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RESEARCH ARTICLE

To See and Be Seen—Perceived Ethics and Acceptability of Pervasive Augmented Reality

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ABSTRACT Augmented reality (AR) glasses are likely to become omnipresent, providing a continuous and ubiquitous experience of computer-mediated reality. This new *Pervasive AR* will lead to perceptual, acceptance, and ethical issues which are increasingly discussed in the literature. However, given such Pervasive AR prototypes are currently not commercially available, little is known about potential end-users' input into this discussion. To address this, we developed a Pervasive AR (PAR) prototype serving as a technology probe and conducted an empirical study in a semi-public space involving 54 participants. We collected data from focus groups, questionnaires, and observations of users and bystanders. Extending concerns with existing technology, like smartphones and augmented reality, PAR exposes privacy and security breaches with its unprompted, all-seeing capability, has a higher potential to cause societal fractures and divisions, and raises new questions on information transparency and trust with significant implications for the design of future PAR systems.

INDEX TERMS Augmented reality, perception, acceptability, empirical study, technology prototype.

I. INTRODUCTION

Pervasive Augmented Reality (AR) has the potential to disrupt user interface technology in the same way the smartphone did in the last 15 years. Grubert et al. define 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" [1]. Pervasive AR systems tightly integrate computing, display, sensing, networking, and user interaction technology. In the foreseeable future we can expect to have Pervasive AR technology seamlessly built into glasses which are indistinguishable from today's sunglasses, and maybe even as fashionable.

Such Pervasive AR glasses will augment and enhance existing human-computer interaction capabilities, as for instance provided by current smartphones and wearables, promising to provide a continuous experience of computer-mediated reality. Instead of using and controlling dedicated apps for different purposes as with AR glasses, Pervasive AR aims to integrate relevant user interface elements into the current spatial and temporal context of the user in a continuous, adaptive, and omnipresent way [1]. Pervasive AR glasses are intended to be worn constantly to assist with a coherent and meaningful merging of real and virtual reality at the right time and at the right place.

When combined with other advanced technologies, like artificial intelligence and machine learning, Pervasive AR is expected to open up new opportunities for e.g., faster and more accurate in-situ decision making, social interaction and

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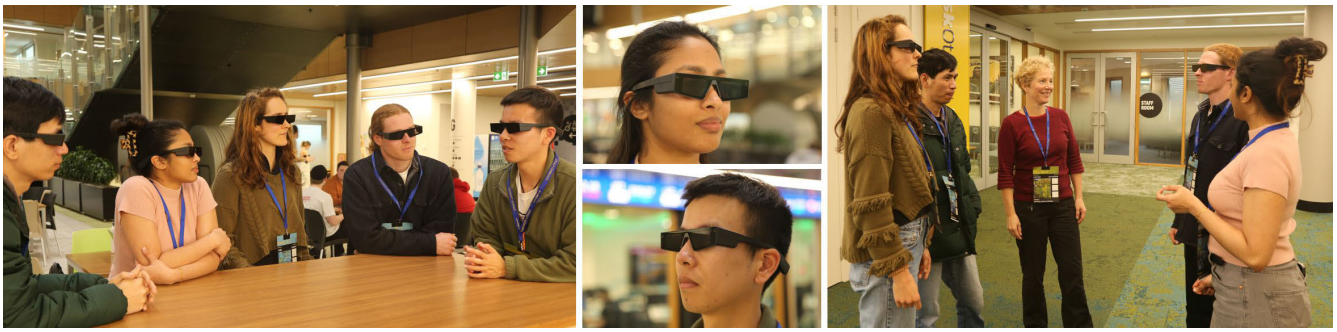

FIGURE 1. Left: Group of Pervasive AR glasses users; Center: PAR users; Right: Mix of PAR users and bystanders in semi-public space.

communication, context-sensitive learning and education, and new forms of entertainment [2], [3], [4]. This potential is not only recognised in research, but also by information technology manufacturers and service providers [5]. Examples of existing systems which can serve as pervasive AR proxies include Microsoft's Hololens range, Magic Leap glasses, and Snap AR New Spectacles; recent announcements by Apple, Google, and Meta suggest further significant investments in such technology. However, the integration of cameras, microphones, and various user tracking mechanisms is likely to lead to social acceptability and privacy issues, as for instance seen with the introduction of Google Glass in 2013 [6].

Besides broad media coverage of issues surrounding AR glasses in general, and acceptability and ethical issues in particular, there is a substantial body of academic work on conceptual, perceptual, legal, philosophical, and socio-psychological considerations surrounding (pervasive) AR [7], [8], [9], [10], [11], [12], [13], [14]. This research covers topics such as privacy, accessibility, virtual property rights, and illusions and beliefs [2]. Some research involves participation by potential end users of AR technology, either in laboratory studies exposing them to application prototypes to test hardware or software designs, or, more recently, to survey user opinions by using imagined AR scenarios. But in general, there has been little systematic consultation of the public about the ethics and social impacts of pervasive AR technologies. In particular, very few studies have exposed potential users to AR prototypes *and then* surveyed their opinions on these topics. Users' opinions may well be shaped by practical experience with a prototype—especially if this takes place in a natural environment, rather than in a lab.

In the study presented here, we expose 54 potential end users to a Pervasive AR prototype in a semi-public space (the atrium of a business school building), observing their behaviour, and canvassing their opinions about the ethics and societal impacts of the technology. Our technology probe, the Pervasive AR system, was developed specifically to support the study, and implemented on state-of-the-art, highly integrated AR glasses. Our analysis of users' behaviour and opinions builds on a review of ethical and societal issues identified in prior work on AR and Pervasive AR, using a mixed-methods approach. We are less interested in how PAR might potentially be aligned with existing norms or codes of conduct, and more interested in how potential end users currently perceive the ethical issues around PAR. Since the technology will probably be introduced and adopted gradually over time, we are interested not only in the perceptions of potential Pervasive AR users but also in the perceptions of bystanders, i.e. people without AR glasses.

Our main contributions can be summarised as follows: (a) we found that Pervasive Augmented Reality is perceived as delivering a novel experience for end users because of its all-seeing and unprompted, continuous delivery of information everywhere and all the time; (b) our participants were concerned about increased societal divisions at a number of levels; (c) we could show that the development and use of technology probes in combination with a mixed methods approach is an effective way to envisioning future technology scenarios; and (d) based on the overall findings of our study, and an accompanying literature review, it is advisable to design and implement a *digital civics space* for PAR and related technologies.

In the remainder of this paper, we review selected related work in the field, present our method, including describing our Pervasive AR technology probe development, present and discuss the findings from applied questionnaires, informal observations, and, as our main approach, a thematic analysis of focus group interviews with Pervasive AR users and bystanders.

II. RELATED WORK

As context for our study, we review work on ethical issues raised in AR and PAR, from two related perspectives. We begin in Section A by surveying ethical issues in their own right. In Section B we consider how they have been perceived by participants in AR environments, in earlier studies of 'social acceptability'. These social acceptability studies are important precursors to the study we report in this paper.

A. ETHICAL ISSUES IN AR

Existing studies of ethical and societal issues in this field are mostly about AR in general, rather than PAR in particular (see e.g. [9], [12], [15], [16], [17], [18]), though PAR scenarios are often implicitly considered, and one study considers them explicitly [8]. For our review, we follow broadly the classes of ethical issues identified by [2].

1) PRIVACY AND FAIR TREATMENT

In a thought experiment, Rixen et al. [18] found that participants were less comfortable with AR devices in general, only consenting to disclose basic personal information, such as gender or interests, however, when people participate in a task they value they may be more comfortable with information being disclosed in AR [19]. On rights to fair and equal treatment, a central issue is who is able to use AR glasses, exacerbating divides that already exist, and creating new inequalities [12], [20]. For people being observed by AR, one can also expect a variety of well-known biases in relation to the processing being done [21]; for instance, biases in visual face processing [22]. These are more properly issues for AI systems that are embedded in AR systems, rather than AR technology in itself. But they must nonetheless be addressed when assessing AR systems.

All of these effects are exacerbated by PAR, compared to AR [23]. A world with PAR is a world where people are potentially constantly surveilled, and where considerable personal information may be disclosed [12], [24], [25]. In addition, this disclosure would happen in immediate physical contexts, and would take place instantaneously [25].

