Exploring Human Values in Mixed Reality Futures

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ABSTRACT

The rapid development of immersive technologies is heralding a shift from purely physical environments to one that seamlessly mixes the physical and the digital. As these Mixed Reality (MR) worlds develop quickly we need to reflect on how human values are incorporated into the design and deployment of the technology. Human values map our perception of the world, reflect attitudes, guide behaviours, and provide us with social and moral grounding. However, there is limited research on incorporating values in the design of MR technologies. This research has three contributions: (1) a playful values-driven workshop design, (2) insights into the values of different groups of people in diverse MR scenarios, and (3) recommendations for incorporating human values for future MR design and application. This work will contribute to improving the ethical and responsible development of current and future MR applications.

CCS CONCEPTS

• **Human-centered computing** → **Mixed / augmented reality**;
• **Social and professional topics** → **Codes of ethics**.

KEYWORDS

Mixed reality, human values, augmented reality, virtual reality, ethics, value-based design, HCI

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1 INTRODUCTION

Questions about the values and ethics underpinning technology design have grown louder over the past few years as concerns about the impacts of new digital technologies on our common humanity have hit the headlines [77]. Mixed-reality (MR) environments, where physical and virtual elements are intermingled, are one such area attracting increased attention and discussion of potential positive and negative impacts and consequences. MR technologies show promise in more faithfully enabling physical interaction in a digital space compared to other Human-Computer Interaction (HCI) technologies, however, there are concerns about which values are compromised in such machine-mediated environments. There is insufficient research to understand the possible impact of such technologies on humans, human values, and lifestyles to meet long-term technical design. Therefore, human-centred reflection on immersive technologies is the core theme of this research.

In this study, we focus on human experiences in designing, developing and applying MR technologies as well as professional visions of MR futures rather than user studies. As Carter and Egliston wrote, "a better understanding of these human-value-technology entanglements can substantially contribute to a more responsible design and use of technologies" ([10], p. 5). To explore human values in MR futures, we propose the following research questions:

- **RQ1:** What human values matter to MR futures and how do they differ across groups and applications?
- **RQ2:** How might human values fluctuate in MR futures over the next 100 years?
- **RQ3:** What actions can we take to incorporate human values in future MR design?

Researchers conceptualise values in a variety of ways. This research is not about coming up with yet another ontology, but instead working with existing value theories (e.g., Schwartz's value theory [70]) to explore the temporal dynamics of what and whose values relate to MR technologies. To better fit the context of HCI and account for the complexity of social life [21], we will use the term *human values* described by Friedman to mean *what is important to people in their lives* ([23], p. 24). We seek to explore the values at an individual level from people's understanding and articulation, and their perception of how those values apply to different *groups of people*[1].

The technical perspective discussed in this research is immersive technology, a technology that blurs the boundary between the physical and virtual worlds. Such technologies, including Augmented

[1]We initially used the term *stakeholders* to describe the different groups of people, but we noticed that the term caused participants to think about institutions such as governments or companies, perhaps due to their familiarity with its use in corporate contexts. To redirect their attention back to people rather than organisations, we first considered using *population groups*, though it has connotations of groups of people with shared characteristics (e.g., race, religion, age, gender, etc.) which do not perfectly match our study. Finally, we chose to use *groups of people* to avoid such loaded meaning.

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Reality (AR) and Virtual Reality (VR), enable users to experience a sense of immersion [82] which reveals a new perspective on human activities. This research focuses on emerging MR[2] technologies that are beginning to have the capability to blend virtual objects with the physical world in a way that is both more pervasive and difficult to distinguish compared to the immersive isolation of traditional VR and the obvious information enhancement of older AR technologies. The potential impacts on people and society of the seamless blending of the digital and physical is both exciting and concerning. Therefore, it is important to introduce human values into the thinking about MR experiences in order to guide the design of future MR technologies and applications.

This paper has the following contributions to improve the ethical and responsible development of current and future MR applications:

(1) A playful values-driven workshop design and template for researchers to continue to explore MR futures orientated by human values. This workshop can be used to identify different groups of people and their values in diverse MR scenarios, prioritise values and explore challenges and opportunities.

(2) Insights into the values of different groups of people in diverse MR scenarios. We identified thirteen MR application scenarios involving various groups and their values. These findings can help MR researchers and designers understand how values differ across groups and scenarios.

(3) Seven recommendations are provided based on findings from five workshops. These recommendations are for incorporating human values into future MR design and applications.

This paper is written for everyone who is interested in or concerned about the possible futures afforded by MR and how they may affect the values by which people want to live. MR researchers and designers can design more responsible and ethical MR technologies based on our recommendations. Technology ethics researchers can use the workshop we have designed to explore values and other ethical issues in their research.

2 BACKGROUND CONTEXT

To introduce the human-value perspective into an MR context, this section first introduces MR definitions and application domains. We then review existing theories and research methods on the discussion of human values. Finally, we summarise relevant research on the discussion of values in MR and the importance of designing for human values in MR.

2.1 Mixed Reality

MR can be defined in a variety of ways depending on the context. Speicher et al. [80] found six overlapping notions of MR in the literature: as broadly describing the *reality-virtuality continuum* [51]; a *synonym* for AR [46]; a type of *collaboration* [7]; a *combination* of AR and VR [55]; *alignment* of environments [67] and as a *stronger AR* [91]. The first and most widely known usage of MR is in describing Milgram and Kishino's reality-virtuality (RV) continuum which was first introduced in 1994 [50]. However, The limitation of this definition is that it focuses heavily on the visual displays mixing the real and the virtual reality (technology perspective) and ignores the continuity of the observer's overall perception (experience perspective). Therefore, Skarbez et al. [78] proposed a new taxonomy of MR experiences based on Milgram and Kishino's RV continuum, and argued that an MR environment presents real-world and virtual-world objects and stimuli in a single *percept*. In this paper, we revert to a human-centric perspective and prefer the MR definition of Skarbez et al.

The above human-centric definition of MR as a single virtual-real percept is appropriate for this paper's human-values concerns and does not limit its applicability to any one technology. However, for context, we briefly review the current state of the technologies upon which MR experiences are being realised as well as their development trajectory. MR, AR and VR are also sometimes collectively referred to as Extended Reality (XR or xReality) [62] as they all provide immersive experiences. VR devices immerse users in a fully artificial digital environment [30]. A current popular example is the PlayStation VR headsets which provide an immersive gaming environment[3]. By contrast, AR technology supports overlays of virtual objects in real-world environments [56]. However, currently, AR users can still distinguish the digital content from the real world, for example, the Microsoft HoloLens can overlay virtual imagery precisely positioned with respect real objects in the environment, but the "Holograms" are not fully opaque and cannot be confused with reality. The strong AR definition of MR considers applications [66] that not only overlay but anchor virtual objects to the real world [52]. There is quite a lot of excitement right now about the emergence of a new generation of commercial video-passthrough AR headset devices that are the first to seamlessly integrate fully opaque virtual imagery with the environment. These include the recently released Meta Quest 3[4] and the forthcoming Apple Vision Pro[5].

The application domains of MR technologies are experiencing rapid and continuous expansion. MR ranked in the top 10 strategic trends for 2018 [19]. Applications of MR include but are not limited to, education and training [34, 75], gaming [27, 89], healthcare [35], cultural heritage [60], tourism [18] and architecture [85]. For example, MR experiences generally provide near-realistic scenarios in education and training, for safety training [53], manufacturing training [29], military training [11, 61] and so on. As the fields of application of MR become more extensive and complex, it is increasingly important to consider ethical issues in MR real-world application.

2.2 Human Values

The exploration of human values has its origins in philosophy [59], ethics [57] and psychology [49]. Perceptions about human values vary across people, communities, cultures and contexts leading to much debate about universal standards [65]. To address this complexity, Schwartz and Bilsky proposed an early version of the theory to introduce the universal content and structure of human values [73, 74] and revised it in subsequent studies [70–72]. In addition to Schwartz's value theory, Rokeach Value Survey (RVS)

[2]There is no single definition of MR [80] and the term is widely used in relation to a variety of technologies along the reality-virtuality (RV) continuum [50]. In this paper, we revert to an experience perspective and prefer the MR definition by Skarbez et al. to mean *present real and virtual world objects and stimuli in a single percept* ([78], p. 4).

[3]PlayStation VR: https://www.playstation.com/en-us/ps-vr/.

[4]Meta Quest 3: https://www.meta.com/au/quest/quest-3/.

[5]Apple Vision Pro: https://www.apple.com/apple-vision-pro/.

[63] and Hofstede's culture dimensions theory [33] indicate the models for universal values.

A growing number of fields have begun to explore the concept of human values in relation to digital technologies [2, 3, 12, 76]. In HCI, values are often used to discuss what should be, rather than what is [77, 84]. Batya Friedman and colleagues introduced the concept of Value-Sensitive Design (VSD) [22, 23, 25] as a methodology for explicitly accounting for human values in the design of information technologies and systems. They have proposed sets of human values which are important for technology design ([23], p. 28), such as universal usability and information consent. However, the definition of values in VSD has been criticised for not being 'accurate' enough, so Alshehri et al. [4] proposed a new definition based on the philosophical perspective. In addition, many other studies have done work on value inventories, which are lists of items that provide explicit categories for analysing the structure and classification of human values. Cheng & Fleischmann [12] conducted a meta-analysis of 12 human value inventories to develop a 'meta-inventory' of values for use in Information Science research. Moreover, Kheirandish et al. [38] presented a value framework that identifies key human values (e.g., respect for others, meaningfulness, and pleasure) but the technological perspective of values is missing in their framework.

