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From needs to values: approaching the 'How' for ethical XR experiences

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As immersive, interactive, and eXtended Reality (XR) technologies are becoming more omnipresent and offer potential in various societal domains (e.g., media and entertainment, health, education), questions about ethics and ethical development are gaining importance. In innovation projects, Human Centered Design (HCD) is a central approach to involve stakeholders to co-create solutions and better understand human needs. To explore ethical considerations of technology, the recent and more practical approach, Guidance Ethics Approach (GEA) can be used. However, limited application in XR development has been identified. In this study, GEA was integrated into an HCD-based innovation project to meaningfully involve stakeholders in discussions on ethical development. Co-creation workshops and interviews were conducted with end users and consortium partners for four different XR applications-developed in the project to identify ethical considerations, underlying values, and options for design action. Although several identified ethical considerations aligned with those previously identified in literature, the findings provide empirical support that they represent central design requirements for future XR applications. Using low-fidelity prototypes for ethical reflection enabled early identification of concerns and solutions in the design process. The findings also demonstrate that GEA effectively complements HCD, as it embeds structured ethical reflection into an already existing participatory design workflow. Although there were several limitations to this study, the combined approach shows promise as a practical framework supporting more responsible, trustworthy, and human-centered XR technologies.

KEYWORDS
co-creation, ethical considerations, Guidance Ethics Approach, human-centred design, innovation project, XR development

1 Introduction

Immersive, interactive and eXtended Reality (XR) technologies are becoming more omnipresent and have the potential to rapidly shape and impact both our lives and industries. XR refers to immersive media technologies like Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). While these technologies started as a novelty mainly used in gaming to offer personalized and immersive experiences, they are becoming more mainstream and are being implemented in various societal domains, such as media and entertainment, health and education. While these technologies offer potential for economic productivity, access to public services, personalized education and, of course, enthralling entertainment – questions on how to predict and address ethical considerations of the technology are becoming more central (Adams et al., 2018; Kenwright, 2018; Spiegel, 2017).

Human Centered Design (HCD) is often a central approach within innovation projects, where collaboration and iterative user- and stakeholder involvement, and the understanding of human needs is key (Harte et al., 2017; Nguyen et al., 2022). Although this approach involves stakeholders to co-create and improve technologies based on the needs of users, there is no concrete step or procedure to explore ethical considerations of the technology. A practical approach to user involvement in discussions on responsible and ethical innovation is Verbeek and Tijink's (2020) Guidance Ethics Approach (GEA). The GEA is a novel approach that only recently has been applied in studies in logistics, security, healthcare, public administration, finance, civic/HR technologies (Hosseini et al., 2024; La Fors and Meissner, 2022; Krom et al., 2025; Aanpak begeleidingsethiek, n.d.). However, limited applications in XR development were identified, wherein one study was found in which GEA was used to explore the values of users interacting with a VR rehabilitation application for long-term SARS-COVID patients (Smits et al., 2022). Prior works using GEA have resulted in guidelines, minimum requirements, and options for action in their respective sectors.

This article aims to contribute to existing debates on the need for an empirically grounded approach to ethical development of XR technologies. It explores how the GEA can be used together with HCD in a large innovation project, and it outlines a set of ethical requirements and suggested mitigation strategies that support the further development of responsible and trustworthy XR applications in similar contexts. The aim of this study is to identify and translate ethical considerations into actionable requirements and solutions for four low-fidelity XR applications that were developed as part of the Horizon2020 PRESENCE project. The questions we aim to answer with this paper are:

1 How can the Guidance Ethics Approach (GEA) be used within Human Centered Design (HCD) processes to translate ethical considerations and values into actionable requirements and solutions?
2 What ethical considerations and values can be identified from end user engagement with low-fidelity XR applications?

2 Related work

When talking about ethics and technology, philosophical theories – such as utilitarian consequentialism, deontology, and virtue ethics – are at the center of discussion (Stahl et al., 2014; Wright et al., 2014). These philosophical theories often deal with central goals such as maximization of happiness and minimization of harm, moral obligations (right and wrong, desirable and undesirable), and virtue of doing good as well as reaching eudaimonic impact or human flourishing (Lee and Hu-Au, 2021).

This article addresses more the applied dimension of ethics, where – in the context of XR development – we look at ethical considerations, i.e., the ethical or moral implications of the technology (Steele et al., 2020). These implications can be physical (health-related issues), psychological (consequences brought on the psychological well-being of users, e.g., PTSD), moral (issues related to inappropriate use or exploitation of personal data), and social concerns (issues related to the social well-being of users, e.g., difficulty to establish relationships) (Steele et al., 2020). Several authors have already identified a body of ethical considerations and issues related to XR development, including data privacy, informed consent, identity and agency, accessibility, and psychological well-being (Fernandez and Hui, 2022; Madary and Metzinger, 2016; McGill, 2021; Ramirez et al., 2021; Slater et al., 2020; Southgate et al., 2017; Cox et al., 2025). In more recent studies, users have also identified ethical considerations concerning racism and harrassment (Raja and Al-Baghli, 2025; Saghafi and Angelopoulos, 2025). There are concerns about the vast collection of data that users may be unaware of, the blurring of distinctions between the real and the virtual, as well as questions about manipulation, addiction, and virtual harm (Fox and Thornton, 2022; Madary and Metzinger, 2016; Behr et al., 2005; Lee and Hu-Au, 2021; Southgate et al., 2017; Cox et al., 2025).

Based on these identified issues and risks, several initiatives have sought to identify principles and frameworks that tell developers what ethical considerations to consider in XR development, which often are inspired by broader fields such as AI and Human-Computer Interaction (HCI) ethics (Cox et al., 2025). Across international initiatives – such as the IEEE's Ethically Aligned Design for XR (The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems, 2019), the XRSI Privacy and Safety Framework (XR Safety Initiative, 2020) – and national initiatives – like South Korea's Metaverse Ethics Principles (Ministry of Science and ICT, 2023)– there is alignment on values such as transparency, accountability, and user autonomy. European projects such as XR4Human and OPENVERSE further aim to establish ethical, inclusive, and interoperable foundations for XR technologies and immersive worlds by co-creating guidance documents on policy and best-practice frameworks (de la Cruz Bernabe et al., 2025; Open Verse, n.d.). These guidelines, frameworks, and codes of conduct provide insight into what considerations and risks there are to consider when developing XR technologies, but not how to explore or uncover potential other issues not foreseen in these guidelines and frameworks. The European initiatives show that there is a push towards using participatory research to uncover ethical considerations in XR development. However, although European projects typically use HCD as a participatory approach, it does not include ethical reflection by default.

2.1 Approaches to XR development and ethical considerations inquiry

2.1.1 Human centered design

An approach commonly used in XR and VR development is Human Centered Design (HCD). It is an approach that emphasizes holistic understanding of human needs, multi-disciplinary collaboration, and the continuous and iterative user- and stakeholder involvement throughout the development cycle (Harte et al., 2017; Nguyen et al., 2022). The approach has evolved from ergonomics and usability engineering to now being a multidisciplinary design philosophy that emphasizes empathy, inclusivity, and co-creation, moving toward humanizing the user experience (Zhang and Dong, 2009; van der Bijl-Brouwer and Dorst, 2017; Probst et al., 2024). Crucial to HCD development processes is that the users or stakeholders who are affected by or who will use the product or technology are included in the design process (Stiles-Shields et al., 2022).

In contemporary HCD approaches, the question of which methods fit which phase and type of problem is emphasized, also stressing how to maintain user involvement in fast workflows to ensure agile delivery (Burns, 2018). Here, HCD incorporates more contextual factors into the design and development process, such as cultural norms and social environments (Probst et al., 2024). As various mixed methods – such as usability testing, field studies, interviews, focus groups, etc. – are used to better and more deeply understand the human experience of technology use, it is also crucial to follow ethical principles for sound and proper user involvement (Probst et al., 2024; Holeman and Kane, 2019). A commonly used standard for HCD is the ISO 9241-210 standard, which provides recommendations and requirements for how HCD principles and activities should be applied to the development of computer-based interactive systems throughout the development process (ISO 9241-210:2019, 2019).

The HCD process consists of four main phases: (1) understanding and specifying the use context (such as user group profiles, personas, and scenarios), (2) specifying user and organizational requirements, (3) producing designs and prototypes of the product or technology that meet user needs (such as scenarios of use, and low- and high-fidelity prototypes), and (4) conducting evaluations and assessments of the designs with users to ensure that needs and requirements are met (Harte et al., 2017; Nguyen et al., 2022; ISO 9241-210:2019, 2019). Some add another step to the HCD process, which is the planning of how to conduct this process as an essential first step (Maguire, 2001; Burns, 2018). The outcome of the HCD process is the translation of insights into a set of user requirements that will further inform the development of the technology, which will then be iteratively evaluated and assessed.