Of course, privacy issues arise in many IT contexts, not just in AR systems: the right to privacy is a general one, that extends over many contexts. But AR and PAR applications have distinctive effects in linking information about user location and user interests: they therefore surface a distinct class of personal data, that may raise distinct privacy issues.

2) AUGMENTING AND ACCESS TO AUGMENTATION

The key question here is who has rights to create augmentations in a given place. In addressing this question, Neely [10] makes two useful distinctions. One is between private property and public (state-owned) property. The other is between a *single-sphere* scenario where all AR users see the same augmentations, and a *choice* scenario where several different augmentations are available. In a single-sphere scenario, the author argues that people should have exclusive rights to augment the physical property they own. In a choice scenario, the author argues that AR systems provide *descriptions* of places, that users can freely choose between, whether they are public or private. How much people would be prepared to pay for access to AR highlights augmentation privileges that the financially well off would have over others [20].

3) ILLUSION AND BELIEF

Many ethical issues relating to AR systems concern the effects they have on users' perceptions of the world [2], [12], [26], [27]. An important scenario to consider is one where the user starts to *treat the augmentations as real* [13]. This need not involve a literal inability to distinguish between the world and augmentations—it could also happen if the user stops *thinking* about this difference, to the point where their behaviour is influenced just as much by augmentations as by the real world [2], [28]. AR applications often aim for this behavioural equivalence, for instance in applications designed to treat phobias or rehabilitate stroke patients [29]. Designers of AR systems obtain power over users by instilling these illusions [14], [30], which compounds their responsibility [14].

Compared to AR systems, PAR systems can be expected to produce more subtle, less obtrusive augmentations for users [1]. The more regularly an augmentation is presented to a user, the more they will *adapt* to it and incorporate it behaviourally: studies of perceptual plasticity demonstrate this point (see e.g. [31]).

B. SOCIAL ACCEPTABILITY AND TRUST

Social acceptability refers to the extent that a behaviour or action is considered acceptable or appropriate by a particular social group, within a particular context [32], [33]. On the other hand, ''trust must be designed as a relationship between people and measured by their ability to depend on one another to play by a shared set of rules,'' [17].

1) PAR AND AR CHALLENGES TO SOCIAL ACCEPTABILITY

As much of our interactions with technologies, such as wearable devices or public displays, occur in the presence of other people, the experiences of interacting with these technologies, and experiences of being in the presence of others interacting with these technologies, can affect decisions around adoption, and ultimately the commercial success of the technology itself [6]. Since existing social norms shape our sense of what is acceptable with respect to interactions with technologies in social settings, understanding the role of these social processes in action requires the perspectives of both the user and that of the non-user, typically referred to as the observer or bystander [34]. As demonstrated in previous studies, social acceptability of novel technologies can be challenged when their presence, or their use causes ''controversy, discomfort and social tension'' [35].

2) TRANSPARENCY

Existing work has investigated ways in which the above challenges can be smoothed over by making the operation of AR systems more transparent. For example, Koelle at al. [36] investigated a ''blinking LED'' cue signalling that an in-built camera was recording, but found it to be insufficient due to the LED not being noticeable, understandable, secure, or trustworthy. Most work around issues of transparency

comes from research in robotics, artificial intelligence, and autonomous systems, some of which also incorporate AR technologies. As Theodorou et al. [37] note, ''What is effectively transparent varies by who the observer is, and what their goals and obligations are.'' Lack of transparency hampers an individual's ability make informed decisions around systems in their environment [38], [39] and could lead to lack of trust in the systems [40]. Transparency with respect to mobile AR applications have been addressed in the context of permission settings, for example, whether to allow or decline object or face recognition [39]. Existing evidence shows that users' trust in technology increases when they ''understand the capabilities of the system, see how well it is performing and forecast future behaviour,'' [41], [42] from [43].

3) APPROACHES TO INVESTIGATING SOCIAL ACCEPTABILITY

In a systematic literature review on social acceptability, Koelle et al. [44] found that studies have mostly occurred in controlled settings and that there is a discrepancy between the findings of empirical studies and the design strategies used for creating prototypes/artefacts. In addition to this we point out that studies outside of realistic settings (e.g. surveys [11]) or using proxies for a functioning AR systems in studies, for example by using photographs [45] or non-functioning mock-ups, demand a huge amount of imagination from future users. To reduce this demand and advance research on social issues around AR systems requires functional technology probes in realistic settings to elicit more informed responses from participants and better contextualised data.

With our research presented here we are extending existing previous work in two main ways: (1) We are not looking at Augmented Reality as a general concept as for instance characterised by sporadic use, direct user control, and a task-/goal-oriented mode of use [1], but are addressing perceptions of Pervasive Augmented Reality as a ''continuous and ubiquitous experience of computer-mediated reality'' [29]; and (2) we are using a functioning PAR technology probe and context instead of rather hypothetical future imagining techniques.

III. METHOD

Based on the findings and gaps identified in literature, in this work, we were interested to gain an understanding of the ethical and social acceptability aspects that are of perceived concern from a pervasive AR technology end user's perspective. More specifically, by deploying head-worn PAR glasses in a semi-public setting, we were interested to investigate the social acceptability of PAR technology, both for wearers (termed *users* in what follows) and observers (termed *bystanders*), as regards i) data and privacy; ii) health and safety; iii) illusion and belief; and iv) rights and access.

With our study we aimed to explore people's ethical and social acceptability perceptions and concerns, elicited after they experience (or observe) PAR glasses in action, with a view to gathering issues that may need to be addressed in the design of future systems. As we discuss in section III-C, we employed a multi-phase study design divided into three distinct phases: an onboarding phase, an observation phase, and a focus group phase (during which questionnaires were completed). We wanted to strike a balance between understanding participants' interactions and experiences in a real world context and ascertaining requirements *in situ*, while still allowing for some controllability of the setting. We therefore opted for a study design that followed a similar approach to a technology probe study [46] or a field experiment [47]. The technology probe, our PAR system, in combination with the semi-public space function as an enabler for an ''informed envisioning'' process.

A. PARTICIPANTS, SETTING, AND STUDY ETHICS

Flyers, announcements to mailing lists and classrooms, and word of mouth were used to recruit 54 participants (32 female, 19 male, and 3 diverse/non-binary) with an average age of 32.04 years. The majority (59%) had no previous experience with AR glasses, 33% had some experience, and 6% had considerable experience (data were missing for one participant). 48% of the participants reported European descent, 26% reported Asian descent, one person reported Maori descent, one person reported Pacific descent, and two people reported Middle Eastern/Latin American/African (MELAA) descent. The participants represent a spectrum of the general population in terms of age, occupation, gender, and previous experience with technology. All participants had normal or corrected-to-normal vision. After the study, participants were offered a $20 coffee voucher as a token of appreciation for their time.

The study environment was a semi-public space at the university campus: the atrium of the Business School building (see Fig. 2). We tried to strike a balance here between ecological appropriateness and controllability of the experiment: participants were acting in an environment which is in actual use by others, including a busy café space, but could be observed in a controlled manner at the same time. The location was signposted, so that everyone present (participants and non-participating individuals) were made aware that an experiment was in progress and that observations were being undertaken. In addition, two large meeting rooms in the same building were used to onboard participants, conduct focus groups and complete questionnaires.

Ethical approval was sought and granted by the University's Ethics Committee board and best practice procedure was followed regarding informed consent, withdrawal, data collection and storage, hygiene, and privacy.

B. APPARATUS AND MATERIALS

For our study we deployed a fully functioning technology probe [46] to participants. The probe was an AR system in the form of sunglasses (see Fig. 1 Center). This system

FIGURE 2. Semi-public study space involving participants as PAR users and bystanders as well as people present during the time of the experiments.

was worn by half of the participants (the users), and observed by the other half (the bystanders) in the semi-public setting described in section III-A. We describe the AR system in section III-B1. All participants filled in questionnaires featuring Likert-like scales, then participated in semi-structured focus group interviews that canvassed their opinions about the potential ethical and societal impacts of the technology. We provide details of the questionnaires and focus group script in section III-B2.