2.3 Human Values in Mixed Reality

The complexity of MR interactive experiences brings the importance of considering human values in MR design and deployment. The complexity arises from the integration of different realities [8, 50], real-time interaction [5], spatial awareness [68], overlaying of digital and physical content [69], and so forth in MR experiences. Human values are part of an ethical framework [6]. Ethics clearly indicates what is right or wrong at the societal level, whereas human values are more concerned with what is valuable to the individual [20]. In addition, values are relatively stable [32], derived from internal principles [14], and therefore guide individual decision-making [64], thus providing insightful guidance for MR design.

Some research in MR has explored specific human values, such as physical well-being, privacy and security [15]. For example, De Guzman et al. [15] presented the first survey on the challenges and approaches to mixed reality with particular attention to security and privacy. Similar to MR, innovations in AR and VR can contribute to improving human welfare, such as assisting disabled groups [10], designing medical applications for patients and medical practitioners, and protecting individuals' physical security [24]. Kudina & Verbeek [41] argued that the introduction of AR technology such as Google Glass "*will impact what privacy means in our society*". However, to the best of our knowledge, no research has systematically explored multiple human values in the context of mixed reality. Overall, comprehensive research on embodying human values in MR technologies needs to be performed. To fill this gap, we designed a workshop to explore human values in MR futures.

3 METHODOLOGY

To address our RQs, we have designed a playful values-driven workshop (simply called "the workshop" in the rest of the paper) to engage both immersive-technology experts and non-experts. We tested our design in a pilot workshop with four participants, then we made modifications before running a series of workshops with fourteen additional strategically selected participants.

3.1 Materials and procedure

We used an online format to bring participants from different locations together synchronously. We designed the workshop in an online whiteboard platform, *Miro* which provides a conducive environment for collaborative brainstorming and ideation. The workshop was conducted via *Zoom Meeting*. We used the "Opening-Core-Closing" framework [37] for designing workshop structures. The workshop opening aimed to establish a shared context, to make participants feel comfortable and prepare them for the workshop core. The workshop core aimed to discuss what human values need to be considered in the development and deployment of MR technologies. In the workshop closing, we asked participants for feedback on what they learnt and how it was helpful in their work. The workshop took two hours in total.

We provide a link[6] to our workshop template accompanied by a brief instruction explaining how to use the template with examples. Readers can open the link and use it directly, or add and modify questions as they see fit.

3.2 Target group

As the workshop is designed to consider MR for society-wide applications, there is a need to have both immersive-technology experts and non-experts in the workshop. We targeted team leaders from a variety of fields as workshop participants. This is because (1) they have in-depth insights and extensive work experience in their fields and (2) their role as team leaders enables strategic consideration of the extent to which MR technologies might be applied in their future work. Target team leaders could come from a variety of fields including, but not limited to, community organisers, medical practitioners, game designers, educators, psychologists and so on.

Following best practices for exploratory studies [40] we designed our workshops for 3-4 participants each; a number that facilitates active and detailed discussion. We aimed to run 3-5 workshops over the time available to achieve a reasonable sample size and a range of participants with diverse backgrounds.

3.3 Workshop activity

To answer RQ1-3, a total of 5 activities were designed in the workshop (for details, see supplementary material Figure 5). We run the workshop in a team-based playful way (through games and visual activities) to maximise engagement in workshop activities and encourage ideation.

3.3.1 Workshop opening. Participants were asked to choose a sticky note in their favourite colour and write down their basic information (name, specialised field, etc.). Then, we introduced the motivation, aim and structure of this workshop. The participants then undertook a warm-up activity designed to establish a shared context. They were asked to write down their initial understanding of MR and human values before we introduced what MR and human

[6]Here is a link to the workshop template: https://shorturl.at/aeD56.

values are. This helped to evaluate the usefulness of the workshop for understanding human values in MR. The workshop opening took 20 minutes.

3.3.2 Workshop core. Two activities were designed in the workshop core to get to the root of the problem via an in-depth discussion. The key activity 1 - *Identify groups of people and their values* - aimed to use an analogy model to enable participants to identify key elements more graphically. This is because metaphors and analogies are commonly voiced as key tools for enhancing creative design [31]. In this activity, immersive technology was visualised metaphorically as a train travelling between the real and virtual worlds. Current users of immersive technology were put as an analogy to passengers who have already boarded the train. Potential users were put as passengers who were waiting on the platform. And people who do not want to use immersive technology as people who do not want to board or have already got off. Participants were asked to brainstorm which groups of people were involved in the different MR scenarios that they proposed; if they were current users/future users/nonusers; and what human values they cared about in these MR scenarios.

The key activity 2 - *Value ranking and hopeful thinking* - aimed to explore what kind of future MR experiences people want and how to achieve it. The value ranking activity followed the Multi-lifespan Timeline method [90] using a 100-year time frame as a scope for discussion. Because we are concerned with designing MR technologies for long-term futures, 100 years is not only a future that we might see within our lifespan but also not so distant as to become as unrealistic as 1000 years. In the context of rapidly changing technology, rapid innovation often prioritises short-term gains and quick solutions. Friedman and Nathan [26] argued that issues related to human values and ethics take time, such as building trust. The concept of a multi-lifespan time frame shifts the focus to the long-term impacts of technology on society and sustainable development, helping to adapt to changing conditions and needs over time. Participants were asked to think about "what values should be concerned about in a future MR world over the next 100 years and rank them in a two-dimensional coordinate system". The horizontal axis was the time span of 0 to 5 years (short-term), 5 to 50 years (mid-term) and 50 to 100 years (long-term), and the vertical axis was three descriptions of the level of value concern (very important, neutral and not very important). Then, participants were asked (1) what are the trends in human values over the next 100 years, (2) what are the barriers that inhibit consideration of human values in the application of MR technologies, and (3) what are the future opportunities when the barriers are removed.

3.3.3 Workshop closing. Participants discussed (1) what they had learnt from the workshop; (2) whether it was possible to apply what they had learnt to their work; (3) what was interesting and meaningful about the design of the workshop and what could be improved; and (4) rate each activity. The workshop closing took 20 minutes.

3.4 Pilot workshop

3.4.1 Participants. We recruited four PhD candidates (*C1, C2, C3, C4*) to test the whole workshop plan, including testing the timing and the effectiveness of workshop activities. Two participants were MR designers, and two were non-MR experts without AR/VR/MR-related knowledge.

3.4.2 Pilot evaluation. All workshop activities have been rated by participants on a rating scale of 1–10. The mean score of satisfaction for each activity is 7.63 (workshop opening), 8.38 (activity 1), 7.38 (activity 2) and 7.00 (workshop closing). Moreover, the participants commented on the design of the workshop during the workshop closing. For the workshop content, C3 commented "the idea is unique, creative and new to me" and "I like the representation of the interior designer". For the workshop structure, C1 commented "the workshop has been designed and managed very well". C4 said "we have guidance" in the workshop and it was "very structured". Overall, participants commented that the workshop was "interesting", "creative" and "collaborative".

Even though some of the comments were positive, participants suggested several improvements they would like to see in the future. C2 and C4 suggested that some questions such as "What are the barriers" should be clearer. C3 believed "more impetus to directly interact with other people's stickies would be fun" such as requiring participants to note on others' stickies not their own. Because in this way the ideas can be better stimulated and spread. Finally, two participants commented that "time is tight".

Based on the satisfaction score and participants' feedback, we improved the workshop design. First, we have simplified the workshop opening and closing to save more time for the workshop core (see supplementary material). For activity 2, we adapted the train analogy model from the pilot workshop to the form of a 2-dimensional table with the horizontal axis representing groups of people and the vertical axis representing different application scenarios. This is because the latter gives participants more space and a clearer partition to write down their ideas than the former. There were no major changes to the value ranking activities in activity 2, except that the vertical coordinates in the pilot workshop were adjusted from a three-point scale "**VI-N-NI**" (**V**ery **I**mportant, **N**eutral and **N**ot very **I**mportant) to a more detailed five-point scale "**VI-I-N-LI-U**" (**V**ery **I**mportant, **I**mportant, **N**eutral, **L**ess **I**mportant and **U**nimportant) (see Figure 1). To visualise the hopeful thinking activity, we used the Future Wheel approach [28] to enable participants to identify barriers, solutions and further social impacts in a step-by-step manner (see Figure 2). In addition, we added a group discussion section to activities 1 and 2 to allow participants to explain and discuss their opinions. To maximise the time for in-depth discussion, the size of each of the main workshops was set to up to four participants. Finally, we used timeboxing and agenda for more efficient time management. With the polished workshop activities, the focus is more clearly on uncovering human values in MR applications.