There are, however, some critiques to the HCD process, where a main point of criticism is that it has too much of an economic focus. Rather than focusing on responding to broader life challenges, HCD allows for technologies to be developed to maximize user engagement by oversimplifying and over-optimizing them, contributing to the short-term gains of business (Borthwick et al., 2022). In Horizon Europe projects, HCD is used as a standard to ensure that technologies meet user needs and enhance user well-being, skills, and capabilities, but also in the context of Industry 5.0, to improve their working conditions (European Commission: Directorate-General for Research and Innovation, 2024). However, it can be difficult to fully consider user input in development, both due to the own experiences and assumptions of the study facilitators but also since it can be hard for users to articulate or verbalize their needs (Steen, 2012; van Velsen et al., 2022). An approach that stems from HCD is the Double Diamond model, which sets out to illustrate how designers can go about understanding, challenging, and implementing design assumptions and input from users (Kochanowska and Rochacka Gagliardi, 2022). This model can help designers work more efficiently with user input as it provides a clear framework of step, but also for assessing the status of projects. Although this model provides a simple overview of the design process, it largely follow the exact steps of HCD and thus it could be used as a complement to better visualize the process. To ensure that technologies also meet broader societal needs and requirements, it is imperative to move beyond the "user bubble" and employ methods and approaches to broaden the perspective (Schneider, 2025). This is especially the case for exploring ethical considerations of technologies.

2.1.2 Approaches to ethical design: guidance ethics approach

The field of ethical technology development is diverse, where several approaches and methods exist to explore ethical considerations and ensure ethical technological design. In a structured review by Donia and Shaw (2021) and in a study by Moore et al. (2025), a number of leading approaches to ethical technology development and design were identified, providing an overview of (commonly) used approaches in the field. These approaches include Inclusive design, Speculative design, Visionary design/futurism, Value sensitive design, Ethicist as designer, Values at play, and Values-led participatory design, which all share several characteristics that stand out as fitting for the purposes of our study. They consist of different ways to explore solutions to ethical considerations based on reflective practice, stakeholder involvement, and value identification, and are dealing with more speculative and visionary methods, but also participatory design and co-creation. However, common critiques to some of these approaches include the difficulty or incapability of addressing complex issues that may emerge with new technologies (especially in value sensitive design approaches) and that there is a lack of clear methodological guidelines where the link between technology and human agency often is misunderstood (Donia and Shaw, 2021).

Although there are several approaches to explore ethical considerations in technological development, the Guidance Ethics Approach (GEA) provides a more practical framework that to a large extent captures and integrates what most of the above ethical approaches to technology design sets out to do. The GEA (Verbeek and Tijink, 2020) is a novel practical approach to user involvement in discussions on responsible and ethical innovation, that only recently has been applied in specific studies concerning ware-house technologies (Hosseini et al., 2024); biometric-based AI in border contexts (La Fors and Meissner, 2022); a Prostate Consultation initiative to improve the care between the GP and the hospital (Krom et al., 2025); AI in procurement, fintech and recruitment, chatbots in voting advice applications and the care sector, and applications and/or solutions for improved care practices in health care contexts (Aanpak begeleidingsethiek, n.d.; Smits et al., 2022). As mentioned earlier, only one study to date applied the approach in an XR context, focusing on the values of users interacting with a VR rehabilitation application for long-term SARS-COVID patients (Smits et al., 2022). Interesting is that the approach sets out to move away from technology ethics as either the acceptance or rejection of technology to a more open perspective where the focus lies in how technology can be dealt with and developed in a responsible manner (Verbeek and Tijink, 2020). The central question of GEA is how a technology can fit responsibly in society, wherein conditions for how the technology can function responsibly are investigated, such as design (ethics by design), social embedding (ethics in context), and how it is used (ethics in use).

GEA originates from broader work of Verbeek, such as the theory of mediation (2016), in which emphasis is put on the importance to empirically and conceptually study how humans give meaning to technological mediation. This theory of mediation reintroduces the philosophical ambition of Science and Technology Studies (STS) – an interdisciplinary field that examines how science and technology are inseparable from social structures and practices (Rohracher, 2015) – but it also adds an ethical layer by looking at the moral mediation of technology (Verbeek, 2016). This refers to the ways in which technology may have an effect on our moral actions

and decisions, but also how technology may shape how we define and experience what values are important to us (Smits et al., 2022). In this paper, we define values as things that people consider important to them in life (Smits et al., 2022). Values, such as justice, sustainability, safety, etc., are at the center of the GEA, and their identification is important as they will guide the development and use of technology (Verbeek and Tijink, 2020). These values are impacted by the positive and negative emotions people have regarding technology. For instance, if people experience fear or concern with features such as the tracking of biometrical data, this indicates that the value of privacy is important to them, which will then act as a guiding value in the further development of the technology (Verbeek and Tijink, 2020). This may result in the adoption of the technology or even in the conclusion that a technology should not be used if it does not align with our values (Verbeek and Tijink, 2020; Hosseini et al., 2024).

To study this relation between technology, values and moral actions and decisions, we must empirically look from within, by involving stakeholders in an iterative dialogue on how they interact with technologies and give meaning to it and its mediations (Verbeek, 2016; Verbeek and Tijink, 2020). This dialogue takes place through three stages, which are to a great extent similar to those of HCD; the main difference is that while HCD focuses on the inclusion of humans to understand their needs, GEA goes a step further by including ethical reflection based on human values and emotions.

Similar to HCD, the first step in the GEA process is to clarify the context of the technology, focusing more on what the technology is and how it can be used, but also what the use of this technology means for the people within the specific context or scenario of use (Hosseini et al., 2024; Verbeek and Tijink, 2020). The second step of GEA – the dialogue – merges step 1, 2 and 4 of HCD, wherein stakeholders that are impacted by the technology are identified, and involved stakeholders discuss the effect and impact of technology on society and what they consider as central values to developing responsible technologies (Verbeek and Tijink, 2020). Involved stakeholders are, like in HCD, the designers and envisioned users of technology, but GEA also includes other relevant stakeholders – such as policy makers, advisors, etc. (Hosseini et al., 2024; Verbeek and Tijink, 2020). Effects and values are explored through dialogue, e.g., in a workshop or through interviews, wherein stakeholders can reflect on and voice ethical concerns that they experience or see with the technology, and the values that are important to them. In this step, approaches such as Value sensitive design, Ethicist as designer, Values at play, and Values-led participatory design are encapsulated. This is due to their aim to identify and implement user feedback based on what values emerged as important to them in (technology) design. In the third and final step, the potential effects and values are translated into concrete action solutions, where Verbeek and Tijink (2020) stress that when talking about how a technology fits into society and with our values, it is important to consider its design (ethics by design), how society may change or need to adapt to fit the new technology (ethics in context), and how users must learn or adapt their behavior to safely and responsibly use it (ethics in use). This step encapsulates the approaches on inclusive design, speculative design, and visionary design/futurism. These approaches focus more on reflecting on and envisioning scenarios where issues or challenges may arise and what solutions there are, utilizing a broad lens to design for all with all but also to understand the complexities and interdependencies of the envisioned challenges and solutions (Moore et al., 2025; Imrie and Hall, 2003; Cordova et al., 2025). While several similarities between GEA, HCD, and other approaches to ethical inquiry of technological design can be found, main differences lay in GEA paying explicit attention to formulating hands-on solutions while taking the interplay of design, context, user, and technology into account.

Similar to HCD, a range of action points and solutions can be found after completing these stages of GEA. However, not all of them may be relevant or feasible, but they can provide a good starting point for the further development of more responsible and ethical technologies. The conversations around technology and ethics by design are continuous and iterative, and to ensure that technologies are ethical and fit into society and with our values, it is important that the conversation continues (Verbeek and Tijink, 2020). In innovation projects, this takes the form of iterative involvement of stakeholders throughout the development process to iteratively evaluate the technology and have a dialogue about ethical considerations and values.

3 Methodology

In this study, GEA was used to complement HCD in the evaluation of low-fidelity prototypes of four different XR applications. The aim of the study was to gather feedback on potential ethical considerations that users may envision related to the XR applications and what can be done to mitigate them. The methodological design of this study consisted of three main stages combining HCD and GEA; (1) clarifying the technology in the use context, (2) exploration of ethical considerations, and (3) exploration of options for action.