1) AUGMENTED REALITY SYSTEM

The technology probe developed for the study was a prototype AR system with a limited, but fully working functionality. The system emulated a pervasive AR system of the future by using state-of-the-art AR glasses and, after initial setup, a user interface which did not require any manual interaction by the user. Our intention was to emulate a future PAR system, whose operation is based on context- and state-aware interaction, and triggered by proximity cues, running in a semi-public experimental environment that gives us good control over the system's use. Six pairs of Snap Spectacles (www.spectacles.com/new-spectacles/) were used for the study. Physically, these spectacles are quite similar to some of the larger styles of sunglasses available today. They weigh 134 grams and provide a diagonal field of view of 26 degrees for the virtual overlay. The brightness is high enough for most indoor and outdoor environments and the run time per charge is limited to about 30 minutes (according to specifications and our own tests). Our prototype app was developed with Snap's own Lens Studio using Javascript. While this prototype only delivers a very limited set of functionality it serves as an effective technology probe as we will show in our study.

Users were able to walk freely around while wearing the glasses and get context-adaptive augmentations without the need for active intervention or control. Because of the current limited computational capabilities of the AR glasses, after a number of iterations, we opted for a prototype application which just detected markers in the environment (pre-defined pictures) and overlayed dynamically generated and changing 3D text and static pictures. A range of markers were deployed in the study: i) eight different posters acting as markers were placed on walls located throughout the atrium and ii) all participants (wearers and observers) wore marker cards on lanyards, which randomly generated *personal data* about the wearer displayed to AR users; see Fig. 3. The marker posters served two purposes: 1) they depict artistic paintings (by artist Anita DeSoto) for the public and bystanders to admire and 2) to be detected by the built-in cameras for virtual content placement. The content of the overlays was designed in a way to prompt discussions among the participants and had topics like "Launch a book club!" or "Form a choir!". The cards on lanyards emulate a future PAR system where personal information is displayed spatially at or near a person for others to see as augmentations. Using marker cards allowed us to reliably overlay information, even under varying lighting conditions, occlusions, etc. For the information displayed on the cards we adopted forms of information currently used in Empathic Computing research [48]. In addition to some static information on the card (persona name, age, occupation, etc.,) we display (randomly generated) values such as eye blink frequency, body movement activity, and eye gaze detection to prompt participants to think about what information can or should be shared with others.

FIGURE 3. Example augmentations provided by our PAR prototype system; Left: PAR user augmentations, Center: Bystander augmentation, Right: Poster augmented over marker in semi-public space; Note: the overlays are in their actually experienced resolution.

2) QUESTIONNAIRES AND FOCUS GROUPS INTERVIEW SCRIPT

Each participant completed three questionnaires obtaining information on demographics, prior experience with AR glasses, and either perceptions of social acceptability, or ethics. All participants completed the demographics questionnaire asking for gender (m, f, d, skip), age (years, skip), ethnicity (European, Maori, Pacific Peoples, Asian, MELAA, Other, skip). All participants completed the prior experience with AR glasses (none, some, much, skip). Participants who were *bystanders* completed a questionnaire measuring perceptions of social acceptability of the AR glasses. For this, we used a modified version of [49] (on a seven-point scale ranging from "strongly disagree" to "strongly agree") as follows:

- QB1: It looked awkward when this person was using the augmented reality glasses. *(Awkward)*
- QB2: It looked normal when this person was using the augmented reality glasses. *(Normal)*
- QB3: It was appropriate for this person to use the augmented reality glasses in this setting. *(Appropriate)*
- QB4: It was rude for this person to use the augmented reality glasses. *(Rude)*
- QB5: I felt uncomfortable watching this person use the augmented reality glasses. *(Uncomfortable)*
- QB6: I would be distracted by this person if I were at a bus stop with them. *(Distracting)*
- QB7: The augmented reality glasses seemed useful. *(Useful)*
- QB8: The augmented reality glasses seemed unnecessary. *(Unnecessary)*

Participants who were *Users* completed a questionnaire measuring their perception of ethical issues. For this, we used the following questions (on a seven-point scale ranging from ''strongly disagree'' to ''strongly agree''):

- QU1: I was aware of the fact that there was a continuous data capture of my behaviour. *(DataAware)*
- QU2: I think, continuous data capture is ethically acceptable. *(DataAccept)*
- QU3: Using this device breached my privacy. *(PrivacyAware)*
- QU4: I was concerned about privacy breaches. *(PrivacyConcern)*
- QU5: The visual augmentations provided plausible illusions for me. *(PlausibleIllusion)*
- QU6: The augmented illusions are of ethical concern to me. *(IllusionConcern)*
- QU7: Wearing the glasses was a health&safety issue for me. *(HealthSafety)*
- QU8: The visual augmentations seemed to intrude upon property rights. *(PropertyRights)*

The questionnaire questions also served as an initial triggering prompt for the participants to reflect on social acceptability.

For the focus groups, we used a semi-structured interview script to guide the discussion with the participant groups. All groups were guided by the same script. The questions and associated prompts in this script were designed to elicit participants' responses regarding

- their overall experience (e.g. How was your experience of being a PAR user / an observer?);
- notable moments of their interactions with the glasses, with the posters, with each other (e.g. Were there any behaviours/movements /gestures that caught your attention? Any thoughts on the visual augmentations?);
- their thoughts regarding using this type of technology (e.g. perceived value and usefulness, application areas, moving around etc.); and (iv) their thoughts regarding areas of concern that have been reported in existing literature (e.g. general ethical concerns, health and safety, privacy, security etc.).

Additional questions were asked to follow up or clarify participants' responses. Given our main goal was to encourage, as much as possible, participants' open commentary and discussion with each other, the interview script questions were primarily used to start the discussion and guide it, when and as needed. The full list of guiding questions for the focus group interviews can be provided.

C. STUDY DESIGN AND PROCEDURE

Individuals who responded to the recruitment call were contacted by email, provided with the information sheet and, if interested in participating, were assigned to a scheduled study session slot. Each session had an onboarding, observation, and focus group phase. There were seven scheduled sessions with a maximum of 12 participants in each session.

1) ONBOARDING

When participants arrived at the dedicated university meeting room, they were provided with the information sheet to read and a consent form to sign and subsequently were randomly assigned to be either a PAR user or bystander. PAR users were given a pair of PAR glasses followed by a practical introduction on how to turn on and use the glasses. Next, participants were asked to select one of 24 pre-prepared *persona* lanyards (see Fig. 4 and Fig. 3) to represent them for the duration of the study. We opted to create these fictional characters for participants to self-assign to, to avoid revealing participants' actual personal information while still providing relevant contextual information (e.g. people's age, occupation, hobbies etc.,) for the study.

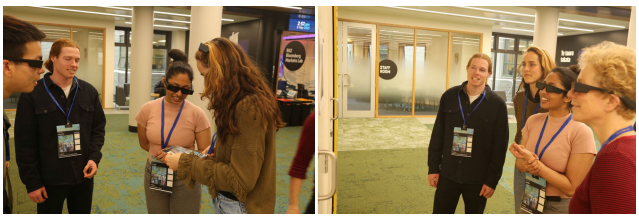

FIGURE 4. Illustration of participants (PAR users and bystanders) exploring the semi-public space.

2) OBSERVATIONS

Both groups, (up to six) PAR users and (up to six) bystanders were guided from the onboarding session in the meeting room to the atrium space where the exposure part (or observation) of the study took place. Once there, the task for PAR users was to look out for artistic posters in the environment (the markers described in section III-B1) and check them for potential visual augmentations (see Fig. 3 Right). The task for the bystanders was to observe the PAR users, including their interactions with the environment, other participants (PAR users and bystanders) and other people present. After about

15 minutes all participants were assembled by members of the research team and guided back to the meeting room for the focus groups.

3) FOCUS GROUPS

Each group (PAR users, bystanders) was moved to a separate room for a 30 minute focus group discussion and to fill out questionnaires (the content of which is provided in section III-B2). Once the focus group discussion ended, bystanders were offered an opportunity to try the PAR technology for about 5 minutes (see Fig. 5). Then all participants were thanked for their time. The entire study took approximately 60 - 70 minutes per session.

FIGURE 5. Bystanders group trialling PAR glasses in a hallway environment (not public; distinct from semi-public exposure environment).

D. DATA COLLECTION AND ANALYSIS

The data collected in the study were of three types: (i) observational fieldnotes, (ii) focus group audio recordings and (iii) questionnaires. The observational field notes were recorded during the Observation phase described in section III-C, and the audio recordings and questionnaires were obtained during the Focus group phase described in section III-C.

