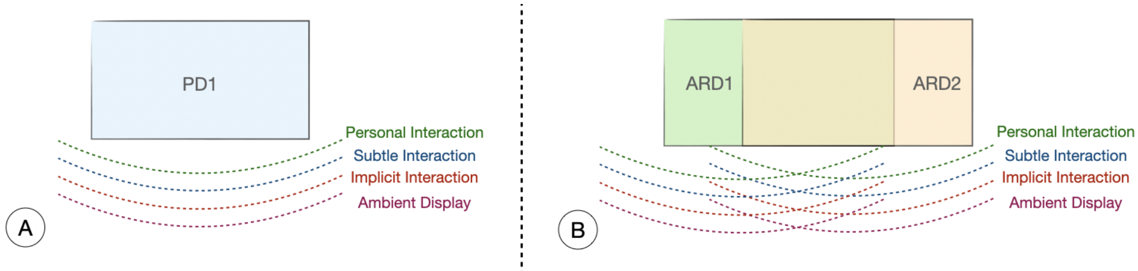



Fig. 2. (A) Traditional phases for interacting with interactive public displays (PD1) as described by Vogel and Balakrishnan [47]. (B) Pervasive AR-enhanced public displays as AR overlays (ARD1/2) introduce ambiguity as they can show the same or different information for different users.

Müller, Alt, Schmidt and Michelis (2010) [36] state that public displays should be able to attract passersby to interact and *"deal with issues of interaction in public"*. They further establish their own distinction of stages in interacting with a public display, ranging from passing by to multiple interactions and follow-up actions.

### 2.4 Research Gap

While empirical studies such as Regenbrecht et al. [39] have explored the ethical and perceptual aspects of Pervasive AR in public settings and offer valuable insights, their work predominantly focuses on the relationship between bystanders and users. Conversely, our study focuses on the relationship among Pervasive AR users, and especially how these relationships are affected by tailored content in public spaces, that are otherwise understood to be shared spaces with equal opportunity for consuming all available information within that space. Tailored content was delivered via Pervasive AR-enhanced public displays that employ proxemics similar to interactive public displays discussed earlier. While interactive public displays show clear ownership of space and content, it is more ambiguous when AR overlays are used (see Figure 2). This leads to the first research question of our study, ***(1) How will Pervasive AR affect society in public settings?*** We referred to the existing research findings on interactive public displays and their use of proxemic interactions, to design a sound Pervasive AR probe that enabled converting a public display to a personal display [2, 16, 33, 36, 47]. Technological probes are used in studies to facilitate learning about users and the use of a particular technology in the wild [23]. The use of a functional technology probe is less demanding for participants as they do not have to rely on their imagination alone, much like with illustrations, images, or video analyses [11, 44]. Secondly, we intended to investigate ***(2) How will the trust between users be affected by the consumption of user-specific information in public settings?*** We assumed that the asymmetry of information in public settings would create a certain level of distrust among users owing to information disparity, resulting in altered social behaviours. This leads to our next question, ***(3) How the altering social dynamic will affect the social acceptability of Pervasive AR?*** We presumed that the acceptability of Pervasive AR would be highly reliant on how the technology will alter our regular interactions with other users, and how the technology itself is shaped to accommodate such behaviours and mitigate potential concerns. Finally, by answering ***(4) What design recommendations can make Pervasive AR more acceptable in public settings?*** we will attempt to provide design recommendations to developers of Pervasive AR systems, so the potential issues concerning tailored information delivery in public spaces can be addressed to minimise the ramifications in the future.

Table 1. Table showing the condition administration of coherence of information based on the priming description of Pervasive AR-enhanced public displays

| | | Information Coherence | |
|---|---|---|---|
| | | Coherent | Incoherent |
| Priming Condition | A) Everyone will see the same information as they would in real life. | Group 1-1 | Group 1-2 |
| | B) You may or may not see the same things as the other participant. | Group 2-1 | Group 2-2 |
| | C) The public displays in the environment are enhanced with Pervasive AR. | Group 3-1 | Group 3-2 |

## 3 USER STUDY

This study followed a pair design where two participants were exposed to the Pervasive AR-enhanced public displays simulation. We focused on the users' perception of such displays and the coherence of information displayed on them. This study explored the effect of two variables: coherence and priming.

In real life, we perceive public displays to be shared, and the information displayed on them to be equally accessible to anyone in the general vicinity of the display. However, when considering Pervasive AR-enhanced public displays we can no longer assume that due to the context-aware nature of such systems. Hence, the first controlled variable of the study was coherence (also referred to as symmetry in Eghtebas et al. (2023)[13]) of the information displayed to the users—coherence describes if the information displayed to both participants is the same (coherent) or different (incoherent). The two levels of information coherence are dependent on a shared experience and are mutually exclusive. This variable was applied within-group.

The second controlled variable in the study was the priming description the participants received about Pervasive AR-enhanced public displays in terms of the coherence of information. This priming condition was applied between-group. The following are the three priming conditions as presented to the participants, along with their descriptions.

(A) *"In the environment you will see Augmented Reality-enhanced public displays. Like in the real world, the displays will show the same information to everyone, regardless of what AR glasses they are wearing."*
This description aligns with our current understanding of public spaces where the information available is equally accessible and shared among those present in that given space.

(B) *"In the environment, you will see Augmented Reality-enhanced public displays. Unlike in the real world, the displays might show the same or different information to different people depending on the AR glasses they are wearing."*
When Pervasive AR is widely adopted, due to its context-aware nature, each user will see specific information based on their personal interests that others may or may not see. And if proxemics are incorporated the change of information will depend on both the users' interests as well as their engagement with the display. Thus, by saying that they will see the "same or different information", we are describing the future view if Pervasive AR is widely in use.

(C) *"In the environment you will see Augmented Reality-enhanced public displays."*
This description aligns with the transitioning view that will follow the current understanding of shared and equally accessible information in public settings and preceding the future understanding of tailored content delivery. It defines a state where the population does not inherently understand the nature of context-aware, tailored content delivery of Pervasive AR systems. This priming was left open so as not to influence participants' existing understanding and perception of the technology.

### 3.1 Study Design and Procedure

Once the participants arrived at the location, they were given the information sheet outlining the specifics of the study to read and consent forms to sign.