As a first iteration of the study, participants were invited to take part in co-creation workshops and 1-on-1 interviews. Initially, the intention was to solely conduct co-creation workshops, but due to practical constraints (national train strike), half of the sessions had to be postponed, and the format changed to semi-structured interviews because of the limited availability of the participants.

The co-creation workshop sessions consisted of an individual 30-min timeslot per participant for testing the XR application, and later in the afternoon all participants who tested the application came back for a 3-h workshop. The semi-structured 1-on-1 interviews lasted one hour per participant and included both the prototype testing and the semi-structured interview. For an overview of the study flow see Figure 1, for more detailed information about the study setup and flow see (Hallström et al., 2026).

The participants involved in the co-creation workshops and interviews were students and employees at the Vrije Universiteit Brussel, who were recruited as 'end users' of each use case (see Table 1). The recruitment efforts were mainly within the university context, since the campus has several departments and fields of study which would fit within the scope of user profiles per use case. We made Call for Participation posters that were hung in several places across campus where large amounts of students pass by daily– such as the cafeteria, the buildings with shared classrooms, the library, etc. We also hung these posters across two buildings of the main offices in which the research departments are located to also recruit colleagues to participate in the study. Finally, a post on LinkedIn was made through our research group's profile and shared through our personal profiles as

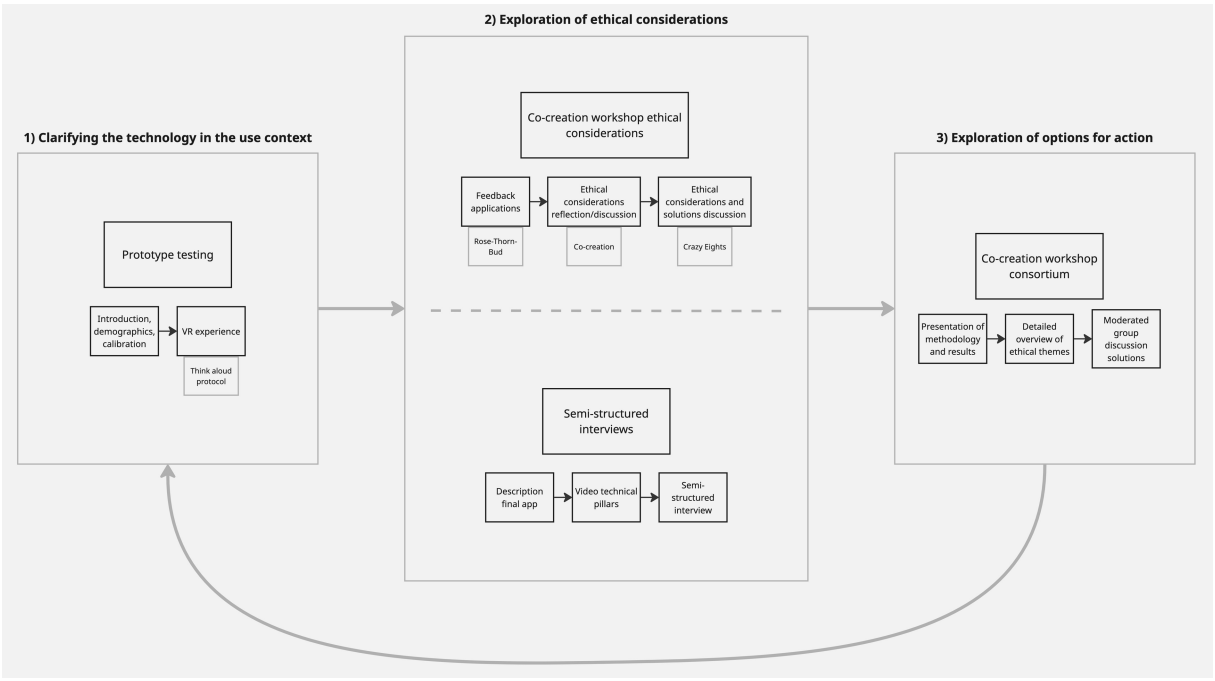


FIGURE 1
Overview study flow.

TABLE 1 Participant overview.

Total	6 participants	19 participants	18 participants
Participant demographics	4 women, 2 men (students and researchers in social sciences and humanities)	11 women, 8 men (students in engineering, developers in engineering and IT, and researchers in technology development)	6 women, 12 men (consortium partners)
Method-format	Co-creation workshop	1-on-1 interviews	Co-creation workshop

TABLE 2 Overview of end user types.

Use case	Professional collaboration	Manufacturing training	Health	Cultural heritage
End user type	Meeting participants	Manufacturing trainees	Patients	Tourists

well, to reach external profiles within our networks. Although the participants were not direct users as per the end user profiles, they functioned as representatives of the intended user profiles, since anyone could essentially be a meeting participant, trainee, patient, and/or tourist (see Table 2).

Participants who participated in sessions using a multi-user setup (professional collaboration and manufacturing training) were divided into two different rooms to best be able to interact with each other through the Meta Quest 3 headsets without disruptions. The hardware used for this study was two Lenovo Legion S5 i7-13700H/32GB/512GB/16″ computers and two Meta Quest 3 headsets with two controllers each. In single-user sessions, only one computer and headset were used. In the Professional Collaboration, Manufacturing Training, and Health applications, the Meta Quest 3 headsets were connected to the PCs due to these experiences not being developed as stand-alone experiences. However, the Cultural Heritage application was used as a stand-alone experience, and was casted to the PC screen for the moderators to follow what the participant was seeing.

In a second iteration and as part of the third stage of the study, a separate co-creation workshop of one and a half hour was organized with consortium partners online through Microsoft Teams. In this co-creation workshop, they were invited to reflect on implications and mitigation strategies to the ethical considerations and solutions that came out of the prior sessions. Recruitment efforts took the form of an internal email to the entire project list, asking at least one representative per partner to fill out their availabilities in a Doodle form. It was stressed that it is crucial that the partners responsible for each use case and for each technological pillar of the project were present. We then checked for which date most representatives were available and scheduled accordingly. The outcomes of the consortium workshop were presented at the following General Assembly of the project, so those partners who were not represented could also get insights into the study results and next steps.

As can be seen in Figure 1, this is part of an iterative approach. Other iterations are planned to further explore ethical considerations and solutions of a more close-to-final prototype of the applications. The upcoming iteration will be conducted with professional users, such as meeting leads, manufacturing trainers, medical personnel, and cultural heritage professionals. However, this paper only presents insights from the first iteration that has been conducted as described above.

3.1 Methodological setup

3.1.1 Clarifying the technology in the use context

In the first stage, the context of the four low-fidelity XR applications was described. These applications were developed as part of the PRESENCE project, based on four use cases; professional collaboration, manufacturing training, health, and cultural heritage (see Figure 2). For each session, one XR application was tested and evaluated. Before starting the study and the experience, participants first had to read and sign an informed consent form. Then they received an explanation of the use case to get an idea of what the scenario entails and what their role is (e.g., a meeting participant, a manufacturing trainee, a patient, or a tourist). In each XR application, the user is immersed in a virtual world where they can interact with different objects and – in two experiences – with another person, they can teleport from one location to another, and they can complete a given task (see Figures 3–6). After having instructed the participants on what to do in the experience and how the controls worked – i.e., how to teleport, interact with objects, etc., – they were able to test the XR application.

After testing the experience, participants were asked about their first impressions and general feedback of the applications tested, to feed into the HCD-part of the study to understand user needs. As the aim was to explore ethical considerations and solutions, we wanted the participants to envision potential future considerations as well. To give them enough context to do this, we provided a more detailed description of the use context (see Table 3). On top of the previous contextualization, explaining the scenario and role of the user, it was also explained what other actors are present in the experience (e.g., a virtual trainer, trainees, and a supervisor), and how other integrated technologies – such as holoportation, haptics, and intelligent virtual humans – are used (see Figure 7).

3.1.2 Exploration of ethical considerations

In the second stage of the study, a dialogue was facilitated in which participants discussed what potential ethical considerations they envisioned with the XR applications. In the workshops, this took the form of a group exercise and discussion, and in the semi-structured interviews it was part of the interview. During both the group session and the interviews, we made use of a semi-structured topic list with open questions (Karatsareas, 2022; Mortelmans, 2007) that were mainly focused on envisioned impacted user groups, effects of the technology on envisioned user groups, and what important values should be considered in the applications' further development. We ensured that our questions were not suggestive nor guiding for the participants, so they were able to share their own ideas and sensemaking.