3.4.3 Pilot results. The pilot workshop demonstrated the significance and usefulness of the workshop. (1) The workshop activities raised the participants' ethical awareness of human-centred values in the application of MR. C4 commented that we "must predict the impacts of MR" and "we may need a human value committee with the advancement of these technologies". (2) It can guide participants who work on MR to bring human-value reflections into their future MR design and application. For example, C3 presented that beyond "ease of use, and convenience", values metrics would be added to

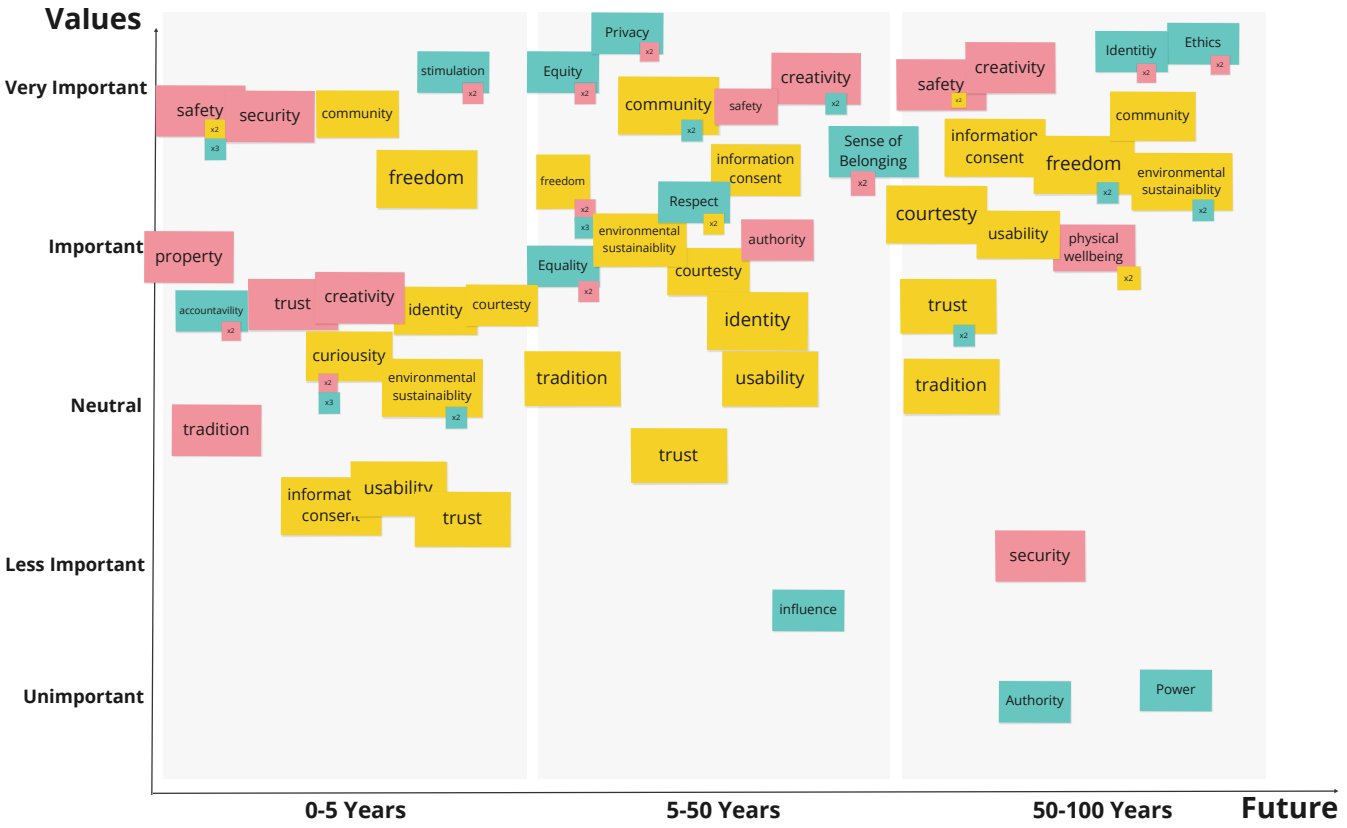

Figure 1: Example of the value ranking activity from one of the main workshops. The colour of sticky notes refers to different participants: P6 (pink), P7 (yellow) and P8 (cyan). The sticky notes "x2" refers to "two participants agreed to the placement of the sticky note" and "x3" refers to "three participants agreed to that placement".

their evaluations of MR technologies design. (3) It can inspire participants in non-MR-related work to develop ideas for future MR experiences. For example, C2 commented that they expect MR to contribute to human "communication, sense and memory" over the next 100 years. (4) Bring new knowledge to the participants. C4 said they did not know that there were many possible MR applications. The possibility of using MR in participants' own work is 40%, 50%, 80% and 100% based on the poll result.

3.5 Main workshops

3.5.1 Participants. We recruited participants from a wide range of domains through AR and VR communities, four authors' professional and social networks, snowball sampling, and social media such as Twitter, LinkedIn and Eventbrite. In addition, we posted general recruitment information to some potential application communities such as GLAMs[7] and Digital Health Research. P1-P4 were recruited through local AR and VR communities. Through the authors' extended professional and social networks, we recruited participants in design (P6), energy (P8), sociology (P9), finance (P13) and sustainable environment (P14). Through snowball sampling, we recruited participants in health (P5), mechanical industry (P7), education (P10), defence (P11) and psychology (P12). A total of 14 participants took part in five workshops (see Table 1).

The participants have extensive work experience in their respective fields (median=11.5 years). Seven participants' works are not related to XR, such as psychology and finance; four participants' works are related to XR, such as VR game design and AR arts; three participants' works are partly related to XR, such as using XR as a tool partly for education assignment. We kept multicultural backgrounds in mind when recruiting participants, 64% of the participants were from Australia and 36% from other countries. The workshop registration form shows that participants were motivated to participate by "sharing ideas with other people who are excited about the future of MR", "learning from exchanging knowledge with people", "interested to meet and talk with other VR developers", etc.

3.5.2 Materials and procedure. We held a total of 5 online workshops (W1, W2, W3, W4 and W5). There were 3 participants in each workshop, except for W2, which was 2 participants[8]. One researcher attended and conducted each workshop in the role of a

[7] GLAMs refers to Galleries, Libraries, Archives and Museums.

[8] It was because two other participants were not able to attend as planned, attending subsequent workshops instead.

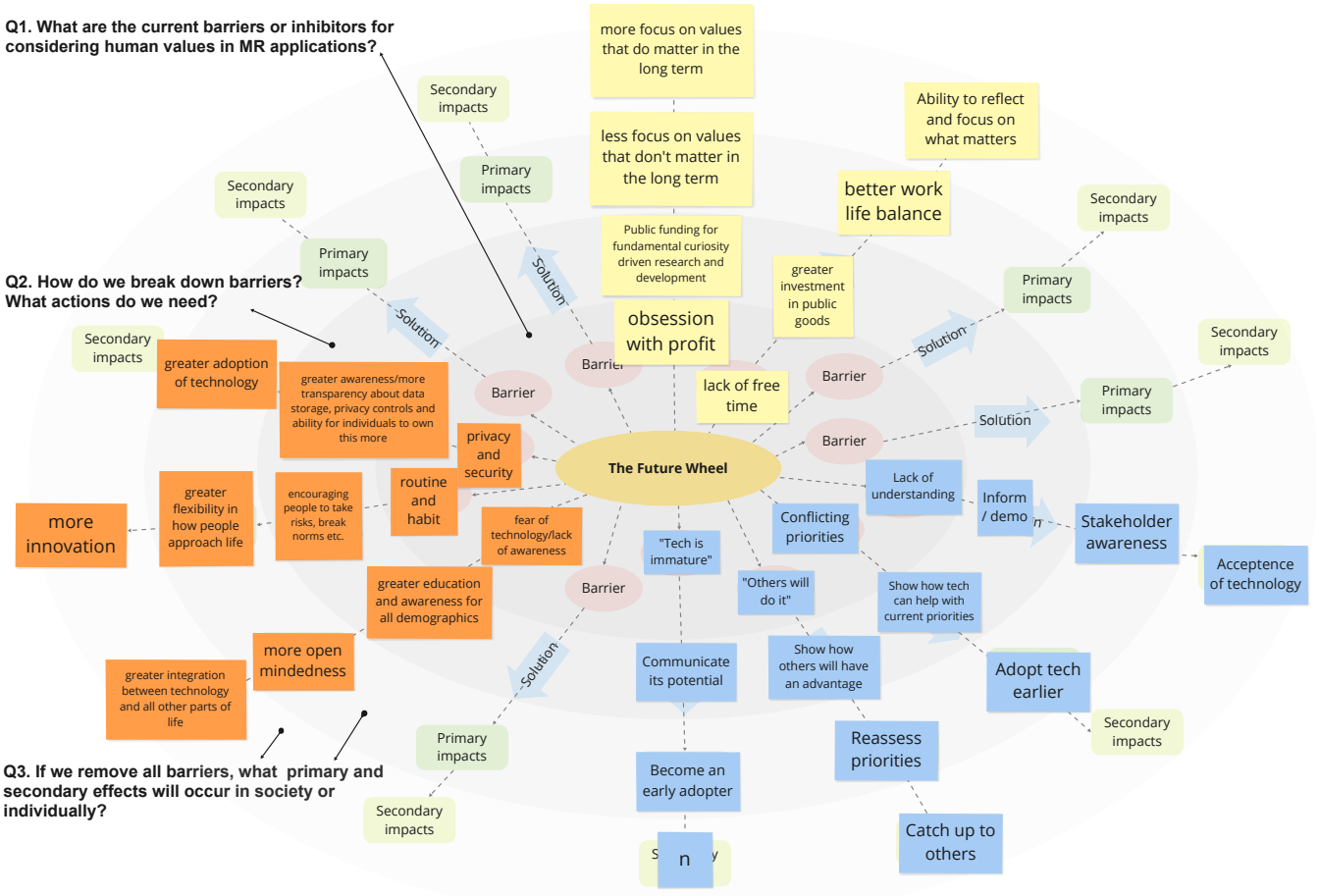

Figure 2: Example of the future wheel activity from one of the main workshops. The colour of sticky notes refers to different participants: P9 (yellow), P10 (orange) and P11 (blue-grey).

Table 1: Workshop participants.