Then, an experimenter verbally outlined the study, the duration of the study, and the withdrawal opportunities to the participants. Following that, an introduction to Pervasive AR was given and each participant was given a pair of Snap Spectacles [1] along with a battery pack (see Figure 3).

The study consisted of two sessions carrying out each condition (see Table 1). Before the start of the sessions, the assigned priming description was relayed to the participants. The task for the participant pairs was to take between 5 and 10 minutes to explore the Pervasive AR-enhanced public displays in the hallway together while discussing the content they saw in the environment. Additionally, they were instructed to refrain from discussing how the experience made them feel, to avoid them influencing each other. While the participants explored the hallway, an experimenter noted down observations of the participants' behaviour. Upon completing the viewing of the Pervasive AR-enhanced displays in the hallway, the participants returned to the study room to fill in the two questionnaires about trust and Pervasive AR acceptance, respectively. The second session followed the same procedure. Upon completion of both sessions, the participants answered the mini-questionnaire. Following the completion of the demographics forms, the participants took part in a 15–30 minute semi-structured interview. After the interview, participants were debriefed about how (regardless of the type of space or device) Pervasive AR systems will always deliver content that is tailored to the user. Following this, the study was concluded by thanking both participants for their time by offering them each a gift voucher from New World (New Zealand) at the value of NZD20. The study altogether took about 60 minutes to complete.

### 3.2 Apparatus and Implementation

A technological probe was developed using Lens Studio to organically simulate the influence of Pervasive AR systems in information dissemination within public settings. The probe was experienced on Snap Spectacles (2021). An external battery pack with a 10000mAh capacity was used to power the spectacles during the study. The technology probe consisted of two applications (referred to as "lenses" in Lens Studio) that employed proxemics as defined by Müller et al. (2010) [36]. We employed proxemics-based subtle interactions (focusing on a display) and direct interactions (moving closer to a display) with the displays. The displays consisted of posters and overlays as defined by Müller et al. (2010) [36] in their taxonomy for public displays. We displayed superimposed posters with content taken from the Information is Beautiful website[2] in a hallway, much like they would be displayed physically. The AR posters were aligned to the hallway walls and initialised by using a physical marker on the wall. The functions of the two applications were as follows:

**Coherent Lens** A connected (shared) experience where both participants viewed the same posters. Regarding proxemics, when at least one participant walked up to a poster, it changed to a new shared poster for both participants.

**Incoherent Lens** The posters, when viewed from afar, were the same for both participants (in line with the related work regarding proxemics). When a participant engaged with a poster by moving closer, it changed to a new poster for that respective participant only. This new poster remained individualised to each participant and was not shared.

[1] https://www.spectacles.com/new-spectacles/
[2] https://informationisbeautiful.net/

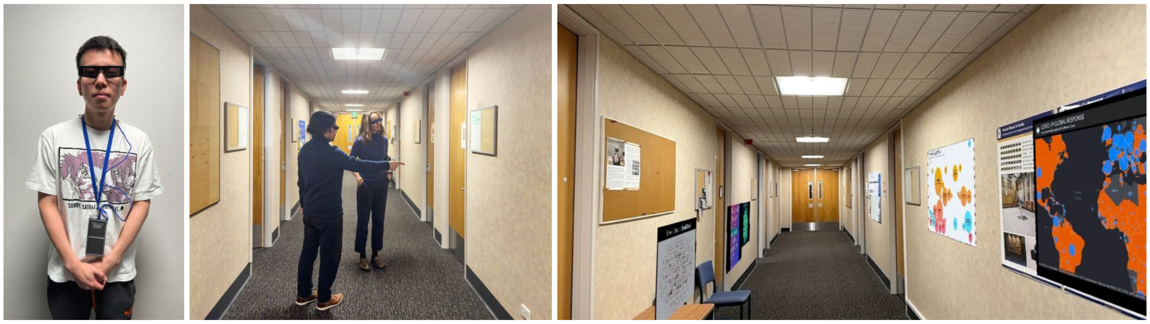


Fig. 3. (Left) Participant with PAR glasses and battery pack on lanyard. (Center) Participants in the study environment wearing Snap Spectacles while exploring information shown on Pervasive AR-enhanced public displays realised as AR overlays. (Right) Hallway with example virtual poster overlays.

*3.2.1 Questionnaires.* We administered four questionnaires in this study. Two questionnaires were filled out by the participants following each condition. All participants completed a demographic questionnaire about their gender, age, profession, ethnicity, prior experience with AR and a short questionnaire developed from the interview questions for this study (mini questionnaire).

Following each session the participants first answered the *Trust in Pervasive AR-enhanced Public Displays and Information Questionnaire*, to investigate the perceived trust in information following their Pervasive AR experience. The questionnaire was developed with items taken, adapted, and modified from Grazioli and Jarvenpaa (2000) [15] (originally from Jarvenpaa, Tractinsky and Vitale (2000) [25]). All of the above items, except for one question were answered on a 7-point Likert scale (from 1–7) ranging from *"Strongly disagree"* to *"Strongly agree"*. The remaining question allowed users to select one or more terms to describe how deceptive they believed the information to be.

The second questionnaire, *Pervasive AR Acceptance Questionnaire* was adapted[3] from the Technology Acceptance Model scale [31]. The questions were answered on a 7-point Likert-like scale ranging from "*Extremely disagree*" to "*Extremely agree*".

The final questionnaire was developed by deriving the questions from the interview guiding questions and was answered once during the study by participants on a 7-point Likert-like scale ranging from *"Strongly disagree"* to *"Strongly agree"*.

*3.2.2 Guiding Interview Questions.* A semi-structured interview was conducted with the participants discussing their perception of tailored content, especially in public settings and how they believed that would affect social behaviours.

### 3.3 Participants

The study had a total of 40 participants. 14 participants each were subjected to priming conditions A and C (as referred to in Table 1) and 12 participants underwent the priming condition, B. The participants were recruited from across the campus in pairs via classroom visits, flyers, and emails. They were instructed to bring a friend to ensure a consistent sample of people knowing each other. In this particular study, we were interested in investigating the social behaviour

[3]The term, "product" in the original questionnaire was replaced with "Pervasive AR glasses" and any references to job or job performance were replaced with day-to-day life or daily tasks.

between participants who had a pre-established relationship with each other to ensure that the participants could comfortably and candidly converse with each other during the experience without any reservations.