1) OBSERVATIONAL FIELDNOTES

While participants carried out their assigned tasks in the Observation phase, members of the research team observed them from a distance, and made handwritten observational fieldnotes on participants' general behaviour (pace, navigation patterns, gaze, body posture), their interactions with other participants or members of the public (e.g. type, length of interaction), any verbal comments, affective expressions, gestures, or anything else that was considered noteworthy.

2) FOCUS GROUP AUDIO RECORDINGS

All focus group interviews were audio recorded using a multi-directional digital audio recorder (Zoom H1) and an iPhone (SE 2nd generation). The audio files were transcribed and pseudonymised for purposes of data analysis.

3) QUESTIONNAIRES

Collected questionnaire responses were manually entered into spreadsheets, visually inspected for outliers and anomalies, and medians and 25/75 percentiles calculated with R using shiny.chemgrid.org/boxplotr/. The results are depicted in Fig. 6 and Fig. 7.

4) THEMATIC ANALYSIS

The data collected from the observations (fieldnotes) and focus groups were combined for purposes of data analysis. Data were analysed thematically using both a data-driven inductive approach and a deductive approach [50], [51], [52]. For the deductive part of the analysis we developed an *a priori* template consisting of the key areas of ethical concern for AR glasses as identified in previous research (e.g. Health and Safety, Privacy, Security). These were included in the codebook and used as high level codes that supported the organization and interpretation of text alongside the inductive analysis of the data. The inductive part, in line with Braun and Clarke's approach [51], involved careful reading and re-reading of the transcripts and notes to ensure familiarisation with the dataset, line-by-line coding, generation of initial codes, sorting and the construction and reviewing of sub-themes and themes. The analysis was conducted by two of the authors who agreed on the codebook, divided the dataset and conducted independent analyses. A subsection of the dataset was double coded (by the same two researchers) to allow for reviewing and discussion of initial codes and themes. The resulting codes and sub-themes were audited by another member of the research team who carried an independent, blind coding of a subset of the transcripts. Members of the research team reviewed and discussed the final themes until consensus was reached that they represented accurately the patterns of meaning that occurred across participants during the focus group interviews.

In the following sections, we present our findings from: (1) Participants' responses as PAR users and bystanders to the Likert-like questionnaire items (QB1-8 and QU1-8, respectively), (2) our observations during the PAR exposure sessions and (3) the thematic analysis of the focus group interview transcripts.

IV. QUESTIONNAIRE FINDINGS

Fig. 6 shows the responses of the PAR users group to their questionnaire items. To summarise: our PAR users were quite aware of the (potential) capture of behaviour data (DataAware), and were neutral to negative about whether this data capture would be ethically acceptable (DataAccept). While no behaviour data capture actually happened in our experiment, participants might well have assumed it was happening, because of the (mocked-up) *personal data* augmented on top of the lanyard persona cards. Ratings given for potentially breached privacy (PrivacyAware) and potential concerns about those breaches (PrivacyConcern) were quite low. Our analysis of the focus group discussions sheds some light on this, including whether the source for such low ratings is due to a general *giving-up on privacy* attitude or the fact that participants were aware they were acting in an experimental study and were therefore

less concerned about privacy. Somehow in contrast, our prototypical PAR system seemed to have provided a sufficiently plausible augmentation illusion (PlausibleIllusion), and along with this, a fairly strong idea that this could be of concern (IllusionConcern). There seemed to be no substantial concerns regarding health and safety (HealthSafety) when wearing such PAR glasses; and AR property rights have been rated inconclusive (PropertyRights). Again, both these findings might reflect the inherently artificial nature of our experimental setting.

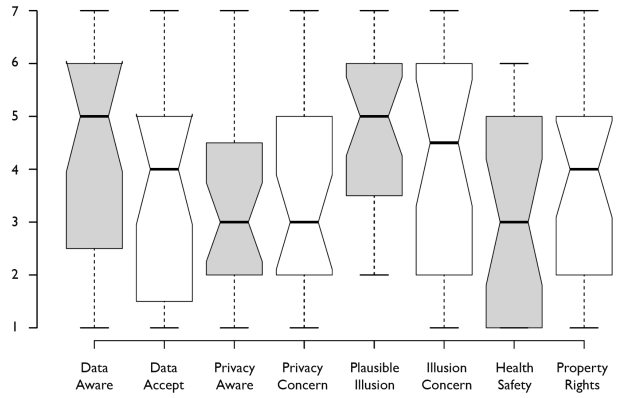

FIGURE 6. Questionnaire Responses for PAR Users. Center lines show the medians; box limits indicate the 25th and 75th percentiles as determined by R software; whiskers extend 1.5 times the interquartile range from the 25th and 75th percentiles, outliers are represented by dots. n = 28, 28, 28, 28, 28, 28, 28, 27 sample points. The notches are defined as +/-1.58*IQR/sqrt(n) and represent the 95% confidence interval for each median. Non-overlapping notches give roughly 95% confidence that two medians differ. Plot produced with R using shiny.chemgrid.org/boxplotr/.

Figure 7 illustrates the responses of the bystanders group to their questionnaire items. Note: The bystanders did get a chance to try the PAR glasses for themselves afterwards (see figure 5), during the exposure session they did not know what the PAR users were seeing or experiencing; as it would be the case when PAR glasses are introduced to end user market groups gradually. Possibly therefore, the bystanders found it rather awkward how the PAR users looked (and behaved) (Awkward). But they were inconclusive as to whether this would be considered as normal (Normal). At least in our study setting (requiring participants to approach reproduced paintings on walls in a semi-public space) those glasses seemed to be appropriate (Appropriate) and certainly not considered as rude (Rude). Apparently it neither felt comfortable nor uncomfortable to watch PAR users using the glasses, but people would feel distracted by people wearing PAR glasses in public (Distracting). The responses for the potential usefulness (Useful) and whether they are unnecessary (Unnecessary) are rather polarized: While the median rating for usefulness is quite high there are outliers indicating potential disagreement; a similar pattern occurs with the notion of whether those glasses would be necessary.

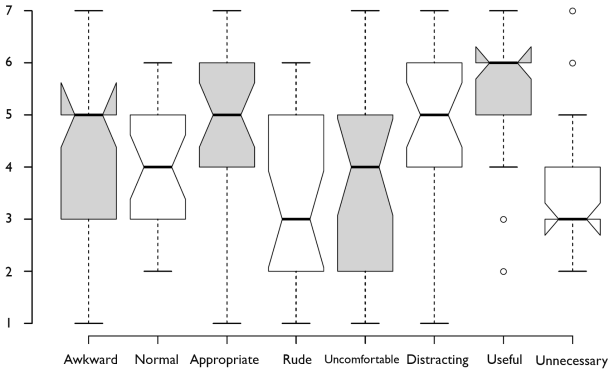

FIGURE 7. Questionnaire Responses for bystanders. Center lines show the medians; box limits indicate the 25th and 75th percentiles as determined by R software; whiskers extend 1.5 times the interquartile range from the 25th and 75th percentiles, outliers are represented by dots. n = 26 sample points. The notches are defined as +/-1.58*IQR/sqrt(n) and represent the 95% confidence interval for each median. Non-overlapping notches give roughly 95% confidence that two medians differ. Plot produced with R using shiny.chemgrid.org/boxplotr/.

V. OBSERVATIONS

During each study exposure activity, members of the research team observed participants and made handwritten field notes on their general behaviour, their interactions with other participants or members of the public, any verbal comments, affective expressions, gestures, and other relevant signals. These notes were subsequently analysed and considered in combination with what participants reported during the focus groups. From the field notes, three interactions were observed more prominently: (i) groupings of participants with the same role (e.g. PAR users with PAR users); (ii) pairings between PAR users and bystanders; (iii) social awkwardness regarding the information on the lanyard and interactions around that.