The semi-structured interview questions (see Table 4) covered topics largely found in literature such as accessibility, privacy and trust, and fairness, respect and inclusiveness (see section 2), but there was also room to identify other ethical issues or topics that participants envisioned. Participants were also asked to reflect on what ethical consideration or issue they found most important to consider. To follow up on participants' answers, they were asked to reflect on how they envisioned their "top consideration" to be solved. In the workshops, the exercise "crazy eights" was used, where participants had 8 min to come up with 8 different solutions to the problem.

3.1.3 Options for action exploration

The third stage of the study explored potential options for action, which took place in two separate steps. In the first step, as mentioned in the previous chapter, participants of the co-creation workshops

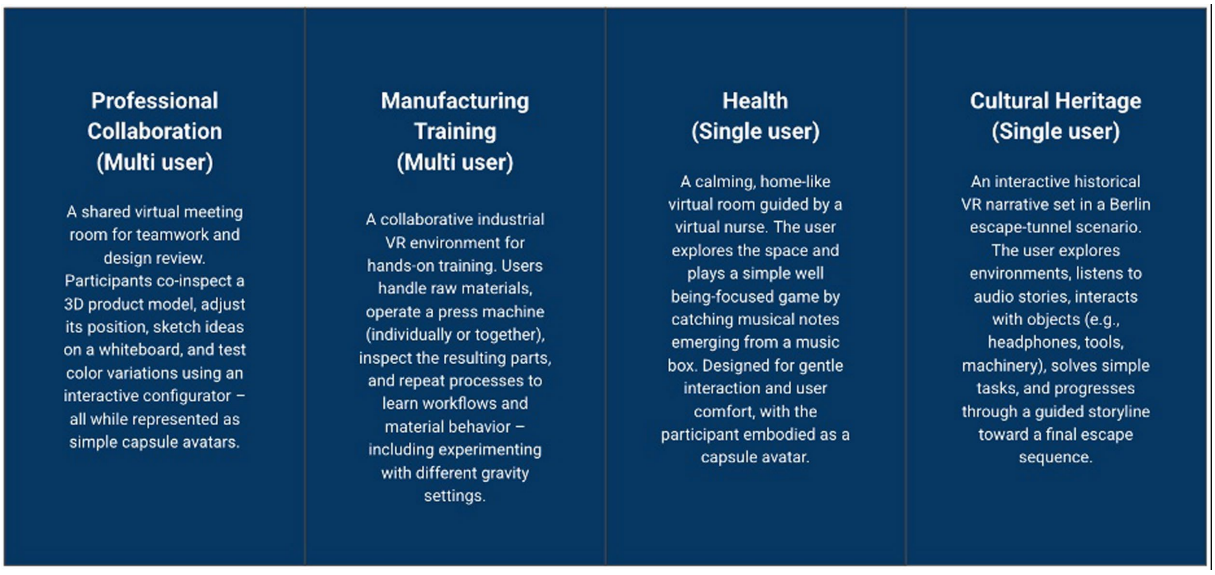


FIGURE 2
Description of the low-fidelity XR application prototypes-context.



FIGURE 3
Use case environment professional collaboration.

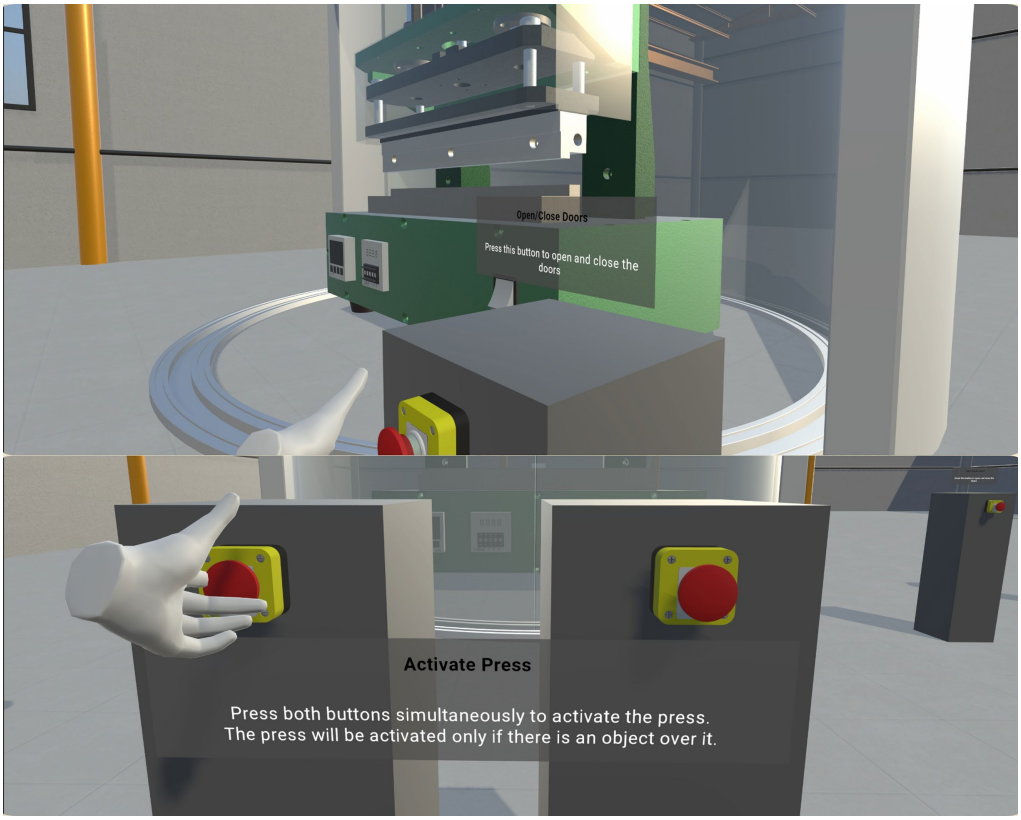


FIGURE 4
Use case environment manufacturing training.

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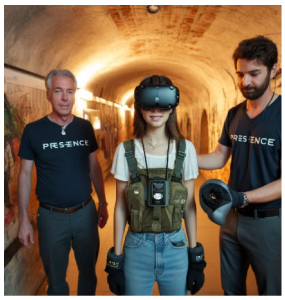
FIGURE 5
Use case environment health.



FIGURE 6
Use case environment cultural heritage.

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TABLE 3 Overview scenario descriptions of final XR applications.

Use case	Description
Professional collaboration 	In this XR-based professional collaboration scenario, four actors wearing VR headsets come together in a virtual meeting room while physically being in different places to discuss the design of an armchair. The meeting room is equipped with a meeting table, a pedestal showcasing a 3D model of the armchair under review, a whiteboard, and a wall panel displaying a PDF document detailing the chair's specifications. Actor 1 (holoported) updates colleagues on recent chair modifications, while Actor 2 visually illustrates these changes on the whiteboard. Actor 3 consults the PDF document, indicating to Actor 4 the required functionalities of the armchair. Actor 4 interacts with the virtual armchair with the haptic glove, verifying its rotation and height adjustment as per the document's instructions. All actors inspect the armchair features, confirming its capabilities and exploring material alternatives presented on a menu. After collaborative discussion, they reach a consensus on the preferred material and conclude the meeting, exchanging farewells before disconnecting from the application.
Manufacturing training 	There are five actors in this use case scenario: four trainees and a supervisor. All trainees are physically located in the training room and put their VR headsets on to participate in this training scenario. They all enter a virtual environment that has the appearance of a production department of industrial manufacturing where the hydraulic press will be placed and users will be trained on its safe usage. A virtual trainer (IVH) will explain the general operation of the machine and indicate the three main systems that users will have to learn to use: 1. hydraulic clamp for the placement of the heavy sheet of steel inside the press and for the removal of the scrap after pressing, the actor must wait 60 s to let the sheet cool down before taking it to avoid being burned (trainee with haptic gloves will feel vibration from the sheet if they touch the sheet before the 60 s interval) 2. safety door (opening/closing, locking/unlocking) 3. pressing two buttons to start the blanking action The virtual trainer showcases the incorrect usage and the potential consequences of each of these actions in VR while the other actors stay still and observe the virtual trainer. After that, the trainer invites the trainees to carry out all these actions on their own in VR. While they do so, the Supervisor (holoported) evaluates the correctness of what has been done by them to make a judgment on the level of preparation achieved. In the end, they agree to conclude the training and disconnect from the VR application.
Health 	A nervous patient arrives at the clinic for a joint injection procedure. To help them cope, they dive into a distracting virtual environment where they can play a relaxing game of catching musical notes. The patient is wearing a haptic glove, which gives haptic feedback when touching the musical notes. To feel reassured during the procedure, a friend of the patient can join remotely as a holoportation to provide extra support. The experience is guided by Ava – an intelligent virtual human – who can answer any questions the patient may have about their procedure. As the patient feels relaxed and distracted in the virtual environment, the doctor can (in the real world) concentrate on the procedure without any disruptions.
Cultural heritage 	This scenario is about exploring the escape "Tunnel 57" under the former Berlin Wall. The following actors are involved in this scenario: tourist, time witness as a pre-recorded holoportation, and a tour guide as a holoported expert. To start, the tourist puts on the XR headset, haptic gloves, and haptic vest. The virtual environment loads and immerses the tourist in the virtual space. The tourist enters a replica of a cellar with the holoported tour guide and can explore the room. The tour guide starts introducing the tourist to the experience and the room and invites the tourist to explore the digital points of interest (POIs). With the ability to freely explore, interact, and engage with POIs in the room, the tourist delves into the past while conversing with the tour guide and uncovering hidden truths. Upon discovering a triggering POI, a time-witness appears (recorded holoportation) transporting the tourist deeper into the narrative as the tour guide steps away. Navigating through a virtual tunnel, the tourist experiences the tension and urgency of an escape, culminating in a pivotal moment of decision and consequence. Emerging from the tunnel, the tourist witnesses the aftermath of historical events unfold before their eyes, shedding light on the complexities of division and reconciliation. With immersive haptic feedback from the vest and gloves and audio cues amplifying the emotional journey, the tourist is not merely a spectator but an active participant in revisiting the narrative of the past.