The participants had a mean age of 21.9 years (19f, 19m, 2d). 33 of the participants reported having no prior experience with AR while 7 participants reported that they had some prior experience. 35 of the participants were students from the university and 5 were professionals. In terms of ethnicity, 21 participants were reported to be of New Zealand European descent, 4 each as Māori, Pacific and Asian, 2 as both Māori and New Zealand European and, 1 each as Brazilian, Latin American, South African, European and American-Caucasian. Regarding how well they know their partner, 23 responded very well, 16 well, and 1 a little.

### 3.4 Ethics

Ethics approval was obtained from the [anonymised] Ethics Committee prior to conducting the study. The participants were informed that the data collected would be anonymised and that the recording obtained would be destroyed once transcribed. Furthermore, the participants reserved the right to withdraw from the study at any point to no disadvantage to themselves and were given a period during which, if they chose to object to the use of data collected during the study, could withdraw said data.

## 4 DATA COLLECTION AND ANALYSIS

This study yielded data from (1) interview recordings, (2) questionnaire responses on Likert-like scales and (3) observation field notes.

Interviews were recorded on an iPhone (14 Pro), transcribed and pseudonymised using *otter.ai*. To further ensure accuracy, the first author checked the transcripts against the audio and, where necessary, cleaned and revised the transcript manually. We followed the process prescribed by Thomas (2006) [46] for conducting general inductive thematic analyses. Additionally, we referred to Braun and Clarke (2006) [5] and Clarke and Braun (2017) [7] for further understanding of the thematic analysis process. The following steps were followed focusing on both semantic and latent meanings of data extracts. (1) Two of the authors read and re-read the transcripts to fully understand and familiarise themselves with the material. (2) Both authors independently generated and defined initial codes for the text. (i.e., *Independent parallel coding* [46]) (3) The authors discussed the independent codes from both lists and collated similar codes to generate a cohesive list of codes. (4) The first author used the list of codes generated in the previous step to develop the initial themes. (5) The codes and broader themes were checked for clarity by an independent coder, who was given the codes, the descriptions for the codes and raw text excerpts from the transcripts, to match with the suitable codes. (6) The authors reviewed the resulting themes of every iteration for consistency. (7) Following the final iteration, the generated four themes and their overall descriptions encompassing the sub-themes were provided to four independent stakeholders. Each stakeholder matched a comprehensive list of quotes to the main themes based on the provided definitions, resulting in initial agreement rates of 86%, 89%, 92%, and 96%. Any discrepancies were discussed to understand the reasoning behind them, and adjustments were made to the selection of example quotes as necessary. Furthermore, we have deliberately avoided quantifying our data when presenting our thematic analysis results. This decision stems from the semi-structured nature of the interviews and aims to prevent unjust generalisations of our findings [34].

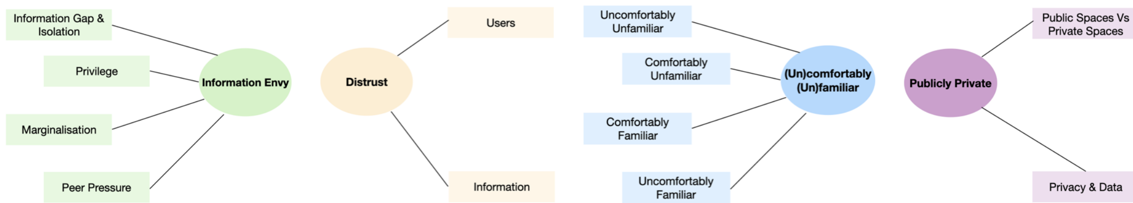



Fig. 4. Thematic map illustrating the four main themes developed.

Questionnaire responses were collected on paper and manually entered into spreadsheets. This data was analysed using *R*[4]. The analysis included the calculation of means, standard deviations, Shapiro-Wilk normality tests, paired t-tests or Welch two-sample t-test (for samples of two sizes), ANOVA, Kruskal-Wallis tests, Cohen's effect size tests for the *Pervasive AR - Acceptance Model* and regression analyses along with Pearson's Correlation for *Trust in Pervasive AR-enhanced Public Displays and Information Questionnaire* —in line with the studies the questionnaire was adapted from [15, 25]. Additionally, boxplots, bar charts, and scatterplots were also created using *R*, for visual inspection.

Handwritten observations were manually transcribed and analysed for general themes. The observational findings were derived to assist with our findings from the interviews.

## 5 RESULTS

In this section, we report our findings from the data gathered. Our primary source of information is our interview data with a subsequently conducted thematic analysis. The questionnaires served two purposes: (1) to collect quantitative data and, (2) to initiate a more guided and informed discussion with our participants in the interviews. The observation notes are used to better interpret the interview and questionnaire data.

### 5.1 Interviews

Following an inductive thematic analysis we generated over 40 initial codes that were collated over several iterations to develop four main themes (illustrated in Figure 4): (1) ***Information Envy***, (2) ***Distrust***, (3) ***(Un)comfortably (Un)familiar***, and (4) ***Publicly Private***. Each of these themes will be discussed in detail in the following sections accompanied by direct example quotes from the participants[5] and researcher observations. While the majority of the partners for the quoted participants agreed with the statements below, the rest remains inconclusive.

*5.1.1 Information Envy.* Participants believed that the experience of receiving tailored information in a public space such as a hallway or an atrium could lead to users being distanced from each other due to an information gap. The information gap was suspected of creating a sense of privilege among users, marginalizing those without access to the information or device. This disparity led to peer pressure, influencing the need to adopt the technology.

Participants identified three potential outcomes of information asymmetry. Firstly, the inequity of information was believed to make it more difficult to connect with each other due to a lack of shared ground.

> $Will_A$: *"It was very difficult to have a conversation about something we have in common because we don't see the same thing."*

[4] https://www.r-project.org/

[5] Participants have been pseudonymised and the subscript letter next to the pseudonym indicates the priming condition they were in.

> *$Nelly_C$: "It sounds a bit unsocial and probably not what I would want, [...]. And you wouldn't be like, 'Hey, friend, look at this thing that you can't see', [it's] kind of potentially isolating..."*

But in contrast to creating a gap between users, we noticed in our observations during the incoherent sessions that when consuming different information, the participants were more prone to converse with each other about what they were seeing, even if it was only to confirm their content.