#W	#P	Country	Role	Work Experience (Years)	Specialised Field	XR related work?
W1	P1	Ireland/Australia	Director	24	VR Game Development	Yes
W1	P2	Australia	Marketing Director	7	Tourism Marketing	No
W1	P3	Australia	Independent Artist	3.5	AR Content Creator	Yes
W2	P4	Australia	CEO & Co-founder	12	Volumetric Video	Yes
W2	P5	Australia	Director	21	Paediatric Surgery	Partly Yes
W3	P6	Australia	Program Director	15	Human-Centred Design	Partly Yes
W3	P7	Australia	Engineer	7	Mechanical Engineering	No
W3	P8	Australia	General Manager	8	Energy	No
W4	P9	New Zealand	Director	20	Human Migration	Partly Yes
W4	P10	UK/Australia	Education Manager	11	Education and Entrepreneurship	No
W4	P11	Australia	Discipline Leader	23	Aerospace Engineering	Yes
W5	P12	Australia	Senior Researcher	20	Behavioural Science	No
W5	P13	China	Manager	11	Accounting/Finance	No
W5	P14	Bangladesh	Climate Ambassador	6	Climate Change	No

workshop facilitator. The screen and audio were recorded during the workshops.

3.5.3 Data analysis. The workshop analysis process for RQ1-3 is shown in Figure 3. Data collected from the workshop activities (warm-up activity, activities 1& 2, reflective discussion) included sticky notes that participants posted on the Miro board and transcripts from audio recordings. The sticky notes directly show the participants' responses to the workshop questions, while the audio records the group discussions.

The primary researcher (R1) conducted the first round of coding to code all sticky notes (n=425) based on reflexive thematic analysis [9]. We exported all sticky notes from the Miro board to a CSV (excel) file in the Transcription & Formatting step. We used Zoom closed captioning and otter.ai to capture the transcripts from the audio recordings. These transcripts are integrated into the CSV as

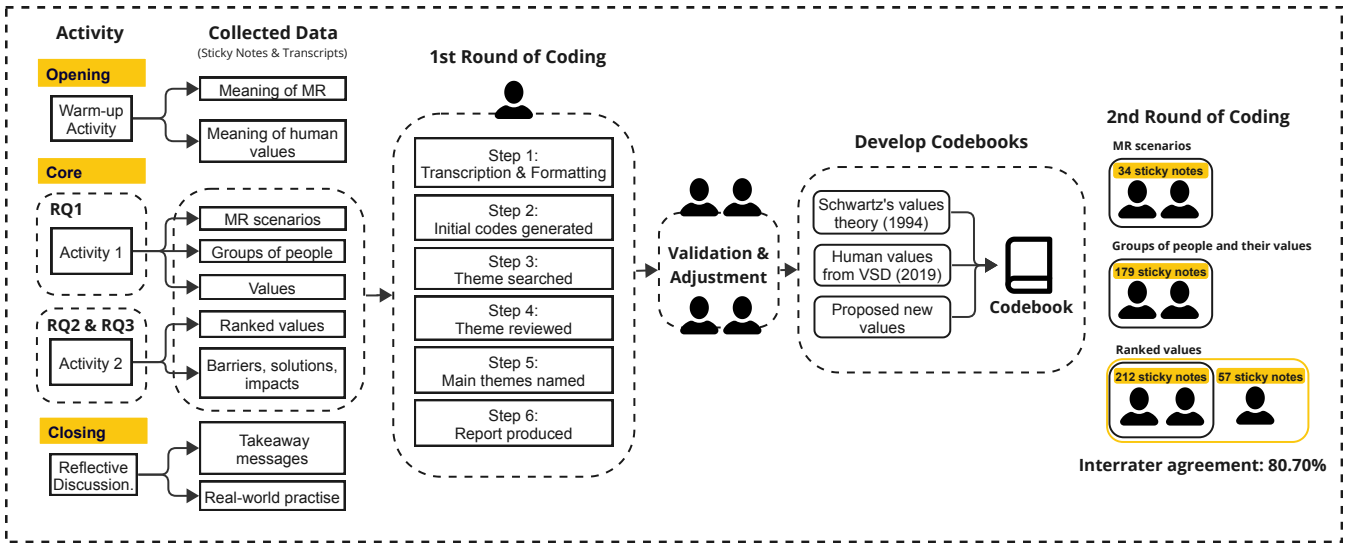

Figure 3: Data analysis process for main workshops.

mentioned above, aligning the data from the sticky notes with the transcripts (participants' oral interpretations of the ideas on their sticky notes). The entire coding process was conducted within this CSV file. Subsequently, we generated an initial list of codes such as "those who use online or virtual tools for training" as one of the groups of people in the education and training scenario. We refined initial codes and identified potential themes, e.g. the group "those who use online or virtual tools for training" was refined to "online training users" under the sub-theme "trainees". After reviewing themes and naming the main themes[9], the results are reported in section 4.

Validation and adjustments were made by focusing on the robustness of the coded results by the four researchers (R1, R2, R3 and R4) in three 50-minute meetings. Then, we developed a codebook based on the human values from Schwartz's values theory [71], VSD [23] and our proposed values (see Table 2).

In the second round of coding, three researchers (R1, R2 and R3) sorted the sticky notes according to their themes by using affinity clustering [47] to classify similar MR scenarios (n=34). The primary researcher (R1) and an additional coder (R5) coded the sticky notes of the groups of people and their values (n=179), and ranked values (n=212). The audio and screen recordings (n=5, 2 hours/recordings) were reviewed by two researchers (R1, R5) to identify interpretations of the participants' perspectives. To evaluate the robustness of the results from the second round of coding, two researchers (R1, R5) and another external researcher (R6) coded the 57 sticky notes of ranked values with an interrater agreement of 80.70%.

4 RESULTS

4.1 Identified groups of people and their values

A total of 34 MR scenarios were generated from 5 workshops. After grouping similar MR scenarios, the 13 themes are listed below in descending order of frequency of mention by participants: medical and health; education and training; tourism, exhibitions, events; industry and manufacturing; aviation; fashion and social media; games; sports; remote work; architecture and interior design; outer space exploration; social work; and finance. Figure 4 shows the relationship between MR scenarios, groups of people and human values[10]. Interesting to consider how much of the discussions of MR in the general media are about lifestyle applications where the value of hedonism is to the fore, whereas for our workshop participants, other values are more prominent in the MR scenarios they chose to discuss. The MR scenarios we included insightfully discussed values are reported below[11]. The representative quotes in parentheses can provide a rich description of the qualitative data. The critical reflection on the results can be found in the discussion (section 5).

Medical and health. Medical and health scenario was discussed in all workshops except W1. Participants identified the groups of people in this scenario as PATIENTS and HEALTHCARE PROFESSIONALS (e.g., surgeons, researchers, medical trainees, doctors, nurses, clinicians, psychologists, general practitioners, medics in the field and medical interventionists). As an expert in digital health, P5 stated that some medical teams have experimented with AR/VR technology for open surgery, orthopaedics and paediatrics. For both patients and healthcare professionals, the value that participants felt should be of most concern was *security* ("100% prove that something is not going to harm a patient (P5)" and "making sure that using mixed reality to allow people to do things more accurately and therefore improve safety and have more trust (P8)"). For healthcare professionals, there is also a need to focus on *universalism* ("new technology that improves health should not just be available to people who can afford it, it should be available to

[9]A final thematic map for groups of people in the Education and Training scenario can be found as an example in the supplemental material.

[10]Created with *Visual Paradigm Online*: https://online.visual-paradigm.com/.

[11]Groups of people and their values in other MR scenarios can be found in the supplementary material.

Table 2: Human values codebook. Core values determined by Schwartz [71], short descriptions adapted from [39] and value examples summarised in this study.

Core values	Description	Value examples
Achievement	Personal success through demonstrating competence according to social standards.	Ambitious, Capable, Influential, Intelligent, Successful.
Benevolence	Preservation and enhancement of the welfare of people with whom one is in frequent personal contact.	A spiritual life, Forgiving, Helpful, Honest, Loyal, Mature love, Meaning in life, Responsible (Accountability*), True friendship.
Conformity	Restriction of actions, inclinations and impulses likely to accept or harm others and violate social norms or standards.	Honouring of elders, Obedient, Politeness (Courtesy*), Self-discipline.
Hedonism	Pleasure and sensuous gratification to oneself.	Enjoying life, Pleasure, Self-indulgent.
Power	Social status and prestige, control and dominance over people and resources.	Authority, Ownership and property*, Preserving my public image, Social power, Wealth.
Security	Safety, harmony and stability of society, of relationship, and of self.	Clean, Family security, Healthy (Human welfare*), Information consent*, National security, Reciprocation of favours, Sense of belonging, Social order, Trust.
Self-direction	Independent thought and action-choosing, creating, exploring.	Autonomy*, Choosing own goals, Creativity, Curious, Freedom, Identity*, Independent, Privacy**, Self-respect.
Stimulation	Excitement, novelty and challenge in life.	An exciting life, A varied life, Daring.
Tradition	Respect, commitment and acceptance of the customs and ideas that traditional culture or religion provide the self.	Accepting my portion in life, Detachment, Devout, Humble, Moderate, Respect for tradition.
Universalism	Understanding, appreciation, tolerance and protection for the welfare of all people and for nature.	A world at peace, A world of beauty, Broadminded, Environmental sustainability* (Protecting the environment, Unity with nature), Equality, Inner harmony (Calmness*), Social connection***, Social justice (Freedom from bias), Universal usability*, Wisdom.