Some PAR users were observed to sometimes wander off around the atrium space to look at the paintings without engaging with anyone else (see figure 2) or only engaging with other PAR users, while bystanders shadowed in the distance in separate groups. PAR users rarely shared the *hidden information* they saw in the paintings, only disclosing it to bystanders when explicitly asked to do so. This resulted in split groupings of only PAR users or only bystanders coming together to look at and discuss the paintings or the information revealed by the glasses. It also engendered feelings of missing out (for the bystanders) and uncomfortable privilege (for PAR users), among other things, that were discussed extensively in the focus groups (see section 5.1 below). As a counterpart to this, for several groups of participants we also observed the divide between PAR users and bystanders become an opportunity to pair up and experience the paintings together. In this case, PAR users acted as *the eyes* of the bystanders, in that they would look at a painting and describe the augmented information they saw. To a lesser extent, bystanders were observed to inform PAR users of what the actual painting

was showing (as PAR users could barely see the paining under the overlaid information). Interesting conversations were sparked, as participants worked with the other to make sense and combine the different pieces of information or discuss the novelty and implications of the PAR technologies. A third key observation was around the *reading* of the information on the lanyards. As per the study design, some of that information was visible to everyone (e.g. name, age, hobbies of persona), but a subpart of it was only accessible through the PAR glasses. PAR users had some difficulty accessing the augmented information: they had to stare for a while at the card on the lanyard from a certain distance while the other person held still. Having to stare, instead of an easy quick glance, and having access to personal information about someone, without them knowing, created significant social awkwardness and made especially PAR users self-conscious. Bystanders were seen to be equally uncomfortable, and were often frustrated, especially when they felt that not all information was communicated to them.

We note that the form of our study, in which some participants had PAR glasses and others did not, might have created (or at least exacerbated) some of the divisions described above. But it is unlikely to be responsible for all these divisions. Participants were never instructed about whether they should share information or not. And it was entirely up to participants to make the decisions that led to the observed arrangements (e.g. pairings or groupings) and social dynamics. In any event, the asymmetrical access to information that we engineered in our study prompted rich conversations in the focus groups around ethical concerns such social or other divisions, privacy, control and accountability which were discussed in the focus groups. We summarise some key findings from these conversations below.

VI. FOCUS GROUPS

Participants discussed to a great extent similarities but also key differences between the PAR glasses and existing technologies and how those manifest with regards to privacy, security, and social interactions. Significant concerns were expressed about PAR technologies' potential to cause significant societal divisions between *'the haves and have nots'*, pronounce further existing class and privilege structures, and blur reality boundaries. Governance, trust and accountability questions were also debated and often left unanswered. We present these in detail under three thematics: i) The Great Divides; ii) Same, Same, but Different and; iii) Big Questions Unanswered: Who owns, who controls and who is accountable?.

A. THE GREAT DIVIDES

Participants felt the PAR glasses had the potential to cause divisions in society through the asymmetry of access to information, social status and disconnect from reality. These divides were the most prevalent concerns throughout the interviews. Responses to the questions on usefulness of the technology and whether PAR is necessary in our questionnaires also indicate potential for divides. Similarly, our PAR prototype (technology probe) was apparently convincing enough, despite some "awkwardness", to raise questions about what is real and what might lead to a plausibility illusion, including concerns around this; this is quite strongly reflected in the questionnaire responses.

FIGURE 8. Illustration of unequal access to Pervasive AR.

1) THE HAVES AND THE HAVE NOTS

Even in the short amount of time that participants engaged in their tasks in the semi-public space, uncomfortable mixed emotions emerged, along with concerns about the varying access to information and its social implications. A division between the *haves and have nots* was widely described by both bystanders and PAR users with uncomfortable feelings about the divide and power dynamics on the part of the PAR users and on the bystanders' side, feeling left out, excluded from the activity and any enjoyment related to it.

> *Russel*[1]*: "(. . .) there's the haves and the have nots. And what I am trying to say that this world kind of is, you know, there's a divide here, and those with glasses get to see you and hear more about what's going on. And that I'm a little bit uncomfortable with."*

> *John: "(. . .) looking at people's cards, got a bunch of information that people didn't know that I had access to, like, their blinking rate, I think was one of them. Which they didn't know I could see about them. And they couldn't see about me, which again, created a really uneven dynamic and flag power. And I can see whatever I want about them, they didn't know anything about me."*

> *Miriam: "Well, it was curious. That was one thing. But at the same time you're feeling out of place out of fun and what was happening around. So you, I was feeling like left out from what's been happening."*

In addition to the awkwardness and discomfort experienced by PAR users and bystanders, the asymmetric access to information between the 'haves and the have nots' prompted a number of responding behaviors - such as pairing up and purposefully sharing information (see section V) - as a way

[1] all names are pseudonymized.

to repair the divide or diffuse the awkwardness. PAR users felt that they *"should"* tell bystanders what they were seen, but bystanders felt this did not always resolve the issues as illustrated by Matthew's and Miriam's quotes below.

> *Matthew:"(. . .) because they couldn't see what's going on, it felt like you're reading it but they didn't know what was on it. I felt that you should tell them what you're reading."*

> *Miriam:"But from their perspective to understand how it was going, it was nice to hear what they say, though we couldn't figure out what exactly was going on (. . .)*

PAR glasses were seen as pervading all aspects of everyday life, from work opportunities to participation to social and fun activities. Interestingly, opting out was not perceived as a viable option. As John describes below, one can choose to not use the glasses but that can set them 'on the backfoot' as they won't be able to participate in everyday activities in the same way:

> *John: "Yeah, it's like, you basically have the choice, but not really, like you could choose not to use the stuff but in return, you're not going to be socializing, you're not going to get the information you're getting. And you're also not going to get the same opportunities and stuff. So it's like, sure you can if you want to live like a miserable existence, like go for it. (. . .) already, if you don't use the internet, you might not see like any jobs or like you can't talk to people, unless they choose to call you or (. . .) so that was one thing where it was like, the people without the glasses just couldn't participate in the same way. And they were just immediately on the backfoot, socially."*

PAR glasses were considered particularly problematic in the context of social interactions as they were seen as creating a boundary and significantly altering the way people engage with each other as Joni, one of our bystanders, highlights. Both PAR users and bystanders discussed how in addition to social awkwardness, a distinct otherness was felt and the social judgement went both ways, deepening the divide.

> *Joni: "I had a different experience. I didn't make a group with anybody because I was anti, I found it just very hard to like, just go and converse with people. Very restrictive, like that was a barrier. (. . .) I also observed a lot of people in the glasses were looking at our badges, and not at the faces (. . .) it would still make me uncomfortable because I would think that they would be looking at that info looking at my face and not paying attention to me, not making eye contact"*

> *Andy: "It was awkward wearing them, when other people were not wearing them, it is a distinct feeling of otherness."*

2) CLASS, CASTE AND SOCIAL CREDIT

A number of participants also discussed how they anticipate the PAR glasses creating (or extenuating existing) class, caste and privilege divisions in society. It was discussed, as illustrated below, how, especially in the early days of adoption, PAR glasses may be a symbol of exclusivity and privilege as it not everyone will be able to afford them.

> *Rita: "I don't know, create a little bit more division. Because I think, obviously, glasses in the future become kind of a maybe a class thing. If you can afford them, can you? Rick: "Felt like a bit of an in-club". George: "Yes exclusive.(. . .) Quite uncomfortable, because some people looked at me and they said, Oh, you are kinda poor? Ah, it's so mean. And like, I don't know, like judgey (. . .) very disconcerting."*

Several participants extended this concern to other forms of social casting that can be caused by people's financial or other sensitive information (e.g. criminal records) being made available to the public through the use of the PAR glasses. It was discussed that such 'social credit and casting' practices already exist nowadays in some form but the glasses were perceived as capable to make them more widespread. Others, though, were less concerned about the economic or class divide as they foresaw that companies will make sure they are affordable so they can have more widespread adoption which fits with their business model of collecting and disseminating information.

> *Mary: "I don't see the economic divide. Because I think marketing companies are too clever now. So when this actually becomes accessible, they'll just make it super cheap and accessible to everybody, because the powers and the information they can feed you"*

3) REAL/NOT REAL

Another *great divide* that was discussed extensively by our participants was the reality divide. When discussing potential concerns around the PAR glasses, participants foregrounded how users of those glasses may lose the ability to distinguish what is real and what is not, especially if there is over-reliance to accomplish everyday activities.

> *Jenny:"(. . .) if you rely too much on the glasses, or if there's too much information on the glasses, it might take away from reality and the actual things and structures around you, you might get blinded to them, because you're focusing on something like that."*

> *Paul: "I mean, same as the deep fakes, and I could very well be Johnny Depp in your glasses right now."*

Further, participants who wore the glasses during the study described their experience as disconnected and being in a separate world. This disconnect from the real world as well

FIGURE 9. Illustration of current mobile phone and PAR technology concurrently used (Left) and control and ownership requirements (Right).

as the merging and conflation of what is real and what is not, were seeing as having potential (detrimental) implications for people's mental health.