Secondly, participants were concerned about the sense of privilege, the information disparity would create among users. The following conversation between the two participants illustrates this concern.

> *$Charles_A$: "I feel, if two people walk down the street together, they basically have the same opportunity to gather the same information from their surroundings. But then, with that [Pervasive AR systems], it's not quite the same anymore. And then, the extra information that you get is also personalised [...]"*
> *$Alex_A$: "[...] there could be an opportunity for kind of, privilege [because] some people are able to access something."*

Furthermore, we identified that even the knowledge of receiving their own content in place of what their partners were seeing did not ease the discomfort of privilege and information disparity.

> *$Helen_B$: "Even having my own experience, having different information I felt left out, so I think the idea of not being able to access that information at all [if they didn't have the system at all] I would feel even more left out [...]"*

The third potential outcome of information disparity that was discovered was that participants believed it would lead to marginalising a certain group purely because they do not have access to or cannot afford to have access to the same information as others.

> *$Ricky_C$: "I think, it would definitely provide like a split between me and him. Because I'm seeing all these cool things or all this extra information he's not. So, [I] have to feel almost like higher up, almost like a different level to what you would be because I've got all this extra information and technology, and you don't. [...]. So it would be like different hierarchies."*

Moreover, participants believed that this marginalisation would not be just due to the access to information but also the access to the device itself. In support of this notion, we noted in our observations that when interacting with passers-by, although some participants seemed relaxed and unfazed, others seemed uncomfortable due to being aware of how only they could see the information but not the non-users. Similar findings were reported by Regenbrecht et al. (2024) [39] and Wolf, Grodzinsky and Miller (2016) [51] in their work, with Wolf et al. emphasising the importance of equal accessibility of technology and devices, in the event it becomes commonplace.

Finally, we identified that these outcomes of information disparity leading to the feeling of missing out and the privilege of information might influence a certain group to adopt the technology, creating a sense of peer pressure, meanwhile doing the opposite for another group, discouraging them from adopting this system. The following conversation is an example of this finding,

> *$Meredith_C$: "If it just got implemented into the society and then everyone else goes and gets them. So if it became the new normal then probably yes [buy Pervasive AR devices]."*
> *$Rose_C$: "Like if everyone was doing [it] you might as well do it."*

*5.1.2 Distrust.* This theme addresses how user-specific information in public settings, that are otherwise equally accessible to everyone present in the space, creates a sense of distrust; this sense of distrust extended to fellow users when they attempted to relay what they were seeing, as that could be subjected to their personal opinions and intentions. The sense of distrust was further affected by the credibility of the sources presenting the information.

Firstly, addressing the distrust in fellow users, participants revealed that due to the asymmetrical nature of information, they had to rely on their fellow users telling them what they were seeing and trusting that they were, in fact, being truthful. However, the lack of a way to share what they see with each other could create a potential for misleading each other, thus creating a sense of distrust and reluctance to trust fellow users as being wholly truthful.

> *$Jane_A$: "I think it's cool [asymmetrical information]. But at the same time, it's not cool. Like in the sense of, if we both are seeing two different things, we can tell each other about the things we see, also, at the same time, you don't actually see the same content. So it's like, 'Oh, maybe they could be lying', we don't know."*

Although trust among users might be affected by asymmetrical information delivery, participants expressed that if one user already knew the other user well, then the concern of them being distrustful is no longer critical.

Secondly, participants raised concerns about trust in the information itself. This was a result of a few factors, one of them being the issue where one can no longer verify what they were seeing together with someone else. The following extract is an example of both distrust in information and other users.

> *$Rose_C$: " [...] it [incoherence of information] does make the content feel untrustworthy, because you can't get second opinions on it, and you can't discuss it with others. I mean, you kind of can discuss [it], [....] talk about what was on the [poster] and share opinions. But, you can't get someone to physically look at it and be like, 'Look, does this sound right to you?' You can just sort of explain it. And to be honest, you could be making the whole thing up[...]"*

Furthermore, participants commented that the credibility of the sources generating the information instils distrust in information. In our observations, we noticed participants often tried to read the source of the Pervasive AR posters they were seeing, especially in the Incoherent session. And they relayed this concern later in the interview. The sources and moderation of the content delivered by Pervasive AR systems were believed to be crucial to how acceptable the system would be. The following quote from the participants illustrates the importance of credible sources for Pervasive AR information delivery:

> *$Andrew_B$: "[...] it does seem like [the information] could be targeted towards you, but it could also be [that] whatever company pays the most might get whatever their content pushed more[...] And if they're wearing these glasses, they might just continue seeing that kind of stuff [from] a certain corporation [...], I mean, depending on who has the most money."*

The importance of sources in Pervasive AR systems was previously reported in the works of Regenbrecht et al. (2024) [39]. The distrust in sources further stems from the information providers' intentions. Participants raised the concern that the use of tailored content could lead to misinformation and content manipulation that could create conflicts among each other.

> *$Monica_C$: "So, if it's for example, a political poster. And then two people [...] see a poster from two different parties or even the same one, that could cause different interpretations of why they're seeing it. So one might be like, 'oh, yeah, 100% agree', and the other ones like, 'no', and then they start a conflict between themselves because of it."*

*5.1.3 (Un)comfortably (Un)familiar.* While participants identified certain aspects of Pervasive AR and the delivery of tailored information in public spaces to be novel (unfamiliar), certain other aspects were believed to be similar to technologies that we use on a day-to-day basis (familiar). They discussed features such as being always-on to be unpleasant (uncomfortable) but also identified that in specific use cases, the technology could be beneficial and even interesting, especially if users were kept informed about the state of the information delivery (comfortable). Although participants found some of the similarities between the analogous technologies comforting, they predicted that if certain features, such as seeing tailored advertisements online, were to be incorporated into Pervasive AR, it would be an unwelcome experience. We will discuss our findings under this theme in four sections.

Firstly, the uncomfortably unfamiliar dimension discusses how participants found the delivery of tailored content in public spaces by Pervasive AR both uncomfortable and unfamiliar.