and interviews were asked to think of potential solutions to the ethical issues and considerations they found most important. The ethical considerations and identified solutions were compiled into a list that were further dealt with in the second step of this stage.

In the second step, consortium partners of the project were invited to participate in a separate internal co-creation workshop to reflect on implications and mitigation strategies to the ethical considerations and solutions in the compiled list. The main questions addressed concerned

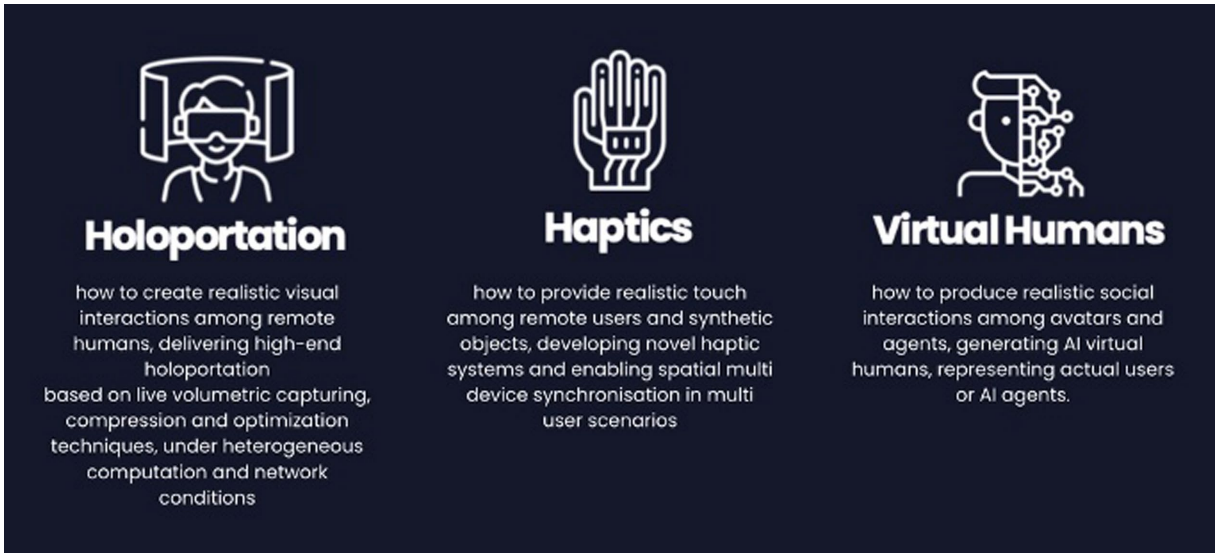


FIGURE 7
Overview of the integrated technologies.

TABLE 4 Semi-structured interview questions for ethical exploration.

#	Question	Link to GEA
1	What types of people or groups do you think might find this experience easy or enjoyable to use? • Why do you think that is?	Stakeholder identification & Exploration of effects and values
2	What types of people or groups do you think might struggle with it or feel left out? • Why do you think that is?	
3	If this experience would be collecting the data of the different user roles in this scenario, what kind of information do you think the experience would be collecting about them? • What kind of information do you think the experience would be collecting about users in different locations?	Exploration of effects and values
4	What could be some barriers - physical, technical, or cultural - that could prevent someone from fully enjoying or using this experience?	
5	What could be an example of something in this experience that might feel unfair or exclusive? • E.g., are there any elements of the experience that favor certain groups or that create friction/discomfort for certain people/groups?	
6	What other ethical considerations or topics do you envision?	
7	Based on the considerations explored, what ethical consideration is the most important to consider according to you? • What are some options to solve or address this consideration/issue?	Options for action

how to overcome or mitigate the ethical considerations envisioned, the feasibility of implementing envisioned solutions and mitigation strategies, as well as who is responsible for the implementation of what and when. This resulted in a validated and prioritized list of key ethical considerations and mitigation strategies that should guide the further development of the project technologies.

3.2 Analysis

The co-creation workshops and interviews with participants were audio-recorded and subsequently transcribed using transcription software (Scribewave), and the consortium workshop was recorded and automatically transcribed through Microsoft Teams. The transcripts were first checked for inconsistencies and corrected accordingly, and then inductively and thematically analyzed in MAXQDA to identify ethical considerations, values, solutions, and mitigation strategies. This was done in three main steps, as indicated by Lochmiller (2021).

The first step of the analytical process was to setup the research data, in this case the transcripts from the workshops and interviews. Although the transcripts were generated with help of transcription software, they were all double-checked by the research team by listening through the audio files, removing and/or adjusting inconsistencies, and pseudonymizing them. The team, which consisted of two researchers, divided the transcripts among each other to divide the work but also to best familiarize themselves with the data at hand, which leads into the next step of analyzing the data. While familiarizing themselves, the researchers made informal notes using the memo function in MAXQDA to write own reflections on what they read and understood from the data. The coding process was done in two cycles; the first one was done to achieve more descriptive codes that informed the second cycle of creating broader categories of codes. For instance, participants talking about users with visual impairments or bodily impairments may not be able to use the XR applications properly, this was then in the first cycle coded as "barrier to use: visual impairment" and "barrier to use: bodily impairment," and then in the second cycle it was clustered into a broader category of "barriers physical impairments." In the last step of the analytical process, the research team moved to the interpretation of the data, wherein they explored the relationships between categories to merge them under one theme. Following the example given, the broader theme under which these codes then ended up was "Accessibility." These three steps were conducted individually by the research team members, but after the final step, they convened to discuss their findings. This was done to verify codes, categories, and themes, and to validate their interpretations, but also to identify patterns within and across use cases. The outcome of this discussion was a complete code book.

When the code book was completed, it was possible to also see what values were prominent in the data. By arriving at the higher-level themes and interpreting what participants said, we could establish what the values at stake were. The underlying emotion informing the value at stake was interpreted based on how participants expressed this, e.g., concern or excitement, and based on the emphasis put on the consideration. When categorizing the solutions and mitigation strategies from both participant- and consortium sessions into ethics by design-, context-, and use, we first translated the feedback into user requirements and then based on the content of the requirements we checked within which category they would fit. For instance, requirements for the possibility to use the application with different setups (with or without the additional hardware components) directly inform the design of the application, while requirements for the pricing of the hardware components inform changes that may be needed on a higher societal/structural level that are outside of the project's control. Requirements that then outline other unforeseen areas of use or that require the users themselves to change their behavior to safely use the applications (Smits et al., 2022), such as users wanting to change difficulty settings or sufficient onboarding tutorials, were categorized into ethics in use.