> *Leanna: "(. . .) it was a little like, not being in real life. It's like being a little bit in somewhere else (. . .) for me, I would like a be a little bit concerned from mental health point of view, how that would affect people (. . .) what the effects of kind of feeling disjointed from reality would have on somebody, and I'd be concerned about that."*

B. SAME, SAME BUT DIFFERENT

In the focus groups, participants generally did not find the PAR glasses to be more ethically concerning than current technologies such as mobile phones, social media or other *smart* internet connected devices. However, certain attributes of PAR glasses, relating to their inherently *permanent, unprompted, all seeing* capabilities, were found to be particularly concerning.

1) SAME SAME. . .

Unsurprisingly, a number of concerns surfaced with regards to the use of PAR glasses around issues such as security, reliability, privacy and the overall business model of harvesting personal data and machine learning. However, these concerns were for the most part discussed in an unimpassioned manner and recognised as not new or specific to the PAR glasses but rather common across most, if not all, technologies nowadays. Future versions of practice (and issues) were also contemplated as part of the natural continuity between existing devices and applications and the PAR glasses, as seen in Andy's quote:

> *Liam: "my concerns are similar to current concerns of like, when you're using your phone, or you're on your computers got a microphone, the person who's recording (. . .)"*

> *Andy: "(. . .) But in saying that, cell phones the way they are now it is pretty much the same thing, you can put it in someone's face to scan it up and link it into the social media, there are things which hasn't not been done yet. It wouldn't be that hard just pulling a bunch of random s**t and stacking it on top of each other to make it happen."*

The similarity between the concerns for PAR glasses and those of current technologies such as mobile phones made some of the participants feel generally optimistic in the sense that these are well known issues and will be addressed. In this respect, it was also suggested that it is a matter of time and education for familiarity and appropriate social etiquette to be developed. This is illustrated by Russel's quote below, where he draws parallels by bringing up the example of smartphones, their etiquette evolution, breaches and current social acceptance.

> *Russel: "Yeah, see, I think phone etiquette has evolved substantially in the last 14-15 years, you know, to where they were highly suspicious devices, and the first people that had phones, 'Why do you want their smartphones? Why you won't like that.' Whereas now that, you know, there is an accepted usage pattern around them. And yeah, you're right. There's still breaches of that. But it's always breaches in society (. . .) And I suspect with enough education, time, and that sort of thing, you know, issues around privacy (. . .) will probably become a bit relaxed once we know how to engage with them once we know how to convey certain usage practice around them."*

On the other hand that same similarity and the foreseen integration of the PAR glasses into the existing technological ecosystem and companies' business model, made other participants, such as George and Andy below, feel suspicious and resigned to the idea that not much can be done and this *"would just be the way it is"*.

> *George: "I think it is concerning. Yeah. But I think that you wouldn't have a say in it. And what happens, would just be the way it is. I mean, there's lots of stuff like that, that is already in place."*

> *Andy: "business models being what data you're going to sign into your eyeglasses, your Google account that you sign into this account. Everything's linked anyway. And that opting in and out, doesn't really exist anymore (. . .) you are the product and they are the customers for your data, mining stuff."*

2) . . . BUT DIFFERENT

Differently to mobile phones, smart watches and other similarly ubiquitous technologies, participants assigned to the PAR glasses an *unprompted, all seeing* capability, which was a prominent point of concern as it allowed for different types of privacy and security breaches. PAR glasses were perceived as being able to see and expose more and/or different sensitive information of people's physical, personal surroundings compared to current devices such as where they are keeping their house key or storing valuables.

> *Claire: "when and then when you're wearing this, and you will be definitely accessing very sensitive information like your bank password, or your email*

password or something valuable, you know, that you are storing your valuables in a place, you might be keeping your key, your house key in a secret place for your kids to have access. So all this I think it's kind of out there in the space that anybody can take it and misuse it."

For many participants the biggest issue was that this *all seeing* capability could be 'always on', available in an unprompted and not transparent manner, where PAR glasses were able to see and record the surroundings and others constantly without their knowledge. This aspect was to some extent prompted by the fact that in our study PAR users could see information on the lanyards which was not available to the bystanders.

Miriam: "[in social media] so I have the choice of posting what I want in which group I want. So in that way, I can limit who sees what, I'm not really sure if that's happening with this one. Because whoever has the augmented reality glasses could find [anything]

John: "(. . .) looking at people's cards, got a bunch of information that people didn't know that I had access to, like, their blinking rate, I think was one of them. Which they didn't know I could see about them.

A further distinction between the PAR glasses and existing technologies that participants found especially problematic was how they perceived them as a potentially permanent *"interface" (John)*, augmenting one's surroundings constantly. This was found to be particularly concerning as it could allow bad actors to (more) permanently control and manipulate what one sees. As John explains in the quote below, bad actors can already manipulate what one sees online and over their phone but these can be turned off whereas PAR glasses mediate more directly how one interacts with their physical environment.

Chris: "hackers can actually hack into your glasses and make you see things you don't want to see."

John: "Plus, there's something sort of almost permissively uncomfortable about having everything in my environment, having an interface over it like having, like, on that note of like, people manipulating images, you could argue that kind of happens already with the internet, and then media, you're gonna see that all the time. It's like a small idea that you might get to control your access to because it's in about like a phone and you put it down, but if like, I literally can't look at the physical environment without encountering the idea that would get quite manipulative"

Participants were also concerned about the glasses creating an unprompted and passive consumption of information which exacerbates the current practice of looking someone/something up. This can in turn lead to new forms of or expanding addictive behaviours, The PAR glasses' permanent augmentation was also seen as capable of exacerbating existing echo chambers and prejudice, an equally worrying consequence highlighted by Marco's excerpt.

Marco: "yeah. I feel like it would really contribute to the ideological echo chambers that social media already creates. And it means instead of just being in this, you know, self repeating chamber, when you're online, you would be in it all the time. And I think it means people who are, you know, in those kind of areas are going to really stay and people are gonna really stay entrenched in that because it's, they're going to be bombarded with it or experiencing it all the time if they've got these glasses."

C. BIG QUESTIONS UNANSWERED: WHO OWNS, WHO CONTROLS AND WHO IS ACCOUNTABLE?

Participants also debated questions around the ownership of information, who can, will or should control access to information, potential models of governance and accountability and expressed concerns including general mistrust regarding the handling of those for PAR technologies. This complemented the already identified presence and absence of concerns in the questionnaire responses about the awareness of privacy breaches. While there seemed to be a general notion of whether it is worthwhile to lament over privacy issues, e.g. because one already gives up on the idea of privacy or because the study was seen as an experiment only, there seemed to be a sense of concern around who is controlling information provision.

1) WHO OWNS AND WHO CONTROLS?

A central debate that was sparked among our study participants concerned the ownership of the information shown and collected by the PAR glasses. Possible scenarios were considered where various third parties—central authorities, police forces or even owners of the glasses—are granted automatic access to others' data. Participants expressed their suspicion and mistrust as they recounted several ways where this can become very problematic.

Marco: "we could say, yes, we want our social media presence to be available to anyone with the glasses, but you can easily imagine like police forces and stuff, having access to like a prison record and stuff immediately pop up when they see you (. . .) it's not going to be these just produced for the good of the people. They're produced by some company wanting to make profit and wanting it for some reason."

Unsurprisingly, participants felt strongly that users should have the right to their own information but also acknowledged it becomes more complex as one considers those who buy/own the device and how the device already includes

others' information as Claire reflects very succinctly in her quote below.

> *Claire: "so I think the user should have the right of all information. Or the information of you is your right, not somebody else who is buying the device, though, the device has got somebody else's information."*

Being able to have the right to one's own information extended also into that people should be able to choose what is shown about them (especially as it may be different to official records) and overall, have full control of who, how, when and where can see or access it.