** Refers to the values from the VSD ([23], p. 28); ** refers to the values included in both the VSD and Schwartz's values theory;*
**** refers to the values we proposed in this study; other values are from the Schwartz's values theory [71].*

everybody (P14)"), *benevolence* ("we expect them [clinicians] to be more transparent and accountable and evidence-based (P12)") and *self-direction* ("privacy (P12)", "creative (P5, P8)", "autonomy (P13)"). Both P5 and P12 believed that the application of MR in medicine and health has great potential: (1) P5 stated that MR can be used to reduce pain by distraction when giving children intravenous injections. Giving children a VR device during intravenous injections can give them a better experience because they are more curious (*self-direction*) about what happens in VR (e.g., playing cartoons). (2) MR can be used to communicate with the patient thereby increasing the patient's *security* (trust and information consent. P4 and P5 stated that if MR can be used to visualise the cause of disease, such as superimposing images on the human body, it can greatly improve communication with patients. It may also improve the patient's level of information consent and trust in the treatment plan. (3) MR can be used for consultation with remote professionals to increase their *self-direction*. P13 noted MR offers the possibility for telemedicine, helping to improve the ability of remote professionals to diagnose, rather than being influenced by physical distance.

Education and training. Education and training scenario was discussed in all four workshops except W4. Participants identified the groups of people in this scenario as LEARNERS (e.g., students and trainees) and EDUCATORS (e.g., teachers, tutors, coaches, course advisors, supervisors, research collaborators, education designers and librarians). Participants from W3 pointed out that MR could be used in university education to visualise things without using physical materials to improve the student experience, such as "visualising buildings in an architecture class (P6)". P1 labelled *security* and *trust* for the future students because "they have to believe that it's not going to get leaked or whether they're safe to use this [...] It's not going to be exposed [...] outside of the classroom for example." P2 hoped that MR learning experiences should include values of *stimulation* ("probably like entertainment, like fun and it can be more engaging"). P3 thought *universalism* should be concerned as whoever (including students and teachers) were involved in education could use MR for "a better way of communication".

Tourism, exhibitions, events. Participants from W1, W3 and W4 identified the groups of people in this scenario as VISITORS (e.g., tourists and museums/galleries/aquariums visitors, art critics, educators, students, the general public) and ORGANISERS AND SUPPORT STAFF (e.g., government personnel, curator, gallery/museum managers, artists/designers/content creators, tech support, guard, cleaners, event punters and video music DJs). For visitors, participants suggested *self-direction* ("curiosity + discovery (P9)"), *hedonism* ("entertainment (P1, P3)") and *universalism* ("you can explore a city that doesn't have your language (P2)"). For organisers and support staff, *security* ("if mixed reality technologies especially if they're interactive, they'd [guards] be looking at safety and security (P6)"), *universalism* ("[consider environmental sustainability] like firework shows could be virtual instead of actually using real explosives (P2)") and *power* ("exerting their power to make sure that people do things correctly (P6)") were more concerned.

Aviation. Participants from W3 and W4 identified the groups of people in this scenario as AVIATION PROFESSIONALS (e.g., pilots, airline staff, maintenance crews, air-traffic control staff, engineers, commanders, defence experts, aircraft manufacturers and quality assurance staff) and AVIATION RELATED INDIVIDUALS (e.g., passengers, passengers' families and aircraft owners). As an aerospace engineer, P11 believed MR can help aircraft maintainers crews remotely in repairs and evaluations which would benefit *security*, *universalism* and *benevolence*. P11 said aircraft deployment and rapid response were critical in the defence field. So the use of the MR could make defence experts more capable (*achievement*) to remotely assess the aircraft, thus maintaining greater response flexibility. However, wearing MR equipment might also hinder the speed of repairs, so experienced engineers might not want to use MR equipment as they are more experienced in the current way. In

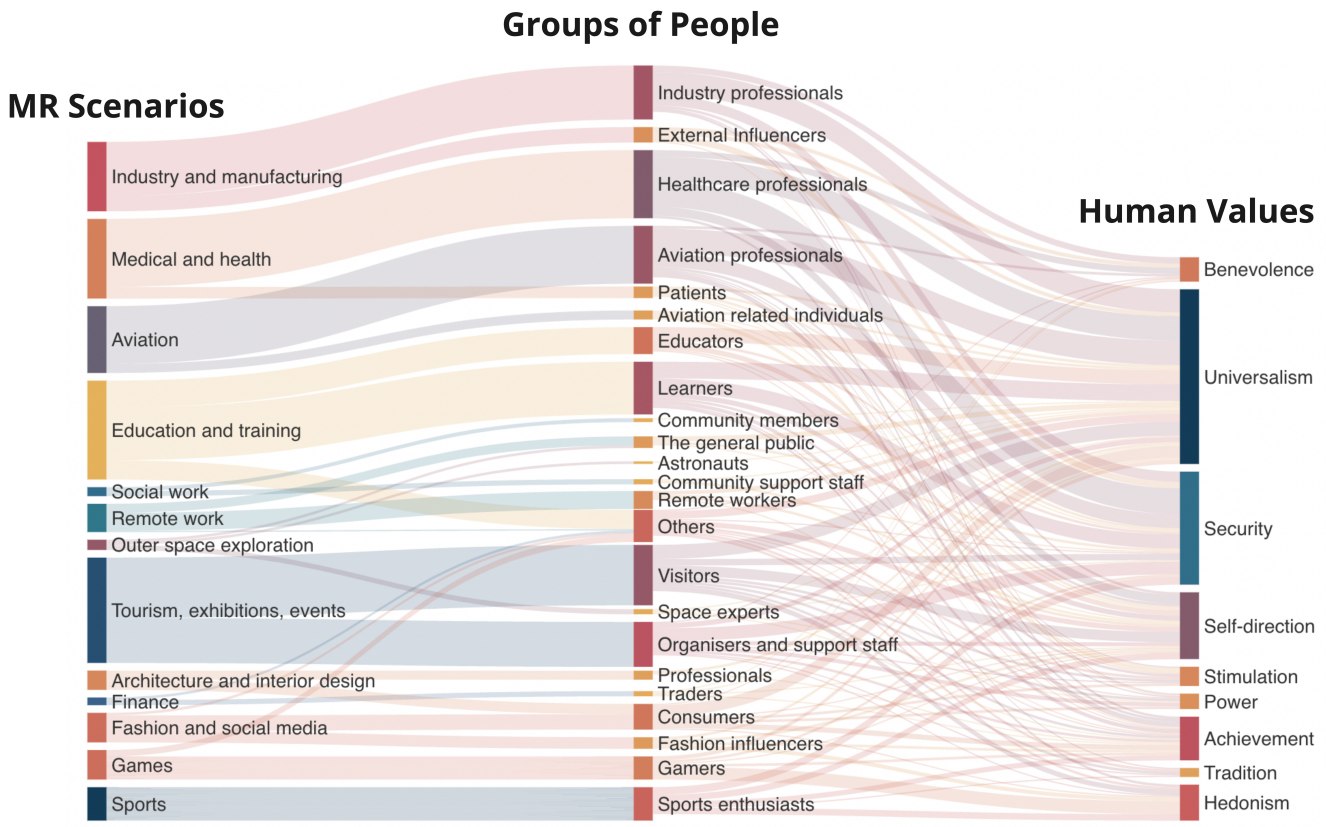

Figure 4: Identified MR application scenarios, groups of people and their values in five workshops. The different groups of people involved in each MR scenario are listed in the groups of people category. The human values category lists values that are of concern to the different groups of people in MR scenarios. A few flows of data are missing from groups of people to human values because participants did not list the human values for some of the groups of people.

addition, P8 proposed in-flight MR experience ("people don't want to travel in a box"). P8 believed this MR future application allows passengers to increase their *simulation*, interest and engagement during flights. Passengers' families or taxi drivers who pick them up could also use MR to show passengers' progress of arriving in real-time. They could use MR for entertainment during the waiting time (increase *simulation*).

Outer space exploration. Participants suggested that ASTRONAUTS and SPACE EXPERTS (e.g., engineers, scientists, mission designers) be included in this scenario. As a VR designer, P1 was designing tools for VR navigation on other planets ("although this is not strictly MR as they are using VR headsets, it is VR using real terrain data, so it is recreating them"). P1 explained that instead of astronauts having to go outside into the vacuum of space (outside their habitat) to drive a real vehicle, they can instead use the VR headset to control the rovers. To achieve the mission of space exploration, P1 believed that *security*, *achievement*, *power* and *universalism* are embodied values of space experts. In addition to navigating rovers, P1 and P2 proposed other interesting visions of future scenarios like the release of MR outer space games ("to get people excited about the missions (P1)") and the display of objects in MR such as planets, satellites and constellations ("you could just look at the moon and it'll tell you the names of the Astronauts who are up there (P1)").

In the discussion section, we provide recommendations for MR designers and practitioners to guide the design of MR experiences in which value can be operationalised.

4.2 Value ranking

The value ranking activity sought participants' perspectives on the significance of values in MR futures. The data reflects what they hope for rather than making accurate predictions. Envisioning how values may change over the short, medium and long term can help MR designers be more aware of the value propositions being baked into the technology, and consider community and societal alongside individual impacts. This activity provided a creative stage where all ideas were welcomed.