Following the exposure sessions, the majority of the participants had noticed that during one of the two sessions, they were seeing content that was different to their partner—our observers noted that the 60% of the groups at this stage looked visibly surprised or taken aback. This realisation was followed by an attempt to make sense of the asymmetry and to work out their thoughts towards the phenomenon, during the session, this attempt translated to figuring out and testing proxemics. A substantial proportion of the participants voiced the experience to be unusual, unexpected, *"creepy," and "weird"*.

> *$Andy_C$: "I think I'm a little bit skeptical to be honest. I think that I thought it [was] creepy that we could have personalized experiences. And that we were seeing different things."*

Participants conveyed that the constant feed of tailored information that they would receive from systems such as this would, in fact, deter them from wanting to introduce the technology into their day-to-day lives.

> *$Jeremy_A$: "[...] even if you're not paying attention to the information that's being shown to you, you're still kind of, absorbing it even if you're unaware."*

As a result of such a constant feed of information, participants were concerned that they might no longer be able to accurately judge what is real and what is virtual upon being immersed for prolonged periods.

> *$Monica_C$: "[. . . ] [when] you have your phone, and then you see something [content], as soon as you put it down, it's away from you. But if it's in your vision mixed together, it would be a bit more difficult to separate reality from technology."*

Finally, under this dimension, we report on participants' emphasis on the importance of being informed and having a choice in information consumption. Participants believed that the option to see tailored content should always be reserved by the user, so as to ensure that the user is always aware when they're seeing something different from others, especially in a public setting.

> *"$Rose_C$: I think I like to be told that I'm seeing something different to what other people are seeing. So it's not jarring when you find out that we're seeing different things"*

The second dimension, comfortably unfamiliar explores the potential benefits of a technology that was yet unfamiliar to the participants. A considerable segment of the sample expressed how receiving tailored content could, in fact, be interesting and beneficial in some cases. These participants viewed receiving tailored content as being more appealing than the consumption of generic information that was in no way customised to them.

> *$Jessie_A$: "I feel like it'd be a bit more interesting if it [the information] was catered to your own personal [interests]."*

Moreover, participants viewed the delivery of tailored content to be more acceptable if it was treating a disability or helping a user with a medical illness. This is in line with the findings of Kelly and Gilbert (2018) [27], where they stated that wearables are found to be more acceptable when described as medical devices.

> $Andy_C$: *"I think that it's kind of cool for, disability stuff. I saw something about people who are deaf, and they [Pervasive AR systems] transcribe what people are saying onto their eyes. I'm into that. I think that's so cool. [...] I feel like it [Pervasive AR systems] could have really cool things like that."*

Participants drew comparisons between Pervasive AR's information delivery and other technologies in the third and fourth dimensions, thus familiar. They explored both the comfortable and uncomfortable aspects of these analogous technologies.

Addressing the comfortably familiar dimension, participants pointed out similarities between the tailored content delivery by Pervasive AR and the delivery of tailored content on social media. A substantial proportion of participants expressed that this sense of familiarity made the Pervasive AR experience more acceptable as just being an extension of the current experience with the internet.

> $Jeremy_A$: *"I don't feel it's [tailored content] worrying because it's already like the same system [that] is already in place with the internet; you're always gonna see content for you. So having it in real life, I don't really see that as a problem."*

Addressing the final dimension of uncomfortably familiar, eventhough some participants accepted the familiarity, they were still sceptical due to the novelty of the Pervasive AR systems. Following is a conversation between two participants that depicts the scepticism towards the system,

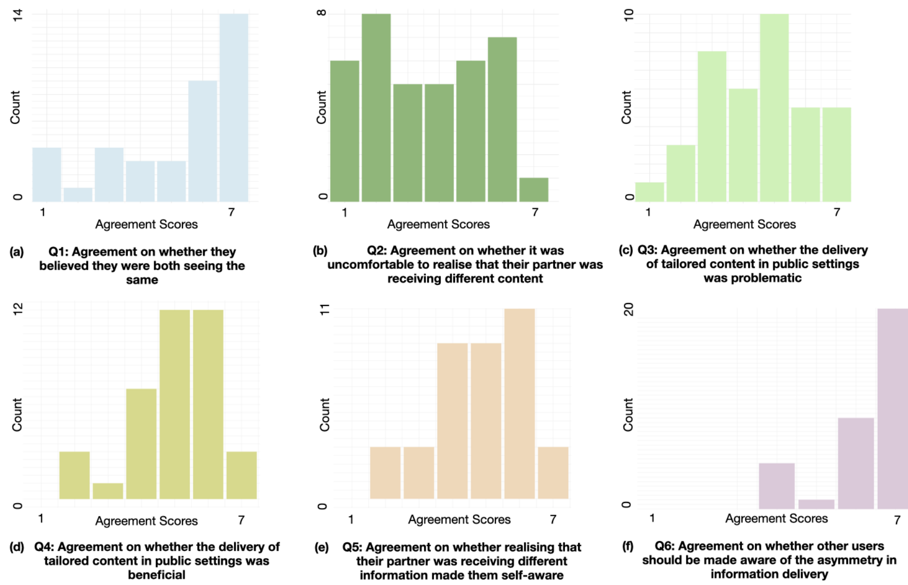
> $Christy_B$: *"[...] It's [personalised content on the internet] always been that way. [...] But in real life, it's never been like that. So it'd be weird to transition to that. And I don't know if a lot of people would like it."*
> $Alan_B$: *"The sort of thing [Pervasive AR systems delivering tailored content] if I was born [with knowing], I'd definitely accept. [...] kind of like social media."*

Moreover, because of the recognized parallels between social media content and the delivery of information through Pervasive AR, participants expressed their significant lack of enthusiasm for constantly consuming advertisements via Pervasive AR systems.

> $Jo_B$: *"[...] But then also the idea of businesses using that for their own benefit. Like, you know, how ads are targeted to you or how people use your data to target things to you. It's not always great. No one likes ads."*

*5.1.4 Publicly Private.* There were several concerns and discussions about what should remain private and what should remain public if Pervasive AR systems were widespread. Participants expressed their preference for information in public spaces remaining equally accessible and limited to public information whilst tailored content being delivered only in private spaces. Participants were also concerned about potential data privacy violations by Pervasive AR systems.