> *Joni:"but I think what would be important is knowing what's displayed and choosing what's displayed about myself.(. . .) How, what you present, and what information you give to people might not always be what's recorded."*

Where full control and ownership was not seen as a viable option, a number of other solutions were suggested, from small mitigation mechanisms to opt in/out, to more major interventions. With regards to the small mitigations, participants discussed having a distinct recognisable form factor for the glasses, visual or other indicators of when the glasses are in use. Interestingly the form factor preference shifted depending on whether one was seeing themselves as a PAR user or bystander which participants acknowledged as a difficult dilemma:

> *Liam: "Possible mitigating factor is have like, some visual indicator that like, oh, the microphones being used, oh, your gate gaze detection is being used. And then like, by whom, for what, but that's a lot of information show one. So it could just be to have some small icon saying this feature is being used."*

> *Anna: "I wouldn't want them to be too recognizable, because you know, wear them because it's embarrassing. But then again, like I think that people should be able to tell because like, if they had like an app that (. . .) It's kind of Black Mirror-esque, but like if you looked at someone, then like in the glass would like, list all these facts about them. You didn't even know that, like, as the person subject, you probably want to know that"*

In terms of the more major interventions, participants expected legislative action to be taken to protect privacy and even discussed options like declaring people as a "*protected entity*" for purposes of the PAR glasses.

> *Andy: "But I feel like, you know, the easiest way to avoid most of the issues with it would just be to call human beings like a protected entity that can't be scanned by them or something."*

The ownership and control of information collected/shown through the PAR glasses was also critically examined with respect to empowering people. Some participants saw opportunities for PAR glasses to create more transparency, open up access to data and break the monopoly of companies and governments; while others disagreed and stressed how this cannot happen unless the proprietary access to the making of such devices is democratised.

> *Andy: "My opinion is that it's not power to the people until we can actually make our own AR glasses or cell phones from scratch using sort of stuff that's been checked out by people, because we're still signing into the business model of data being bought and sold. We don't know yet, whether it be the government or the Apple, or whatever."*

2) WHO IS ACCOUNTABLE?

Participants also debated the accountability of PAR glasses and pervasive technologies in general. A particular concern was around who is responsible to prevent such technologies from getting misused and moreover, who is responsible (to hold others accountable) when things go wrong. Some participants felt strongly that each one of us is responsible for ensuring that such technologies do not get misused or abused.

> *Claire: "I think it is your personal responsibility to not wanting to see something else, which distracts you, like a movie, or maybe like horror movie or something like that (. . .) If it is something important, something that confidential, it is your responsibility to take it out and maybe switch it off or keep it but it won't happen all the time. You know that"*

Others felt that accountability and moral responsibility need to be attributed and checked long before such technologies reach end users, starting with the companies that make them, from the coders – and their potential inherent bias – to the company ethos and policies.

> *Joni: "I just want to comment on this as well, just about anything that's coded. Right? It all comes from somebody's code is not magic, so who is coding it? So would it again, be a bunch of white people coding these glasses?" Michael: "But again, it depends on which goes back to the policy of the company. So what how do they promote? Do they have certain stance against say, 'Look, we're not going to promote any extreme extremism content?'*

However, when things go wrong, it was deemed that it was not *up to the people* to come up with solutions; it was further felt that companies would not have the will or the power to administer accountability. Accountability was seen as the responsibility of various branches of the government or *higher authorities*.

> *Lucy: "You raised a good point before about, like, the moral obligation of the companies that are collecting the data, like of the data indicates something that could potentially go badly. Like, where's the line? Do they have an obligation to*

report it to people or it's a well, you know, we're not the police, we're not, you know, the higher authorities, we're just essentially data collecting, like, obviously, something will have to be done about that as well. That's the road we're going down. And that's really interesting."

Alongside the discussion of the moral or formal responsibility or accountability, questions about who gets to decide what is a good or nefarious use of such technologies and/or what is good or bad in general, came to the forefront as a big concern. As one participant posited, the amount of information that will be available with PAR technologies and the judgment attribution possible, can be so powerful (in good or bad ways) that it could constitute a new religion.

Michael: "So who defines I mean, like, is the company that is collecting the data that starts defining this is good this is bad? So to me this will start becoming a new form of I think religion because it's, it's about someone defining how can we use this data? Again, it's all collected in from structured data and start making decisions based on what they think is right or wrong."

The three thematics presented in this section have highlighted participants' nuanced understandings and concerns regarding PAR glasses and their deployment in everyday life. In the next section, we discuss how this study and findings are situated within existing literature and propose key recommendations.

VII. DISCUSSION AND CONCLUSION

There is a substantial body of literature in the space of augmented reality and pervasive technologies that provides valuable insight into potential future effects of AR in general and to some extent pervasive AR (even in the absence of this term) [53], [54], [55], [56]. Our work contributes to this space by providing a nuanced understanding of people's perceptions after they have experienced the use of Pervasive AR glasses (either directly or as a bystander) in an realistic everyday context. We aimed to investigate the perceptual and ethical space of pervasive AR in an open, exploratory manner that approximates real world conditions, similar to Moran et al.'s study [57] but in a controlled way to ensure the safety and wellbeing of our participants.

We developed a pervasive AR glasses prototype system serving as a technology probe and deployed it in a semi-public context somewhat similar to that which would be experienced in the future with actual PAR glasses. It simulated a scenario in which PAR glasses are gradually introduced, where some early adopters have glasses while others do not. Finally, it exposed our participants to the general public and not only to other participants, all these with the aim to provoke more ecologically valid responses from our participants. We felt this was necessary as in previous studies (e.g. with Google glass [58], [59], [60]) the technologies used did not offer the same form of augmented reality nor a continuous (pervasive), context-adaptive experience. Google Glass in particular, while often a reference for academics and general public, is not an augmented reality system since it does not register any virtual content in the real environment; it can and should rather be seen as a near-eye smart phone monitor. Our study found that several issues raised by our participants aligned closely with issues identified in the literature on AR and Pervasive AR impacts. But we also identified several new issues that have not previously come to light. We identified three main themes around the perception of pervasive AR: the great divides between the haves and the have-nots in relation to the new technology, similarities with and significant differences to existing technologies, and the big unanswered questions about ownership, control and accountability. Some aspects of those three main themes have relationships with and are denoted in the existing literature as well in part by our questionnaire findings. Figure 10 depicts a coarse view of the main relationships.

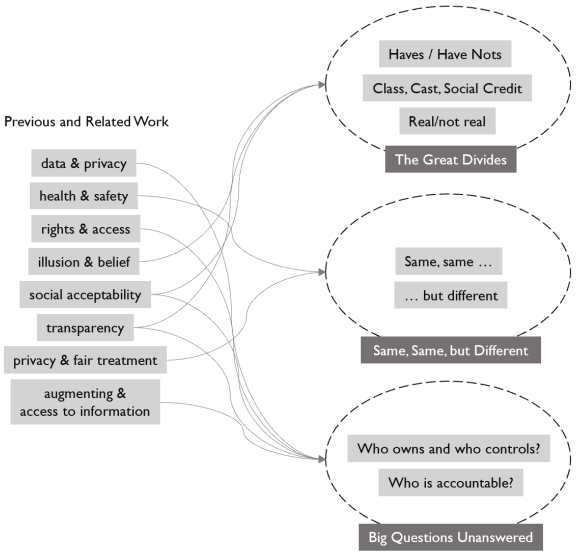

FIGURE 10. Indicative relationships between findings in previous work and our found concepts.

We found that existing technologies as experienced by our participants already show damaging effects on societal equity which might be become even more pronounced and asymmetric with Pervasive AR, but also might lead to mechanisms to repair what is fractured and out of balance.

A. ASYMMETRIES OF THE PAR EXPERIENCE AND FRACTURING EFFECTS

Throughout the literature, and also evident in the findings in this study, the experience of PAR is asymmetric — split between those individuals with access to the pervasive augmented reality and those without. As we discovered in our study, clear asymmetries of experience exist between users and bystanders, which echoes the work of, for example Cho et al. [61], who refer to the environment in which users

and bystanders are interacting, as itself asymmetric. In our data, the asymmetries were evident in the level of uncertainty experienced by the bystanders about what information was being displayed to the PAR users, but also in merely *knowing* that PAR users could access information that bystanders could not. While some PAR users felt a sense of obligation towards bystanders to share that information, this was not expressed by all PAR users. This suggests that if disclosure of the existence of augmentation in the environment is left up to individuals, informational asymmetry may become problematic in that issues of autonomy and consent may not be appropriately addressed in that environment.

However, in our data, asymmetry of experience also plays out along another axis — that between third parties (business, or government interests) and the users and bystanders. Participants in our study grappled with issues of control and ownership of information in the hands of third parties. There were several types of third parties discussed such as governments, state and public authority organisations and private (tech) companies. These were seen to either behave equally problematically in terms of e.g. their collecting of people's data for their own (often non-transparent) purposes; or assigned specific evilness e.g. companies want to make money, state wants to surveil people; or they were seen as having protective functions e.g. government regulating tech companies.