AI-assisted tools, within MAXQDA but also GPT-5.3, were used to support code organization and to explore and identify patterns across sessions and use cases. We decided to utilize the AI functions due to the limited time frame in-between the iteration with participants and the iteration with the consortium partners (for whom we presented the ethical considerations and solutions to reflect on what the project can address and mitigate). The analysis of the findings from the workshop with consortium partners followed the same procedure as for the sessions with participants. AI was only used as a support and did not replace our own analysis. To ensure the reliability of the findings, all outputs generated by the AI were carefully reviewed and validated by the research team, addressing any potential errors or oversights. All interpretations were made by the researcher team.

4 Results

The results of this study are focused on the second and third stages of GEA – exploration of ethical considerations and exploration of options for action – and will be presented in this order. This section presents what specific ethical considerations and issues emerged from the study, as well as what solutions and options for action were found.

4.1 Exploration of ethical considerations

In this part of the study, in both the workshops and interviews, participants identified a broad range of ethical considerations (see Table 5). While the themes 'accessibility and inclusivity' and 'privacy and data transparency' emerged across sessions, considerations related to the themes 'cultural and historical integrity' and 'realism and functionality' surfaced only within the cultural heritage and health contexts. This shows that some ethical considerations are more inherent to XR technologies, while others may be more dependent on the context (social, cultural, and practical) in which the technologies are used.

4.1.1 Accessibility and inclusivity

Accessibility and inclusion emerged as a prominent ethical consideration throughout the sessions. Here, accessibility was framed as moving beyond only physical access to also encompass more economic, social, cognitive, and technological dimensions.

A first consideration related to cost and affordability, where participants highlighted that as these XR experiences depend on expensive hardware (such as headsets, haptic devises, and high-performance computers) they may become financially inaccessible. Here, these barriers were mainly discussed as being prominent for individual users, but also for other stakeholders – such as organizations, companies, or other public institutions. This suggests that participants did not only see accessibility as the availability of technology, but also as an issue of resource distribution where access to the XR applications potentially could reinforce existing inequalities as users of all kinds have differing financial capabilities.

TABLE 5 Overview of ethical considerations.

Theme	Professional collaboration	Manufacturing training	Health	Cultural heritage
Accessibility and inclusivity	Hardware access, onboarding support	Cost, space, VR sickness, mobility, language barriers	Sensory needs, control options, onboarding	Adjustable settings
Privacy and data transparency	Body scan privacy concerns	Surveillance stress, tracking fears	Transparency on biometric/ emotional data	Clear data transparency
Cultural and historical integrity				Accurate and respectful storytelling
Realism and functionality		Realistic graphical depictions, realistic interaction	Realistic simulation of real world in virtual environment	

> "*In a real professional setting, then it sort of needs to be in a way where people are maybe rich because of the [expensive] technology. […] Not everybody is going to be able to have that kind of setup. That might be the more developed version of the app, it might be VIP in that sense*" (Participant 4, male).

Physical accessibility was another ethical consideration that emerged across sessions. Here, participants saw barriers of use in terms of cybersickness, mobility limitations, and for neurodivergent users. What became evident here was the tension between immersion and accessibility. Some participants noted that the features that increase immersion (such as enclosed virtual environments and complex interaction mechanisms) could be potential points of discomfort, stress and anxiety, or exclusion. They emphasized that for the users who may experience this, it is important that they can maintain a sense of agency and control over their environment.

> "*I think this scenario specifically could be terrifying for people with, I do not know, claustrophobia? Crawling through the small tunnel and so on. People also in general who feel less mobile in general. I mean, I'm not only talking about disabled people, but also old people*" (Participant 1, female).
>
> "*Some people do not like the VR glasses because they feel like they lose control over the situation. My son has autism and he has to do regular blood work to check his medication, but I do not think it would work for him because he really wants to have this control of talking him through it and if one step is a bit off, then for him, it's already no*" (Participant 7, female).

Across sessions, participants had also touched upon the inaccessibility that the haptic gloves or vest may cause users with physical or mobility-related conditions. Participants pointed out that some users may be taller or broader than the vest allows, which may limit their ability to accurately feel haptic feedback, which would also be the case where the haptic glove is too big or too small. Some mentioned that users may also have difficulty using the haptic glove if they, e.g., cannot use their hands properly or have other technical issues with their arms or body. Instead of seeing accessibility as something solely solvable through software design, participants saw the material characteristics of XR as a critical point where exclusion can occur, highlighting that accessibility concerns are also embedded in hardware design.

> "*Well, I think that the gloves and the vest will be a certain size. So if you just do not fit the size, if you are too small or too big, yeah, then you cannot use it. Also if you have a disability, if you have one arm, for instance, or if you do not have proper feeling or a technical issue with your arms or your body, then you will be excluded*" (Participant 7, female).

Participants also discussed the fact that some users may have different levels of digital literacy/skills depending on prior exposure, age, or confidence using these systems and technologies. Especially older populations were seen as disadvantaged, as they would not have the same digital skills to use XR applications as younger populations more likely would. However, these considerations extended beyond technical skills as participants suggested that unfamiliarity with XR could have an influence on willingness to engage with it. This indicates that perceived accessibility may be just as important as actual usability.

Inclusion-related considerations highlighted were language and representation. Participants emphasized that there should be representative avatars of a diverse range of people, no matter ethnicity, age, gender, disability, etc. They also questioned whether AI-driven language translation adequately could support individuals who may need to use the application in another language than the original provided, especially in contexts where safety-critical information is central, such as manufacturing training. Thus, inclusion is not only seen as providing access but also as ensuring meaningful participation across diverse user groups.

> "*At least when I tell ChatGPT to translate stuff from French to Spanish or because of the university, I translate the stuff because it makes mistakes. So people that do not speak English very well, that maybe do not know English at all, would be more excluded from this kind of experience. Or they get taught incorrect procedures and then when they go to work, you have to re-educate them basically*" (Participant 21, male).

4.1.2 Privacy and data transparency

The discussions around data and privacy mainly revolved around broader questions of trust, surveillance, and accountability. Participants specifically expressed concerns around data tracking and collection of data (e.g., personal data, biometric data) within the XR applications, but also who data is stored and who may have or gain access to it. The kind of data that participants raised concerns about were biometric data, behavioral data, data captured through

holoportation systems, and AI-supported systems and functionalities. In professional contexts, participants raised concerns about whether trade secrets or other sensitive information would be safely and securely stored in such XR applications. They also questioned the boundaries of data collection, and then even though the technology may be intended for a certain purpose (such as holoporting a person into a meeting room), the systems may capture more data and information than intended. As participants also raised concerns about data governance, it is indicated that privacy is not only connected to confidentiality but also to transparency and trust.

Another pattern that emerged concerned the relationship between surveillance and behavior. Participants noted that as users are aware they are being monitored or recorded, e.g., while conducting manufacturing training, they may alter the way they interact within the experience. Participants perceived data collection thus as increasing stress, anxiety, and pressure to perform, which highlights a tension between the desire to support safety and accountability through monitoring systems and the desire to maintain user autonomy and comfort.

> "*If you were to record those interactions, like you would feel the need to be perfectionist and do everything and then you would make more mistakes*" (Participant 21, male).

In similar contexts, participants also raised questions about inappropriate or harmful behavior in virtual spaces. There was uncertainty about the legal and ethical responsibilities in XR environments, in relation to harassment, hate speech, and misconduct. This suggests that participants saw virtual interactions as having real social consequences and thus they expect corresponding mechanisms for accountability and governance.

> "*But what if you try to grab the instructor and throw him in the machine? You know, can you do these things and is that a bad sign? You know, like, should we be tracking these, like virtual crimes?*" (Participant 20, male).

4.1.3 Cultural and historical integrity

This ethical consideration emerged specifically in the cultural heritage use case, where participants stressed the importance of not romanticizing or distorting sensitive topics in immersive environments and experiences. They questioned whether these experiences may unintentionally prioritize entertainment and engagement over historical accuracy and ethical representation, presenting the tension between creating compelling user experiences and ensuring accurate representations of historical realities. However, participants did not only focus on aspects of factual accuracy, but also on how representations respect the emotional, social, and moral significance of these historical events. This shows that for participants, authenticity was not only a question about factual and historical correctness but also about ethical responsibility when creating these types of experiences.

> "*When it comes to these historic sensitive topics, I do find it super important to lay focus on specifics, to not romanticize it as this fun escape action and so on. [.] Is this actually a representative reflection of reality or is this a game? I do find that it is very important to make this clear in the beginning to not manipulate historic happenings and make them seem fun and cool or unjust or whatever*" (Participant 1, female).