Overall, a total of 212 sticky notes of human values were generated by 14 participants in the 5 workshops (W1=36, W2=25, W3=74, W4=50, W5=27). We conducted holistic analyses to focus on the short-term, mid-term and long-term priority of different human values. As can be seen in Figure 5, the distribution of sticky notes

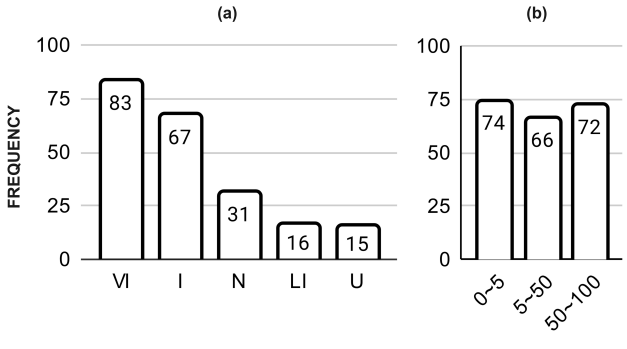

Figure 5: Distribution of 212 sticky notes. (a) shows the distribution of the sticky notes based on the five-point scale (Very Important, Important, Neutral, Less Important, Unimportant). (b) shows the distribution of sticky notes in three time frames (from now to 5 years, from 5 to 50 years and from 50 to 100 years).

does not differ significantly across three time intervals (right figure), while showing a decreasing trend in the five-point scale of values priority (left figure). This decreasing tendency might be attributed to several factors: (1) The discussion of human values for an MR world over the next 100 years prompted participants to consider the long-term consequences. This forward-looking perspective encouraged them to prioritise those values that they believe will have a lasting positive impact on future generations. For example, P9 said, "*I found this exercise really interesting, [...]made me sort of think about things that are probably really important to human individuals and human society in the long run, which we aren't necessarily respecting today.*" (2) Participants are more likely to focus on values that they believe hold direct relevance and significance for their lives and the future. Therefore, values that are seen as impactful in shaping a positive future naturally took centre stage in discussions.

Trends in participants' expectations of values priorities over the next 100 years are shown in Figure 6[12]. The importance of values overall shows three different trends: a clear upward trend, a clear downward trend, and a steady trend[13]. Values showing a clear upward trend are *identity* ("become more important for us (P10)"), *freedom* ("freedom was connected to identity (P1)") and *pleasure & enjoying life* ("a larger driver of people's lives (P11)"). In contrast, values showing a clear downward trend are *ownership & property* ("importance of physical attachment will decrease (P6)") and *wealth* ("things like success and wealth won't mean what they mean today, [...] we will value other things (P12)"). The rest values remaining a steady trend are *privacy* ("permanent internally important things (P4)"), *healthy* ("it will still be seen as important (P2)"), *sense of belonging* ("maintain a cohesive society (P6)"), *creativity* ("creativity and knowledge is also essential (P13)"), *social justice* ("equity is always a problem (P12)"), *politeness* ("that's part of what makes us human (P12)") and *environmental sustainability* ("[we] will have solved it (P1)"). The following are explanations from the participants.

An expectation of identity and freedom is increasingly important in MR Futures. P6 believed that currently, MR was not that pervasive so "you can just choose not to engage with it", but people will have to think about their values relating to *identity* and *freedom* as they move into a world in which mixed-reality further blurs the lines between their real and digital lives. Take *identity* for example, P5 mentioned that digital identity in MR is less important now, but "as we move forward everyone would want to have a digital avatar to represent them in digital space" such as the VTuber (virtual YouTuber[14]) trend in the fashion and social media scenario. To realise the transformation of identities in different MR application scenarios is a long-term process, as P5 imagined "it would be more of a societal issue in 100 years rather than the next 5 years". It is interesting to note the participants picking up on short and long-term value trade-offs. For example, P1 thought there was a tendency at the moment for people to give up their freedom in exchange for the promise of safety ("I think that's gonna decrease"). P8 was concerned that if we have different realities ("moving into separate realities that don't cross over") and how to maintain a cohesive society ("*sense of belonging*")?

Pleasure and enjoying life will matter more in MR Futures. P11 thought "the pursuit of happiness might be a larger driver of people's lives", rather than *wealth* and *ownership and property*. P11 gave the example of "the Star Trek universe where money isn't a thing". P12 agreed with P11's opinions and said "what will work in 100 years, like success and wealth, won't mean what they mean today, they won't be important and we will value other things." Moreover, P11 commented "[these values] are probably undervalued, to some extent, by society maybe not by individuals."

As MR continues integrating into our daily lives, its impact on our attachment to physical possessions presents a complex scenario. Participants thought the importance of physical attachment (such as *wealth* and *ownership and property* would decrease regarding MR. However, P6 suggested the opposite trend could occur, as "the more digital things become in your work life for efficiency's sake, the more attached you might become physically to the things that mean something to you personally". P6 provided an example as "the more music became digital, the more people started collecting cassettes and records". Moreover, P6 surmised that something similar will happen with MR, as "the more I use MR at work over the next 50 years maybe, will I want to have more physical interactions in my personal life". This phenomenon also reflected the value of *respect for tradition*, as P10 said "even when the world tried to break that for us the last few years with COVID, and shaking things up, we've kind of all in some way snapped back into old and familiar routines".

We further discuss the perception of how values may change in MR futures in the discussion section and provide our recommendations accordingly.

[12]Other values were not included in the figure because they were mentioned less frequently. For detailed step-by-step instructions on how we aggregated the sticky notes representing human value priorities from the five workshops onto a single chart, please see the supplementary material.

[13]A steady trend means that the linear trend lines do not cross more than two intervals of importance, such as *privacy* moved from **I** to **N**; A clear upward/downward trend means that the linear trend lines cross more than two intervals of importance, such as *freedom* moved from **N** to **VI**.

[14]VTuber: https://en.wikipedia.org/wiki/VTuber.

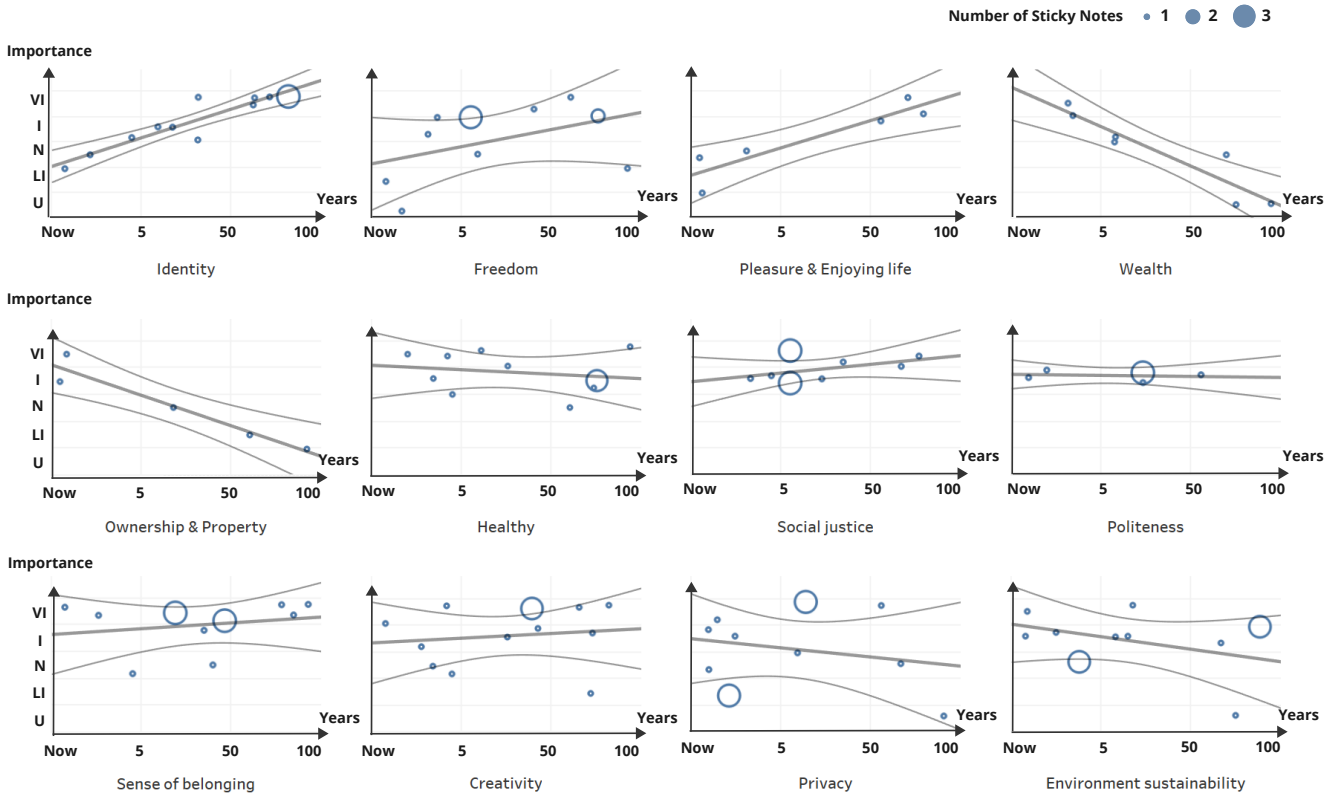

Figure 6: Trends in participants' expectations of values priorities over the next 100 years. We added linear trend lines to visualize the trends for each human value. Confidence bands (two curves) were used to represent the agreement of participants' opinions for each value. The narrower the confidence band (the closer the two curves are), the participants agreed more with the trend (e.g., the agreement of trends in *identity* is higher than *freedom*).

4.3 Challenges and opportunities

We followed the Multi-lifespan Envisioning process of the Multi-lifespan Timeline method to envision barriers, solutions and impacts of embodying human values in MR applications. Overall, a total of 140 sticky notes of barriers (n=40), possible solutions (n=39), primary impacts (n=32) and secondary impacts (n=29) were generated by the 14 participants in the 5 workshops. The reason for the decreasing number of sticky notes is that the participants found it more challenging to come up with possible solutions and then consider their impacts. Figure 2 shows an example of the future wheel activity from W4. Barriers (or inhibitors) were grouped into three categories: LOW ACCEPTANCE ("lack of trust on it (P14)"), LACK OF REGULATORY/GOVERNANCE FRAMEWORKS ("the law is not as strong as the software (P2)") and MARKET FORCES ("obsession with profit (P9)").