These asymmetries are concerning for our participants who foresee broader fracturing effects on people's lives and society at large. If the informational, interactional, social and regulatory asymmetries are allowed to continue, or are exacerbated further through the use of PAR technologies, it can lead to worsening digital equity issues, financial disparities, abuse of power and human rights. Considering how this can be prevented or addressed is a challenging problem in itself.

B. REPAIR WORK

In our study we also observed how participants engaged in direct actions or negotiations with others to try and address or overcome these asymmetries and carry out the activity we had set for them. For example, as we presented earlier, participants either paired up (bystanders with PAR users, or PAR users with PAR users) or withdrew altogether from trying to interact with PAR users or the task (usually the bystanders). We call this 'repair work' and we see it as an attempt to mend or cope with an uncertain or socially uncomfortable situation. The term is not new — it has been used in similar ways in human geography to address divisions of labour along class, gender etc., [62], in sociology to describe the *mechanics of the workplace* [63] and in HCI for example, in the context of conversational agents [64]. Similarly to those works, we posit that overcoming asymmetrical experiences requires repair work between users and non-users that involves fragile negotiations between actual or imagined aspects of the design and ongoing adjustments of the actors involved. This repair work was substantial in the context of our task and was not always successful in 'repairing' as discussed by the participants in the focus groups. Thanks, or due, to our study design, since we had users and bystanders, we could nuance the divides and asymmetries and observe examples of repair work, but different repair work is likely to occur depending on the context, the social dynamics and actors involved. Also repair work is likely to be required between users, non-users and third parties, which is something we did not directly observe but our analysis indicated some possible avenues such as prohibiting use of PAR in certain areas or for certain types of data and placing humans under special protection status. It is possible that repair work or simply the clunkiness of negotiating these asymmetric experiences may smoothen over time, similar to how we have seen behaviour adapt with mobile phones. For example, texting on your phones or taking a phone call while in another meeting used to be socially problematic behaviours at the very beginnings of mobile devices [65] but currently they are commonplace. Other behaviours though, like taking screenshots of someone else's message on your phone and sharing it with others, are still considered problematic and the rules on doing so debatable. In this respect it is hard to say where people will appropriate, adapt and accept or withdraw. Our analysis also showed that the roles played by participants in our study had a big impact on their perceptions of themselves as PAR users or as bystanders/observers. This view can change almost instantly (cf Brock's notion of changing perceptions of social hierarchies [66]), as exemplified by subjects' changing views on whether PAR glasses should look like normal sunglasses, or be identifiable as technologies providing special perceptual abilities. This potentially indicates that the asymmetry between 'have's and have nots' is more transient and can be repaired once/if PAR glasses become ubiquitous. However, the asymmetry and fracturing between users/non-users of PAR and third parties seems more permanent unless some radical change is made such as democratisation of the PAR production.

C. WHERE TO FROM HERE?

Following from the above, we make two recommendations: i) that any future decision-making for PAR technologies should involve a *digital civics space*, perhaps incorporating methods from our current study, to ensure equal and democratic participation about how these technologies should be used and developed; ii) there is also an urgent need for more *transparency* in current discussions of PAR technologies. In this final section, we will expand on these ideas.

1) DIGITAL CIVICS FOR PAR TECHNOLOGIES

Our analysis and the resulting findings are undoubtedly *co-produced*—drawing in complex ways on our participants' past and present experiences, their interactions with each other and the discussion dynamics during the study, and

equally from our own experience as technologists, human-computer interaction experts, and citizens. In the same way that recognising this co-production of knowledge is a key premise of any qualitative approach, our findings from this work emphasise that the debate and decision making around PAR technologies should *also be co-produced*. The exact methods that should be used to achieve this are still a matter for debate, of course—but as an overarching proposal, we suggest that a *digital civics space* [67], [68] should be created for debate and equitable, informed participation. We would suggest to extend participatory design approaches where ''a shift in attitude from designing for users to one of designing with users'' [69] is also applied to ascertain the perception of and issues with current and future technologies.

A digital civics space can interrogate power relations and changing hierarchies and at the same time compel for 'designing for and with the people', bringing participative and dialogical processes to the forefront of discussions about how such technologies are developed, implemented, regulated and held accountable [67], [68] [70]. Such a space can, and should, be used to help us rethink existing divides—for instance, between haves and have-nots, designers and users, governments and people, as mutually responsive and dialogical, as McCarthy and Wright put it in their book *Taking A[part]* [70]. This is particularly important given the transformative power PAR technologies can have in people's lives. Designers of PAR systems will have greater power over users, and greater responsibility. What purposes this power can be used for has not yet received much discussion—but it is a topic where public consultation and discussion is urgently needed [71].

2) AN AMENDED APPROACH TO TRANSPARENCY

Based on our findings, we propose a new, faceted approach to transparency is needed. We need transparency about the options available for pervasive AR in different contexts (such as public or domestic spaces). While such transparency may seem to conflict with the technological intention of PAR, to provide a context-adaptive, almost disappearing interface, our findings suggest that this options space shouldn't be entirely automated. We should give users a high degree of certainty about the provenance of information, about options, and about control and intervention. This can and should be applied to the different environments one is interacting in, to its objects, and also, in particular to people in that environment. Different, user-controllable transparency settings may need to be provided, both for PAR users and bystanders. Given the asymmetry of access, more control and transparency may need to be given to bystanders, perhaps including the regulatory notion of treating contexts as protected and bystanders as a ''protected species''.

Information to be pervasively augmented will come from many different sources: for instance, other PAR users, other media and social media channels, governments, commercial entities, big tech companies, and so on. As different contexts may be liable to different permissions and controls, it is important to make explicit who owns and controls the seeing and collecting of information at any given context [72] and the ability to control for PAR users about what is displayed, by whom, and with what purpose. This might need to include an ongoing mechanism for consent and withdrawal—a dynamic, user-configurable opting in/out scheme. It would also have to include transparency about what is real and what is augmented—without invalidating the pervasive AR experience as such. More research is needed on how to finesse the trade-off between AR realism and adequate transparency; subtle saliency modulations in a user's view can be very effective to this end [73].

One of the main uniquely differentiating characteristics of pervasive AR over e.g. smart phone (AR) technology is its unprompted information capture and display. Neither the non-PAR users are in control of what is captured and displayed (about them) nor the PAR users themselves. Especially for the observed this is not only an undesired effect, but, based on our findings, ethically unacceptable, hence the call for the aforementioned ''protected species'' approach. Technological and empirical research is needed to develop mechanisms for avoiding, or at least mitigating this. Potentially spanning a design space from automated detection of ''information vulnerable'' people, objects, and environments to applying existing capture, detection, and tracking mechanism, e.g. geo-fencing. Whatever mechanisms will be researched, designed, and developed, unprompted information display and capture needs to be controlled.

Future research work should target the specifics for Pervasive AR within an ethical framework, as for instance proposed in a technology-agnostic way by Stahl et al. [74] around conceptual issues and ethical theories, the impact on individuals, consequences on society, the uncertainty of outcomes, perceptions of technology, and last but not least the role of humans, as the way in which we see ourselves and the ways we can interact with PAR environments.

3) TOWARDS DEDICATED REGULATION FOR PAR

Many of our informants' comments were, implicitly or explicitly, about the need for *regulation* in the area of PAR. Participants frequently suggested mechanisms that should be put in place for PAR, to safeguard users and bystanders, and ensure accountability of providers; those suggestions are effectively proposals for regulation of one form or another. The conclusions we reached in the last two sections also bear on regulation: digital civics spaces may provide a useful format for inclusive regulatory discussions, and such discussions are particularly important for determining transparency options for PAR.

There was certainly a consensus in our study that companies have work to do, to make PAR a palatable and safe option for the public. This work may take the form of self-regulation by companies—but we feel it is also likely to require work by standards-setting bodies, or by governments. Much of the work to be done involves decisions about how

PAR companies and information providers should properly *interact*: this is particularly hard for companies to decide individually. Determining conventions for the whole PAR ecosystem may be better done by independent regulatory bodies.

In summary, we would argue that, in addition to the support of technological advancements with pervasive augmented reality, empirical ethics research, information transparency and control, and a new space for digital civics are paramount. These new initiatives may also potentially feed into discussions about regulation for AR and PAR.

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