Firstly, we noted recurring discussions about private spaces versus public spaces and the kind of information that suits each space. A portion of the sample preferred to consume tailored content exclusively in private settings to maintain our inherent understanding of private and public space. This concern extended to the preference only to have shared content in public spaces, still maintaining our natural understanding of what makes a public space "public" and a private space "private".




(a) Q1: Agreement on whether they believed they were both seeing the same

(b) Q2: Agreement on whether it was uncomfortable to realise that their partner was receiving different content

(c) Q3: Agreement on whether the delivery of tailored content in public settings was problematic

(d) Q4: Agreement on whether the delivery of tailored content in public settings was beneficial

(e) Q5: Agreement on whether realising that their partner was receiving different information made them self-aware

(f) Q6: Agreement on whether other users should be made aware of the asymmetry in information delivery

Fig. 5. The histograms above depict the agreement scores for the Mini Questionnaire created from the guiding interview questions and were answered on a 1-7 Likert-like scale.

> $John_A$: *"I feel like in a shared and in a public space, everyone should have the same information like in the real world. If they wanted to bring like targeted advertising [it] could be fine if you're in like a private space like your office or at home [...]"*

Furthermore, we found that some participants were reluctant to view their private (i.e., personal) information in public spaces. Despite knowing that only they could see it, they expressed nervousness, feeling as though others might also be able to see it.

Finally, we identified that users had concerns about their privacy and the constant data collection. This is to be expected with systems such as Pervasive AR and tailoring of information. Lack of transparency about how the collected data about users will be used and who will have access to it was expressed to be concerning, along with the potential of being hacked and being subjected to unsolicited content due to that. This is an area that is often investigated in terms of surreptitious data collection by Pervasive AR systems [9, 40, 41, 49].

> $Jeremy_A$: *"[...] seeing through your eyes and seeing what you've seen, that would be more of a privacy breach in my eyes. [...] and having everything you see be sent to a company [...]."*

### 5.2 Questionnaires

Questionnaires were analysed individually for each of the 40 participants and not in pairs.

In our analysis of the **Trust in Pervasive AR-enhanced Public Displays and Information Questionnaire** ($n = 40$), we first looked at the correlation between the attitude towards Pervasive AR-enhanced public displays (outcome) and the perceived trustworthiness and reliability of the Pervasive AR-enhanced displays (predictor). Only the data collected under the following conditions reported statistically significant correlations, *B - Coherent*, *B - Incoherent* and, *C - Coherent*. Secondly, the linear models for the correlation between the attitude towards Pervasive AR-enhanced

Table 2. Analysis results of the Trust in Pervasive AR-enhanced Public Displays and Information Questionnaire. (* indicates the statistically significant correlations.)

| Correlation | Priming Condition | Coherence Condition | P-Value | $R^2$ | F-statistic |
|---|---|---|---|---|---|
| Attitude towards the Pervasive AR-enhanced displays ~Perceived trustworthiness and reliability in the Pervasive AR-enhanced displays | A | Coherent | 0.6699 | 0.0157 | 0.191 (1,12) |
| | | Incoherent | 0.429 | 0.0529 | 0.67 (1,12) |
| | B | Coherent | 0.04548* | 0.3428 | 5.216 (1,10) |
| | | Incoherent | 0.0039* | 0.5819 | 1.92 (1,10) |
| | C | Coherent | 0.0021* | 0.5597 | 15.25 (1,12) |
| | | Incoherent | 0.1291 | 0.1812 | 2.656 (1,12) |
| Attitude towards the Pervasive AR-enhanced public displays ~Attitude towards trusting information shared by Pervasive AR-enhanced public displays | A | Coherent | 0.8102 | 0.005 | 0.0602 (1,12) |
| | | Incoherent | 0.0361* | 0.3168 | 5.563 (1,12) |
| | B | Coherent | 0.588 | 0.0303 | 0.3127 (1,10) |
| | | Incoherent | 0.8665 | 0.003 | 0.2973 (1,10) |
| | C | Coherent | 0.0037* | 0.5173 | 12.86 (1,12) |
| | | Incoherent | 0.0136* | 0.4101 | 8.343 (1,12) |
| Attitude towards Pervasive AR systems ~Attitude towards the Pervasive AR-enhance public displays | A | Coherent | 0.5159 | 0.036 | 0.448 (1,12) |
| | | Incoherent | 0.8476 | 0.0032 | 0.0386 (1,12) |
| | B | Coherent | 0.0232* | 0.4174 | 7.165 (1,10) |
| | | Incoherent | 0.2275 | 0.1419 | 1.653 (1,10) |
| | C | Coherent | 0.0001* | 0.7194 | 30.76 (1,12) |
| | | Incoherent | 0.003* | 0.5341 | 13.76 (1,12) |

public displays (outcome) and the attitude towards trusting information shared by Pervasive AR-enhanced public displays (predictor), reported statistically significant values for the data collected under the *A - Incoherent*, *C - coherent* and *C - incoherent*. The final correlation we explored was how the overall attitude towards Pervasive AR-enhanced public displays (predictor) affects the users' attitude towards Pervasive AR systems as a whole (outcome). We found statistical significance in the following datasets for this dimension, *B - Coherent*, *C - Coherent* and *C - Incoherent*. An overview of these findings are presented in Table 2.

Besides the linear regression models, the perception of information consumed for each condition was analysed using a simple frequency bar graph for each condition. An overview of the findings is given in Table 3.

**Pervasive AR - Acceptance Model** ($n = 40$) was analysed against priming conditions and coherence conditions with paired t-tests, but we could not detect significant differences in scores for any of the pairings. Additionally, effect sizes from Cohen's D analysis for each priming condition were deemed negligible. From further analysis with ANOVA tests and Kruskal-Wallis tests [6], we did not find any significant differences in Pervasive AR acceptability among the different priming conditions for the coherent and incoherent datasets (coherent: $p - value = 0.70$, incoherent: $p - value = 0.77$).

[6]In cases where the prerequisite assumptions for ANOVA were not met, we opted for its non-parametric counterpart, Kruskal-Wallis test.