4.3.1 Market forces. Seven of fourteen participants identified profit-driven markets as a barrier to the prioritisation of human values in current MR design and development ("MR industry motivated by profit (P12)"). For example, P9 said "[the way] our society is organised at the moment is very focused on financial values [...] nobody has time to focus on things that aren't directly related to making money". To remove barriers, P11 and P12 believed that there is a need to communicate the benefit of embodying human values in MR applications ("show how technology can help with current priorities (P11)", "we need [a] discourse on what type of MR world we want (P12)"). To reflect the benefits of human values, P5, P7, P9 and P12 thought that greater investment in research is needed ("investment research grants (P7)", "public funding for fundamental curiosity-driven research (P9)"). By doing so, P6 and P8 believed in the short term "more ethical products [are going to naturally become] available (P6)". Moreover, P9 thought in the long term, MR will therefore be designed "more focus on values that matter in the long term". An interesting point made by P8 was that consideration of human values in technology cannot be rushed and advocated for ("slow[ing] the pace of change"). This might reduce MR applications in the short term but in the long term "potentially more ethical outcomes overall (P8)".

4.3.2 Lack of regulatory/governance frameworks. Five of fourteen participants identified current concerns about the lack of ethical frameworks for a future MR world. This includes issues of digital identity in MR ("portable virtual identity (P4)") and concerns about data ("reliability on data based on what the MR applications designed (P14)", "data collection concerns (P2)" and "transparency about data storage and privacy controls (P10)"). Solutions can start

with both establishing MR regulations ("protect online assets (P4)", "data protection regulation (P2)") and improving supervision ("oversight (P5)"). For example, P4 proposed that currently, we have to switch between numerous accounts when using cyberspace, so was it possible to create a portable virtual identity in MR to make it easier to move around MR ("[we] might make one identity like a passport and take it with us into every virtual country we go to"). In the short term, the impacts include the creation of a better security MR environment ("nefarious actions are more difficult (P2)"). In the long term, P4 believed that MR might offer 'a fully online life' ("It all seems to come back to online lives for me").

4.3.3 Low acceptance. Participants attributed the main reason for the low acceptance of MR to fear ("fearful about the [MR] environment (P10)"), mistrust ("I don't want either of them [MR headsets] tracking my eyes (P2)"), and concerns about future applications ("MR will reduce quality social connections and entrench our biases (P12)"). This is due to a lack of understanding of MR. P12 explained that, "in a mixed reality environment when you're walking down the street in the city, you can just choose to screen out, people who are homeless, people who have a disability, people whose ethnicity or sex that you don't want to see", which would exacerbate prejudice. Moreover, P13 and P10 believed that low acceptance also comes from people's openness to new technologies ("the general public may not be very open to new ideas (P13)") and their adaptability ("if we're prepared to break free from the routine in our everyday lives (P10)"). P3 and P8 thought that the barriers of fear and mistrust could be removed by communicating and explaining more MR information to the public ("better engagement and communication to foster understanding (P8)", "expression in a more human way (P3)"). By doing so, participants thought it would increase both individual acceptance and social acceptance ("less backlash from [the] community, ultimately greater uptake and consideration of human needs within technology (P8)"). For concerns about future applications, P10 and P12 presented to "encouraging people to [...] break norms (P10)" and "exposure to alternate world views (P12)". Finally, it will "improved implementation and understanding of human values in an MR environment (P7)" and increase social acceptance.

5 DISCUSSION

This research is at the intersection of technology and social science. The original motivation of this article was to explore where our understanding of human values will go in the future as the boundary between the digital and physical worlds becomes increasingly blurred. We reflect on the findings, research methods, limitations and future work in this section.

Our workshop methodology answers RQ1-3 and addresses a lack of holistic discussion of human values in existing MR-related research in three ways. First, there is a lack of literature looking at the impact on human values of MR technologies beyond current and near-future MR applications, whereas the workshop attempts to envisage up to a century in the future, more than a generation hence. The trends of values in subsection 4.2 answer RQ2, which is how values fluctuate in MR futures over the next 100 years from participants' perspectives. Second, the existing literature considers only certain values such as privacy, digital property and safety, whereas the workshop participants discussed a wider range of topics related to happiness, human connectivity, and care/appreciation of nature. Third, in terms of MR application scenarios, the existing literature has a larger proportion of user studies conducted in laboratory scenarios, whereas the application scenarios discussed in the workshop were all real-world scenarios. In subsection 4.1, the identified groups of people and their values in these scenarios answer the RQ1. Below, to answer RQ3, we discuss the outcomes of the workshop grouped according to key themes and give seven recommendations for MR stakeholders of future MR design and applications.

5.1 Issues of identity and freedom in different realities

As detailed in Results (section 4.2), an expectation of *identity* and *freedom* is of increasing importance in MR Futures. Workshop participants felt that a single individual could create multiple avatar identities in the future MR world. This would make it difficult for other users and systems to recognise their behaviours as those of a single individual. As in the current online world, users can open different browser windows and present themselves as completely different identities in terms of demeanour, ability, and gender identity [83]. Similarly, mismanagement of identity in MR worlds may pose problems from a human values perspective, including erosion of trust and security [16]. How to ensure people are who they say they are? How to avoid identity theft or identity infringement? How to protect people's freedom to express their identity in such a changeable environment? Lin and Latoschik [44] found 13 papers based on 814 sources explicitly proposing corresponding protection mechanisms, works or design guidelines, such as avatar authentication and ensuring access control. Prieto, Lacasa, and Martínez-Borda [17] believe the construction of digital identity must be guaranteed through protocols such as the blockchain. The ideal would be measures which assert identity when necessary while allowing privacy and self-expression through skins and avatars in social settings.

In summary, we suggest:
(1) On the application context front, the sensitivity to identity in different reality scenarios should be explored in future research, e.g., in serious scenarios, such as medical appointments, unified identity authentication is needed, while in casual communities more self-expressive and diverse character avatars can be used.
(2) On the technical front, it is necessary to develop robust identity management systems that support user authentication, ensuring effective access control and identity protection.
(3) On the legal front, stringent measures must be implemented to deter and manage identity infringement and related misconduct.

Recommendation 1*: Future MR designs and applications will need to increase the emphasis on addressing issues of identity and freedom in different realities, such as research on identity requirements for different application contexts, development of identity management systems, and improving legal oversight.*

5.2 Enhancing a sense of well-being in MR

Participants believed happiness (*pleasure & enjoying life*) plays a more important role in the future. Pardini et al. [58] found that participants experienced a greater sense of pleasure, relaxation,

engagement and immersion in personalised virtual environments than in non-personalised environments. Chiossi and Mayer [13] highlighted that allowing users to interact with personalised visualisations, contents and interactions holds great potential for creating user engagement and satisfaction. To highlight people's need for happiness, we suggest that MR designers consider implementing adaptive personalised features within MR environments to allow users to customise their MR experiences based on their changing values and preferences.

Recommendation 2*: MR designers should focus on whether and how the MR experience contributes to individual, community and societal well-being when designing long-term MR experiences.*

5.3 Perception of digital presence and physical presence

As detailed in Results (section 4.2), an expectation of *ownership & property* and *wealth* is of decreasing importance in MR Futures. This is partly because as society develops and material life becomes more prosperous, people will place more emphasis on spiritual pursuits. On the other hand, it is because people's increased interaction with digital elements will reduce their attachment to physical entities as our capacity for attention is limited [43]. While the participants agreed on the above trends, P6 held an opposing view on values associated with the physical presence in MR, suggesting that a decrease in interaction with physical objects would in turn increase the act of collecting them. Waterworth and Hoshi [87] discussed the nature of the sense of presence in the physical and digital worlds and argued that a sense of presence in the physical world often competes with that in the digital world. Westermeier et al. [88] explored the impact of presence and plausibility in MR experience and found that congruence in the sensory/perceptual layer is crucial for forming perceptual links between virtual and physical entities. As our sense of presence in current MR is complex and fragmented [86], we suggest:

Recommendation 3*: Further research is required to evaluate the impact of MR designs on the perception of digital presence and physical presence. In particular, we need to study how this integration affects our reliance on the physical world and digital world.*

5.4 Establishing MR policies and improving MR supervision

The long-term future potential of MR cannot be ignored. The example of the smartphone is a useful reference for MR technologies which initially had little impact on society due to its high cost, low connectivity, awkwardness of early products etc. However, as the technology evolved and design improved, smartphone adoption grew exponentially and thus fundamentally changed every aspect of society [45]. Current MR technologies have not yet had a significant impact on society due to their high cost and current awkwardness. However, many technology companies are making huge investments to address these limitations. The immersive interaction of MR environments and the way that new pass-through headset designs (like Apple's) will completely capture the wearer's field of view, has a greater potential to reshape the relationship between individuals and their environment than the small screen-based interaction of smartphones. By drawing on the lessons of smartphones, social media, and current artificial intelligence, establishing MR policies and improving MR supervision can help to remedy the current *lack of regulations*. Therefore, we suggest responsible MR innovation to encompass a range of governance and regulatory mechanisms. By following VSD [23], which includes identifying stakeholder values, ethical issues, potential harms, and benefits, it becomes helpful to conceptualise design requirements for creating a more ethical application.