4.1.4 Realism and functionality

Ethical considerations such as problematic graphical representations and asynchronized representations were highlighted under this theme. In manufacturing training contexts, participants voiced concerns about how realistic or graphic representations will be of dangerous practices. While acknowledging the educational value of realistic simulations (such as what happens if you get stuck in the hydraulic press), they also emphasized the risk of these simulations causing discomfort or psychological harm, pointing to the tension between realism as tool for learning and realism as a potential source of distress.

Another concern was about the asynchronized representations in the environment. For instance, participants who tested the health XR application mentioned that if they had their blood drawn, they would have liked to have some sort of representation of this in the virtual environment. As there was this mismatch between the virtual and real world, it was perceived as potentially more disorienting and even anxiety-inducing in some cases, especially for anxious patients or patients with neurodivergent conditions.

From the ethical considerations envisioned, several values at stake emerged. As participants were asked to reflect on the ethical consideration that they found the most important to address, it also became clear what value(s) were the most important to them. During the analysis and coding process, values such as Accessibility, Adaptability, Fairness, Integrity, Privacy, Safety, and Transparency emerged (see Table 6). For each ethical consideration – or value at stake – participants and consortium partners ideated a range of solutions and options for actions, which are further expanded on in section 4.2.

4.2 Exploration options for action

In this part of the study, participants and consortium partners ideated solutions and options for action to mitigate the ethical considerations envisioned. These are presented alongside the identified values at stake (see Table 6).

4.2.1 Accessibility and adaptability

These two values aligned with each other in terms of what solutions and mitigation strategies were envisioned by both participants and consortium partners. Here, user choice and increasing flexibility of the applications were points emphasized. Most solutions concerned ethics by design – i.e., what is important to consider in the design of the applications – such as availability of different hardware options, personalized and customizable experiences, language translation, and adaptive support features. Participants emphasized the importance of users being able to properly and safely use the applications, which is where solutions for ethics in use – such as more onboarding tutorials and user agency in control settings – emerged.

Consortium partners acknowledged and agreed with several of the recommended solutions and found many of them technically feasible within the time frame of the project. However, some solutions were perceived as important but out of scope for the project and the use case concept. For instance, the pass-through option can be complex to implement technically but could also potentially take away from the experience and the purpose of distracting anxious patients. Consortium partners also discussed what to do about feelings of cybersickness and noted that an option is to introduce less artificial

TABLE 6 Overview of options for action per user needs and values.

Needs and values	Description	Options for action
Accessibility	The applications should be accessible to all users.	Ethics by design: • Availability of different hardware options • Minimized artificial movements Ethics in context: • Minimum hardware setup Ethics in use: • Onboarding tutorials
Adaptability	The applications should be adaptable to different user needs, sensitivities, and contexts.	Ethics by design: • Personalization of experience • LLMs for language translation • Adaptive support features Ethics in use: • User agency in control settings
Fairness	The applications should ensure fair representation of diverse users.	Ethics by design: • Diverse avatar representations
Integrity	The applications should promote responsible and reliable information exchange.	Ethics in use: • References for further reading
Privacy	The applications should ensure and respect the privacy of its users by not gathering unnecessary data.	Ethics by design: • No unnecessary data collection foreseen Ethics in use: • User agency in privacy settings
Safety	The applications should provide users with safe experiences for safe learning.	Ethics by design: • Warning messages to promote and instruct safe learning
Transparency	The applications should provide information about data management, potential risks of usage, factual or fictional content depictions.	Ethics by design: • Content transparency • Informational disclaimers on data collection and management

movements (i.e., users relying less on the controls and instead move more naturally in the environment). There were also some envisioned solutions that were perceived by the consortium as too difficult to address due to practical constraints, such as, e.g., the cost of hardware and sizes. These items are not developed within the project, and thus the market would either have to adapt the prices and size availabilities, making it an ethics in context action. However, this is not something that a single project can easily do, and thus the solution is to investigate and adapt the applications to support a minimum hardware setup. Nevertheless, these findings suggest that although inclusive design principles can guide software development, some accessibility considerations are tied to conditions that are outside the control of a single project.

4.2.2 Fairness

This value focused on the availability and importance of ensuring fair representation of diverse users, wherein avatars represent various ethnicities, gender, body types, etc. This is something that the consortium already was working towards, and thus something that is effectively and continuously being considered in development.

4.2.3 Integrity

Several solutions were suggested by participants to support ethically sound historical representations in the application, such as involving subject matter experts, community perspectives, and including disclaimers distinguishing between historical facts and fictional content. This reveals an emphasis on the importance of transparency and accountability, where open communication about the choices and underlying decisions for historical representations is key. Consortium partners agreed and emphasized that transparency will be achieved through disclaimers but also references to supporting sources which allows users can further contextualize and critically engage with the material of the experience.

4.2.4 Privacy and transparency

Transparent communication about what data is collected, shared, and used was seen as an important consideration to implement. Suggested solutions to address privacy concerns included clear communication about what data is collected, how it is used, who has access to the data, and what choices users have to handle their information

and data. Transparency was thus not only seen as a legal requirement but also as an important component to build trust. By having access to this information whenever the user wants during their use of the application and experience, e.g., in the settings menu, they can feel greater agency and control than by only being told about it at the initial onboarding of the experience. The consortium partners also emphasized the importance of not collecting any unnecessary data, which was not foreseen.

4.2.5 Safety

The discussions on solutions here mainly focused on the balancing of effective education with user wellbeing. Instead of depicting graphic consequences of unsafe actions in the manufacturing training application, consortium partners suggested that alternative points of feedback – such as warnings, auditory cues, or haptic feedback – should be integrated. This way, users are still able to learn procedures in a safe manner. Consortium partners also discussed this in terms of realistic learning, wherein they agreed that realistic movements and interactions should be applicable across the XR applications. Providing users with different interaction options as well as improving the synchronization between the real and virtual world, could also lead to reduced disorientation and increased comfort for users – making the applications safer to use.

5 Discussion

In this study, the aim was to explore ethical considerations, values, and solutions of four different low-fidelity prototypes in an innovation project based on a methodological combination of HCD and GEA. Solutions and options for action were ideated by both participants and consortium partners, which proved efficient in the sense that for those solutions deemed as not feasible within the practical constraints of the project, other solutions to respond to the values of the users were proposed. In this section, we will first briefly discuss the results of the study itself, followed by a reflection on the successes and limitations to our approach of combining HCD and GEA for the purposes of this study.

5.1 Identified ethical considerations and values

This study revealed several ethical considerations and values at stake. As participants reflected on the ethical considerations most important to address, it became clear what value(s) were the most important to them (see Table 6). The findings show that even when interacting with low-fidelity prototypes, users are able to articulate ethical considerations, suggesting that meaningful ethical reflection can take place early on in the design process before significant time and resources have been invested in development. Most values that emerged found a solution in ethics by design, which is likely because the participants were interacting with low-fidelity prototypes of the XR applications and were presented a contextual scenario for envisioning the future and final prototype. As a result, participants primarily reflected on design and functionality aspects of the prototypes rather than broader social implications or the context in which they would be used. In other words, discussions were largely focused on how the prototype could be developed rather than how society might need to adapt or accommodate the technology. One element that was raised related to the broader context was the high cost of the required equipment (e.g., haptics gloves and vest and VR glasses). This touches upon important values of accessibility and inclusion. This goes beyond the scope of the project as we are not developing haptic technology, but it does raise awareness on the need to explore how the experiences can be configured with a minimum hardware setup.

The results also show that the values largely align with physical, psychological, and moral implications (Steele et al., 2020), as they refer to issues concerning physical (dis)ability and that all users should be able to use the experience regardless; the psychological well-being of neurodivergent users and their ability to adapt the experience to their needs; as well as the importance of ensuring and respecting the privacy and safety of users. These values correspond largely to the ethical considerations already found in literature (Fernandez and Hui, 2022; Madary and Metzinger, 2016; McGill, 2021; Ramirez et al., 2021; Slater et al., 2020; Southgate et al., 2017; Cox et al., 2025). Initially this may appear unsurprising, but it is a significant finding since this empirically supports that already identified ethical considerations are also recognized by future users, strengthening the argument that they should be considered central design requirements. This also shows that even if ethical considerations that emerge in empirical studies align with those already identified in literature, it is still important to conduct ethical inquiry in case new ethical considerations would emerge, but also to give users a chance to voice what is important to them and what their primary concerns are. Involving users in this way allowed us to better understand the values, needs, and expectations that they have, but we were also able to explore the nuances of these considerations.