Table 3. The table below depicts how the information consumed during the experience was perceived by the participants as per the Trust in Information Questionnaire (** indicates the highest value reported for a certain category and *, the lowest value reported.)

| Condition | Accurate | Misleading | Truthful | Deceptive | Factual | Distorted |
|---|---|---|---|---|---|---|
| A - Coherent | 4 | 7** | 8** | 4 | 7 | 4 |
| A - Incoherent | 3* | 7** | 4 | 7** | 3 | 5 |
| B - Coherent | 5 | 3 | 1* | 1 | 3 | 4 |
| B - Incoherent | 5 | 2* | 1* | 4 | 1* | 5 |
| C - Coherent | 7** | 6 | 3 | 0* | 9** | 3* |
| C - Incoherent | 5 | 5 | 2 | 4 | 6 | 6** |

The **mini questionnaire from interview questions** ($n = 38$[7]) was analysed as a measure for quantifying our potential findings from the interview. The highest mean of agreement was reported for Q6 on whether other users should be made aware of the asymmetry in information delivery, which was 6.3 ($sd = 1.04$). Q1, the agreement on believing that both participants were seeing the same content in the beginning and Q4, the agreement of tailored content in public settings being beneficial had approximately similar mean values of 5.2 ($sd = 2.1$) and 5 ($sd = 1.3$), respectively. The bar-graphs for the scores of these questions can be seen in Figure 5.

## 6 DISCUSSION AND FUTURE WORK

With the introduction of mainstream Mixed Reality headsets such as the Apple Vision Pro[8], we see that users are eager to incorporate these devices into their day-to-day lives. Therefore, we presume that the investigations done through this study are timely and relevant to the current environment. This study is an attempt to explore the way Pervasive AR can be delivered with users' best interests in mind. In this section, we discuss our findings and how they address the research questions, limitations and potential future work for this domain.

Referring back to our research question one, ***(1) How will Pervasive AR affect society in public settings?*** Our qualitative findings, especially the theme *Information Envy*, discuss several societal impacts to be expected if Pervasive AR use in public spaces became common practice. The most relevant of those impacts discovered from this study is creating a gap among users resulting in an isolating future. During the initial adoption phase of Pervasive AR, when pervasive content tailoring is still unfamiliar and not everyone has access to the device, several issues may arise. First, users may be seen as privileged while non-users are marginalized. Second, the highly personalized information could create a divide among users, altering communication dynamics. With information so precisely tailored to individuals and lacking a means of sharing it, the common ground that facilitates connections may diminish.

Nonetheless, Pervasive AR will also make society more inclusive by catering to differently-abled persons and helping them be more involved with the community, as discussed under the *(Un)comfortably, (Un)familiar* theme. Thus, we can say that while Pervasive AR in public spaces will result in negative societal impacts, the information could be harnessed positively to cater to an already marginalised group.

***(2) How will the trust between users be affected by the consumption of incoherent information in public settings?*** Our findings reported under the theme *Distrust*, discuss how and why incoherent information will affect the trust among users as assumed. The information asymmetry will make users vulnerable to being misled by others because they have to rely on others to learn the information they consume. As discovered by Regenbrecht et al. (2024) [39], our findings confirmed that distrust extends not only to fellow users but also to the information itself and the sources.

[7]Due to a variance in the study process, two responses for this questionnaire were omitted from the analysis to preserve the integrity of the findings.
[8]https://www.apple.com/apple-vision-pro/

***(3) How the altering social dynamic will affect the social acceptability of Pervasive AR?*** Besides identifying several potential outcomes of Pervasive AR and tailored information delivery in public spaces, we were unable to identify factors that would convincingly influence the social acceptability of Pervasive AR. We are inclined to believe that the sense of privilege, the divide among users, and the concerns about trust and privacy will negatively affect acceptability to some extent. However, the identified benefits and the familiarities might make Pervasive AR appealing to some users.

### 6.1 Design Guidelines for Future Pervasive AR Systems

To potentially mitigate the concerns mentioned above they should be addressed during the design process, which we explored through our final research question, ***(4) What design recommendations can make Pervasive AR more acceptable in public settings?*** One of the key and vital features that Pervasive AR would need to implement in its design is **a reliable method to share what one user is seeing with another user**. *Exclusion* is an extensively researched topic in terms of AR and Virtual Reality (VR) in regards to users and non-device-using bystanders [18–20, 24]. These work recommend the use of external visualisations of users' content via an attached monitor that displays the user's view to address the exclusion of non-users. To our knowledge, only a few studies have explored the exclusion of fellow users, especially concerning tailored content. For example, Billinghurst, Poupyrev, Kato, and May's (2000) [4] work relies on collaboration facilitated by common virtual information. For Pervasive AR, we recommend the implementation of a mechanism similar to the *View Sharing* method discussed in Xu, Yang, Liu, Cheng, Masuko and Tanaka (2019) [52], in which the non-user sees the user's view via a live stream. In the context of Pervasive AR, implementing a similar feature that allows users to share their views upon request while ensuring the live stream accurately represents the sharer's perspective could address many concerns discussed under the theme of *Information Envy*. This would enable users to discuss what they see with each other while still receiving information tailored to their individual needs. At the same time, the feature's non-interactiveness would give the sharing user more control in dictating what the other user can see. Besides the View Sharing feature, Eghtebas et al. (2023) [13] recommends the implementation of metaphors such as portals, windows and doors into other users' augmentations, especially in shared spaces. Moreover, incorporating features like this would ensure that users are not susceptible to being misled by other users, thereby diminishing distrust among peers, as elaborated upon within the theme of *Distrust*. Similarly, this functionality would resonate with users, resembling a familiar feature already present in social media platforms, thereby enhancing comfort levels with Pervasive AR, as discussed within the theme of *(Un)comfortably (Un)familiar*.