Recommendation 4*: MR innovators and policymakers need to meaningful participate in their development by thinking about the guardrails that need to be in place earlier in the innovation cycle by identifying stakeholder values, ethical issues, potential harms and benefits. As well as the incentives for value-driven MR design through enrichment grants opportunities, awards and recognition programs.*

5.5 Engaging and empowering the public in MR design process

The MR experiences should be designed in which the public is involved in the design and have flexible options according to their preferences. At the workshops, it was recognised that better public engagement in the design would increase social and individual acceptance. Public MR environments should adhere to shared values to establish and maintain trusted MR experiences. For private MR environments, individuals should have the right to make decisions based on their own values under conditions that do not affect others (e.g., playing Pokémon Go in a memorial is disrespectful behaviour). Individuals should be provided with transparent explanations to understand the effects of MR features before choosing to use them. Social connections within the community should be fostered, not replaced or weakened by MR technologies. Nam and Oh [54] explored how the public can be engaged as co-creators in the design of mixed-reality space to inspire a sense of belonging and social presence, the feeling of being 'connected'. In addition, there should be a balance between individual participation and centralization of power. To gain a better understanding of the general public's concerns regarding the use of MR applications, MR designers and policymakers can employ tools such as the MR Concerns Questionnaire [36].

Recommendation 5*: Engaging and empowering the public in the MR design process such as using participatory design frameworks or co-design approaches may help to raise both individual and social acceptance.*

5.6 What if MR environments are too real?

It is worth noting that the MR-related experts (P1, P4 and P11) also mentioned specific technological limitations ("short battery", "low resolution", "creating 3D is expensive"). Although these technical limitations are not directly related to human values, participants felt that solving technical issues could provide a more realistic experience, which could make it impossible to distinguish between the digital (virtual) and physical (real) elements of the MR world. Lakhnati et al. [42] found the research related to the different nuances of real and virtual elements remains largely unexplored. Mann et al. [48] provided a multidimensional multisensory mediated reality that allowed for a more direct experience real through our five

senses and additional senses, including sensory sonar and sensory radar.

***Recommendation 6**: MR designers may need to develop a visual language or user controls to explicitly disambiguate physical from virtual objects in anticipation of emerging technology capable of seamlessly blending the two.*

5.7 The importance of considering human values in MR context

Due to the potential for MR to significantly impact society, introducing human values is necessary to align the technology to individuals' hopes for the long-term future. For example, in our study workshop participants discussed the issue of multiple identities in different MR realities. To bring human values into MR, VSD provides methodologies that can be practised (e.g. stakeholder analysis, value scenario and multi-lifespan timeline). VSD has been used in both AR [24] and VR [79]. However, MR environments are more complex compared to AR (where digital objects overlaid on physical space can be clearly distinguished) and VR (where it is a fully artificial digital environment). Spiekermann and Winkler suggested including a value expert in the value-based engineering process [81]. A value expert is an individual with deep knowledge of values, who supports the ethical exploration phase by identifying relevant values for technology design. This ensures that the development team understands the benefits of integrating human values into their projects. Beyond their knowledge of values, a value expert possesses strong communication skills, which facilitate clear communication with external stakeholders like policymakers and the general public to ensure that designed MR applications align with societal expectations for the future[15]. Therefore, it is important to communicate the benefits of integrating human values into MR applications.

***Recommendation 7**: Clear communication from value experts to both MR development teams and external stakeholders about the benefits of integrating human values into MR applications may help to counter the negative impacts of MR development driven only by market forces.*

5.8 Limitations

We acknowledge several limitations to our findings, mainly associated with the scope and exploratory nature of our workshops resulting in a breadth of findings rather than deep analysis:

MR scenarios discussed in our workshops could be explored in greater depth. Our research aims to explore whether and how human values can guide the widespread use of MR in society. Therefore, there is a lack of discussion of in-depth value analyses in the 13 scenarios. Such as the details of how different value considerations play out in specific contexts. Are there conflicts and dilemmas between the values of different groups of people in the same scenario? How to manage trade-offs for value conflicts? Are there differences in values across cultures, even for the same MR scenario? Is it needed to develop different strategies according to different cultural contexts in MR applications? We suggest that MR researchers explore these questions in future studies using the 13 MR scenarios we have summarised.

The human values identified by the 14 participants are not sufficient to express all human portrayals of MR futures. Being the first time the holistic design and application of MR technologies has been explored from the perspective of human values, our sample size was insufficient to support a comprehensive exploration, but care was taken to find a balance of expertise. All participants have extensive experience in collaborative projects with industries, governments, NGOs, etc., and thus bring to the workshop the perspectives of a wide range of stakeholders in their fields. Our results therefore reflect concerns about a variety of domains and our participants' values and rich professional experiences. It should be noted, however, that our participants do not represent a wide variety of socioeconomic groups, educational levels, or a greater diversity of minority groups. Further research would be required to determine how these recommendations may be applicable to society as a whole. Therefore, we are only offering tentative recommendations for future regulatory/governance frameworks, instead of providing policies and industry regulations. These recommendations can be used as a reference for policymakers when formulating MR policies. It was reassuring to see that the workshops also conveyed voices from different cultures (e.g., P14 from Bangladesh shared about local environmental protection and social work).

The identified values of the different groups of people are based on subjective perspectives. For some MR scenarios, all participants belong or have belonged to the groups of people (e.g., visitors, patients and consumers) they discussed and can therefore express the value of the group based on their own experiences. In addition, participants also imagined themselves as different types of people in some scenarios and speculated about their potential value in MR (e.g., fashion bloggers, plumbers and architects). As a result, there may be subjective bias regarding the value of the presumed groups of people. But there is value in hearing what people think/assume about others in value discussions, particularly with different powers and privileges.

One workshop was smaller than ideal after the recruited participants dropped out at the last minute due to personal emergencies. The recruitment process lasted 3 months as it was hard for team leaders to make time for a 2-hour workshop, even if they were interested in being involved. It was also difficult to find a time for the workshop when several participants were free. W2 was affected when we had four participants scheduled but in the end, only two of them were available to participate. To make the discussion more effective without being affected by the small number of participants, the workshop facilitator introduced ideas from W1 as an example to inspire the participants to diverge their thinking. For example, in the value ranking activity, P4 and P5 asked the workshop facilitator to give them an example of what values might be unimportant in the future because they thought it was hard for just two of them to come up with an idea. So the facilitator provided an idea from the W1 participants, "natural resources are likely to become more abundant in the future, so *environmental sustainability* might be less valuable". Finally, P4 and P5 proposed that *entitlement* and *free*

[15]Similarly, the IEEE Standard Model Process for Addressing Ethical Concerns during System Design includes a role, termed 'value lead' [1]. The value lead is responsible for identifying, analysing and prioritising ethical values and incorporating them into the system design. This role is one of the key roles in ethical value engineering projects.

speech would be less important in five years and *surveillance* would be less important in 5-50 years.

5.9 Future work

The position of this research is to explore human values for the future of MR from a broad perspective. The current findings can be generalised in two ways (1) the identified challenges and opportunities (e.g., low acceptance, market forces and lack of regulatory/governance framework) and possible solutions. For example, communicating and explaining more MR information to the public can increase social acceptance. (2) The prioritisation of human values fluctuates in MR futures over time. We found that participants had different prioritisation for value in the short, medium, and long term. For example, values that reveal human nature, such as *identity* and *freedom* are considered increasingly important. This will influence the ethical design requirements of technologies such as MR. However, the current findings are not generalisable in terms of MR scenarios, groups of people, and their values. For example, we only summarised 13 MR scenarios in our limited workshops, but there are other valuable scenarios that were not included such as animal well-being, agriculture and natural disasters. We suggest that researchers explore the topic of human values in specific scenarios depending on their field. For example, researchers can (1) select target groups (2) identify the value requirements (3) design MR based on the identified value requirements. In the next step of the study, we will focus on the specific values of a specific group based on the results of the workshop. We will design a value-based design process to assist designers in designing more ethical MR applications. We will test the effectiveness of our values-based design process through a series of workshops. Through these efforts, we intend to inspire and guide MR designers, MR practitioners and policymakers for MR design and applications.

6 CONCLUSION

This research aimed to bring consideration of human values into the MR domain. To generate a more holistic discussion of values in MR development and application we used this as the basis for the development of a workshop in which participants could identify different groups and their values in MR scenarios, consider value priorities over time, and reflect on how to embody human values in MR futures.

With initial piloting demonstrating the practicality and usefulness of the values workshop, a further five workshops enabled the identification of a range of MR scenarios beyond what had previously been discussed in the literature. The workshops also provided insight into the kinds of values that are of immediate and longer-term concern with the development and application of MR technologies in these contexts. This revealed some interesting trends with the prioritising of values associated with physical presence such as *wealth* and *ownership and property* may decrease over time, and values that reveal humanity such as *identity* and *freedom* seen to be of increasing importance. The final discussion in the workshops of the barriers to embodying human values in MR design and applications highlighted the need to address the current fears and lack of trust associated with the technologies, tackle market power, and develop appropriate regulations to guide responsible innovation. Notably, we found that the workshop activities raised participants' ethical awareness of human values in MR design, development and applications.

Our research points to the need for more human-centred and value-based approaches to the design and application of future MR technologies and environments. It illustrates the opportunities in bringing explicit elicitation and discussion of values into current and future MR scenarios so that technological development can be better shaped by socio-technical considerations. Based on the results of our study, we make a series of recommendations for incorporating human values into future MR designs and applications. These recommendations will help to improve the ethical and responsible development of current and future MR applications.

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