Beyond exploring ethical considerations, involving two stakeholder groups – end users and project consortium (i.e., developers, project managers, researchers, industry experts) – proved efficient to arrive at more concrete solutions for the envisioned ethical considerations and values as consortium partners could envision other solutions where the ones proposed by participants were not deemed as feasible. However, there were only a few participant-proposed solutions where this was the case, in fact, for a majority of solutions the consortium partners agreed with the proposals. By involving both stakeholder groups, it was easier to determine concrete options for action in line with ethics by design, in context, and in use (Verbeek and Tijink, 2020), based on feasibility, direction of the project, and assignment of actions together with the consortium. This helped bridge the gap between ethical aspirations and practical hands-on design decisions, but it also suggests that ethical inquiry is more effective when involving both users of the technology and those who are responsible for its design and implementation.

The findings of the study suggest that ethical considerations in XR development and user experience concerns are closely intertwined, and that ethical inquiry at an early stage of development can both successfully identify stakeholder values and concrete, feasible ways to address them. Combining the perspectives of end users and consortium expertise was especially valuable to translate ethical considerations into concrete and actionable design actions.

5.2 Human centred design and guidance ethics approach: methodological reflections

Our study indicated that GEA is a good complementary approach to HCD and that both methods can be easily aligned in a research set-up. GEA partially complements the lack of ethical reflection as an

integral step of HCD approaches. HCD on the other hand provides a broader contextual understanding of the needs and expectations of users and can identify usability issues at an early stage. The combination of the two approaches enabled the exploration of ethical considerations within an already existing workflow, as HCD was already established as a standard approach within the project (European Commission: Directorate-General for Research and Innovation, 2024). As HCD provided insight into user needs, expectations, and usability concerns, GEA provided a structured manner for exploring and identifying ethical considerations and values. GEA was also beneficial to the study due to it encompassing several already established approaches in the field (Donia and Shaw, 2021; Moore et al., 2025). By integrating GEA activities into HCD workshops and interviews, ethical inquiry became a part of the iterative process itself and no separate studies or (on a more administrative level) work packages were required. In Horizon Europe innovation projects, where practical constraints (time, resources, staff, etc) may limit opportunities for more extensive exploration of ethical considerations and ethical evaluation in general, the possibility to combine the two approaches is especially valuable. This can also be valuable in providing input on ethical considerations and solutions alongside and for the external ethical advisory board that is appointed to provide checks and balances of the project.

However, due to GEA being a novel approach with limited application in studies on XR development and the practical constraints we were faced with, limitations to the study setup were found. For instance, although the workshop setup was beneficial for a broader discussion and challenging perspectives about ethical considerations, it was not always feasible for the participants to participate in a three-hour workshop. Fortunately, the workshops were easy to adjust into a semi-structured interview format, but the tradeoff was that this broader reflection and challenging perspectives among participants was lost. When looking at previous studies using GEA in XR development (Smits et al., 2022), it seems that the semi-structured interview format would be successful for exploring values before and after the use of the application. However, this is a time intensive endeavor and requires the necessary conditions within a European project to best facilitate this. Usually in European projects, the final product or application is only available for testing toward the end of the project, and the final testing phase is thus limited. Thus, reflecting and speculating on ethical considerations for a low-fidelity prototype is beneficial since this helps avoid unethical applications and experiences from the start.

When reflecting on ethical considerations about technologies as a user, it can be difficult to fully articulate ideas and needs (van Velsen et al., 2022), especially if they have only interacted with a low-fidelity prototype and not the actual final application. Although participants only could speculate about ethical considerations with the final applications, it is still important to iteratively reflect on ethical considerations throughout development, but also in early stages of development to ensure ethical foresight rather than hindsight.

During the sessions, participants were asked to reflect on ethical considerations based on open questions. To start, questions focused on topics identified in literature, while later questions allowed participants to provide personal reflections and add potential considerations. The fact that some questions were based on topics in literature presented a limitation in the sense that it could be perceived as leading the participants' reflections and answers towards a certain direction. However, when preparing the questions, they were purposefully written as open questions to avoid being leading, allowing participants to interpret the questions themselves (Karatsareas, 2022).

Another set of limitations involves the recruitment and positionality of participants and the broader context in which the project takes place. Participants were primarily recruited from a single academic environment, which resulted in a younger, able-bodied, highly educated and relatively tech-familiar sample that may not reflect the full diversity of future XR users. Most of the students involved in the study also came from the same study program. Due to the project and study taking place in a European context, it is also difficult to generalize the findings since the perspectives presented in this study reflects a European perspective. In terms of values, it is difficult to generalize as well due to this positionality, but also due to the interpretations and positionality of the researchers who themselves have their own biases and assumptions that play a role in how the participants' input on ethical considerations is interpreted (Steen, 2012).

In line with this, this is also true for the context in which the study takes place. Due to European projects lasting only three years, partners having limited allocated budget, and limited staff who may also switch during the lifecycle of the project, certain priorities may need to be made that may not fully address the initial input of users. However, since this is an iterative process (Verbeek and Tijink, 2020; ISO 9241-210:2019, 2019), another iteration is planned for the next phase of the project where participants will interact with a more close-to-final product. Additionally, some concerns that emerged, e.g., hardware constraints or organizational policies, extend beyond the control of a single project, making it difficult to address it at this point. Within the project ambition, this ethical guidance should feed into the exploitation plans for the project partners and the project as a whole. Beyond the project scope, future research should involve broader participant populations, culturally diverse contexts, and extended deployment periods to examine how ethical considerations evolve across different settings.

These findings and reflections indicate that HCD and GEA are highly compatible approaches to explore ethical considerations in XR innovation projects. Although there were practical limitations (participants recruitment, project timelines, and prototype fidelity) that are important to consider, this combined approach allowed for the identification of stakeholder values, the facilitation of a dialogue with both users and developers, and it supported the translation of ethical considerations into actionable design decisions. Thus, there's a showed promise for a practical framework that embeds ethics into the early stages of XR development in an HCD-based innovation project.

5.3 Directions for future research

Based on the reflections presented in the previous chapter, several recommendations for future research can be found. First, although the use of low-fidelity prototypes and ethical considerations speculation based on scenario descriptions enabled early ethical reflection and foresight, these considerations and their speculations may differ from ethical considerations that may arise when actually using the final applications. Future studies should investigate how ethical considerations potentially evolve when users interact with different fidelity stages of an application, but especially comparing low-fidelity- and near-final applications. This would help provide insight into how ethical considerations may remain stable or evolve over time, but also if new ethical considerations emerge through prolonged use.

Second, incorporating systematic observation protocols to observe reactions, emotions, and non-verbal behavior of participants throughout the study could provide additional context to the verbal reflections of participants and thus provide deeper insights and understanding of

the experiences of the users and what the underlying values are, rather than relying solely on verbal reflections during analysis to interpret values. This way, the researchers' attention is drawn more explicitly toward participants' emotional and non-verbal responses (Verbeek and Tijink, 2020) which can complement the (more rationalized) input they then give during the interview sessions, and inform what values are at stake. Here, it is also recommended to employ already established approaches to analyzing values from ethical inquiry [such as Values at play, or Values-led participatory design (Donia and Shaw, 2021)]. This can also help researchers in identifying values that participants may find difficult to articulate themselves.

Finally, it is crucial to explore how ethical considerations vary across user groups. In this study, a younger, highly educated, and technologically familiar sample of participants were involved, all from a European academic environment. To best examine how or whether different groups or populations prioritize or envision ethical considerations and values differently, we recommend for future studies to include participants from diverse backgrounds, of different ages, education levels, abilities, and technological experience.

6 Conclusion

This article examined how ethical considerations for XR experiences can be identified and translated into concrete action points for further development, by combining HCD and GEA approaches in the context of an innovation project. The engagement of different stakeholder groups – end users and consortium partners (i.e., developers, project managers, researchers, industry experts) – several ethical considerations, values, and options for action emerged. Using GEA and HCD as complementary approaches in this study proved efficient in engaging stakeholders in ethical reflection, although there are some recommendations for future research to be made. The study shows that treating ethics as an iterative, participatory design practice enables meaningful progress toward more responsible, trustworthy, and human-centered XR technologies.

Data availability statement

The datasets presented in this article are not readily available because our study is based on participants consent, as defined by Article 6(1) of the GDPR. In the informed consent it is mentioned that the data acquired through the study will not be shared with any third parties and will only be available to our research institute.

Ethics statement

The studies involving humans were approved by Ethics Committee Human Sciences (Vrije Universiteit Brussel). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

LH: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. IJ: Conceptualization, Project administration, Supervision, Validation, Writing – review & editing. WV: Supervision, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The author(s) declared that Generative AI was not used in the creation of this manuscript.

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