Secondly, we recommend **the implementation of a clear and continuous indication to users when consuming tailored content** to ensure that they remain informed about the state of the information consumed. Referring back to the literature on interactive public displays, we understand that the proxemics concept by Edward Hall is primarily based on how people interpret interpersonal distance[22]. For example, if two people are standing very close to one another, we perceive that as an intimate interaction, and a third party is unlikely to intrude. Similarly, in HCI research, proxemics serve as an indication of the users' engagement level with the display where if a user is standing very close to the display, we can safely assume that they are consuming personal information. Although this mechanism was incorporated into our incoherent experience in a way that a participant only received user-specific information if they stepped closer to the poster and otherwise received shared information (similar to the state of ambient displays discussed by Vogel and Balakrishanan (2004) [47]), none of the participants identified this technique as a good enough indication or alleviating discomfort about consuming tailored content in public displays. Therefore, proxemics is unsuitable for indicating tailored information delivery via Pervasive AR systems. Nevertheless, awareness in virtual environments has previously been explored heavily in terms of VR users [37, 38]. While some studies address awareness in AR [3, 14, 35], they focus on situational awareness and not augmentation awareness. Nevertheless, we can take inspiration from these studies when implementing persistent notifications in a way that does not unnecessarily increase users' task load. We recommend using a combination of visual and auditory cues [35] to inform users when they are beginning to consume tailored content. This could then be implemented as continuous ambient indicators (similar to battery life indicators) that persistently will inform the user of the type of information they are consuming at any given moment [14]. Moreover, user awareness concerns extended beyond the types of content to include the challenge of distinguishing between real and augmented information, raising the potential issue of users consuming augmented content without recognizing it. Eghtebas et al. (2023) [13] propose ephemerality, as discussed by Döring, Sylvester and Schmidt [10], as a method to inform users about the augmentations in their surroundings. Ephemerality would ensure that augmentations are time-based and, thus, would disappear at a specified time.

Thirdly, when designing Pervasive AR devices, it would be advantageous to **focus on the positives** participants mentioned regarding the technology, such as improving their productivity and supporting differently-abled persons. Retrospectively, several technologies were first developed for medical or assistive purposes and later adapted into everyday life by a broader range of users. Findings from Kelly and Gilbert (2018) [27] show that wearables are considered more acceptable when they cater to medical uses. Therefore, Pervasive AR designs should focus on implementing useful functions rather than being developed solely for the sake of novelty.

Furthermore, we emphasise the importance of **maintaining users' sense of autonomy and agency, and privacy** in ensuring the acceptability of Pervasive AR in public spaces. Our results suggest that it is important to ensure that users maintain autonomy to decide the type of content they consume (advertisements and personal information in public spaces were highly opposed) and the kind of setting that is acceptable for different types of information delivery (tailored or shared). Furthermore, users expect transparency from these systems in terms of data collection (which has previously been discussed in several other studies [8, 12, 21, 28, 29, 50]), who has access to users' data and the reliability of those who provide users with data to consume.

Finally, it is important to **formulate rules on privacy protection** and ensure that there is no malicious intent in the information delivery as well as in data collection [8, 12, 21, 28, 29, 50]. As discussed by Regenbrecht et al. (2024) [39], civic dialogue and consumers' best interests should be maintained in designing systems that intertwine with many aspects of a user's life. More specifically, transparency should be important to design, allowing the option of opting in and out of certain sources of information and specific settings, such as when personalised information should be delivered.

### 6.2 Limitations and Future Work

The work discussed presented several limitations that are worth potentially addressing in future work. Although our work revealed certain aspects that point towards the social acceptability of Pervasive AR, more research is needed to answer *(RQ3) How the altering social dynamic will affect the social acceptability of Pervasive AR?* in a substantial manner.

In our investigations to formulate suitable guidelines, we discovered that several areas in designing future Pervasive AR systems severely lack exploration. We see potential for future studies that explore more rigorously design recommendations for Pervasive AR systems, for which the qualitative findings from this study will provide a good foundation. For example, research that focuses on inter-user relationships, reliable sharing techniques between users, and suitable notification and indication methods, needs to be explored specifically for Pervasive AR systems. Furthermore, we only explored 2D posters and overlays in this research, and there is potential for exploring Pervasive AR and the influence of other forms of content delivery on its acceptability. Similarly different types of information could have an effect on the findings.

Furthermore, the total number of participants for the study was 40, thus creating imbalanced groupings of 14-12-14 for each priming condition. That said, our participant numbers are in line with similar studies in the domain, and the imbalance was not a critical concern due to the qualitative nature of this study. Due to the campus-based recruiting pool, we had a relatively low average age of 22, of which the majority were students. A more diverse group would have provided manifold insights. Moreover, we exclusively recruited pairs of participants who knew each other. The effect Pervasive AR-enhanced public displays have on users with no pre-existing relationships can be explored in future studies. In our quantitative analysis, we initially assumed that participants were independent. However, it's worth noting that they might actually be dependent. However, we believe this issue is less critical because the questionnaires served primarily as probes and do not influence the study's primary qualitative findings.

We opted to use the Snap Spectacles in this study because, with their subtle form factor and in-built processing, the Spectacles were capable of creating a potential future emulation of Pervasive AR for the participants as opposed to the larger AR Head Mounted Devices currently available. While there were limitations regarding the Spectacles battery life, we used battery packs with the device to ensure participants had an uninterrupted experience. Additionally, even though the field of view of Spectacles is very narrow and with this limiting the amount of information which can be overlaid at a given time, the user's ability to look around in the environment practically increases the field of view (FOV) to an extent that is usable for PAR public display applications [48].

Finally, we were unable to follow a more formal procedure for gathering observations during the study as the study was conducted in a semi-public hallway in a university building that saw several non-participants walk through during the sessions. This challenged our initial plans of video recording and analysis of observations due to ethical and consent-related concerns. Nevertheless, the collected observational field notes were able to provide valuable insights into our thematic analysis results.

## 7 CONCLUSION

Pervasive AR has the potential to be a transformative technology, delivering contextualized information seamlessly on the go and reshaping our perception of public spaces through its unique information delivery. To adapt to this new paradigm of Pervasive AR-enhanced public displays, it is crucial to proactively address potential shortcomings. The four themes developed in this study offer valuable insights into users' expectations for the design of future Pervasive AR systems. The most critical issue to address is managing the information gap created by tailored content in public spaces, ensuring this technology does not lead to an isolating future. The provided design guidelines will serve as a foundation for this effort. Ultimately, these systems must be designed with the users' interests and well-being at their core.

## AUTHOR CONTRIBUTIONS

Kushani Perera performed writing - original draft, conceptualisation, methodology, software, formal analysis, investigation and data curation; Tobias Langlotz performed writing - review & editing, conceptualisation, methodology, visualisation and supervision; Nadia Pantidi performed formal analysis, and supervision; Holger Regenbrecht performed writing - review & editing, conceptualisation, methodology, formal analysis, investigation, funding acquisition, and supervision.

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