The Ethics of Extended Realities: Insights from a Systematic Literature Review

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Extended Reality technologies, including Augmented Reality, Virtual Reality, and Mixed Reality, are gaining popularity due to their affordable and beneficial nature. Several ethical issues have been found to arise as these technologies are put to use in various contexts. Most ethical aspects of XR technologies and their applications have been largely explored within a specific context like individual technologies, applications, or demographics. There is a lack of comprehensive research focusing on the overall ethical landscape of XR. This study aims to bridge this gap by conducting a Systematic Literature Review to investigate ethical issues and concerns in XR technologies, explore the adverse effects and barriers they create, and identify ethical solutions and recommendations to address these challenges. The findings of this study reveal that the use of XR technologies gives rise to numerous ethical issues and concerns, including social implications, privacy risks, and moral dilemmas. These issues have far-reaching impacts on various aspects of human life. Therefore, it is crucial to address them in order to develop XR solutions that are both safe and ethical. This study serves as a foundation for future research efforts in understanding and addressing the ethical implications of XR technologies, paving the way for the development of responsible and sustainable XR ecosystems.

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

Additional Key Words and Phrases: Ethics, Extended Reality, Augmented Reality, Virtual Reality, Mixed Reality, Systematic Literature Review

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1 INTRODUCTION

Extended Reality (XR) technologies, including Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR), have been rapidly gaining popularity in both consumer markets and the field of research. It is anticipated that these technologies will soon become ubiquitous and find applications in various fields [45]. The realistic and immersive capabilities of XR have been found to enhance human abilities and positively impact their lives [53]. The affordability of XR devices, particularly VR devices, has been increasing thanks to the investments and collaborations of tech giants like Sony, Microsoft, Google, and Facebook (now Meta). The combination of technological advancements and economic factors has paved the way for the rapid development, and advancement of XR technologies. As a result, the research output in the field of XR has significantly increased, exploring various topics and phenomena [68].

Despite the growing adoption and potential benefits of XR technologies, they also give rise to significant ethical concerns and discussions [60]. Some notable ethical implications include health issues, privacy concerns, the impact of superrealism, and the effects of prolonged exposure [53, 60]. The use of XR for human augmentation and interventions introduces new ethical dilemmas that require careful examination [53]. It is crucial to closely examine these issues

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and develop potential solutions that effectively address the associated risks. By doing so,a responsible and beneficial integration of XR technologies into various domains can be ensured.

Upon examining prior studies on XR ethics, it became apparent that ethical considerations were often investigated within specific contexts, focusing on individual XR technologies, applications, or demographics. However, only a limited number of studies offered a comprehensive analysis that encompassed the broader spectrum of XR, including AR, VR, and MR technologies [11, 38, 60]. To bridge this gap, the current study aims to conduct a thorough exploration of ethics in XR without confining the investigation to a particular context. By adopting this approach, the study intends to examine the utilization and impact of XR technologies across various applications and use cases. This broader scope enables a more comprehensive understanding of the ethical implications associated with XR. With this aim, the primary objective of this research is to gain insights into the practical implementation of XR technologies by industry and research practitioners, and to identify the ethical issues and concerns. Furthermore, the study seeks to shed light on the potential negative outcomes arising from these ethical concerns and their effects on XR interventions. Finally this research briefly tries to evaluate the extent of research being conducted to develop ethical frameworks and considerations that can effectively address these potential threats, ultimately establishing XR as an ethical and safe platform for usage.

This study, aimed at comprehending the current ethical landscape of XR, holds great relevance for the field of Human-Computer Interaction (HCI). As XR technologies are rapidly growing, HCI professionals, both in industry and academia, are likely to encounter XR technologies in their future business and research endeavors. The insights gained from this study can provide a better understanding of the potential ethical concerns associated with usage of such powerful technologies, their adverse effects, and effective solutions to address them. This broad approach is justified because XR technologies are versatile and adaptable, with applications growing across a wide range of use cases and domains. By familiarizing HCI professionals with these emerging technologies and highlighting the importance of ethics, this study equips them to design ethical XR solutions in the future. The integration of ethical considerations in HCI practices will be crucial to ensuring responsible and user-centered design as XR technologies continue to evolve.

To achieve these objectives, a meticulous and unbiased Systematic Literature Review (SLR) was employed as it generates credible results, thereby enhancing the reproducibility of the study and facilitating future expansions and refinements [35]. To conduct this SLR, research papers and short papers addressing the ethics, ethical issues, ethical considerations and other relevant concerns of XR technologies were gathered, screened, evaluated, and subjected to a thematic analysis to synthesize the findings. The article is structured as follows: Section 2 provides the background for the review, offering a brief discussion on each XR technology and significance of XR ethics. It also outlines the scope and limitation of this study. In Section 3, the methodology employed in this study is described, including the different phases of the SLR, the research questions, and a step-by-step account of the findings. Section 4 presents the findings obtained from the thematic analysis, providing answers to the research questions. In Section 5, a comprehensive discussion is presented, examining the findings in detail and discussing the limitations of this study. The article concludes in Section 6, where the key findings are summarized, closing remarks are provided, and future research directions are suggested.

2 BACKGROUND

2.1 Extended Reality Technologies and Use Cases

Extended Reality is an umbrella term for a variety of immersive technologies such as Augmented Reality, Virtual Reality and Mixed Reality [11, 68]. XR applications offer virtuality to varying degrees, ranging from fully simulated

virtual worlds where users can navigate themselves to simple virtual objects overlaid onto the real world [11]. These features are often blended to provide immersive experiences such as watching 360-degree entertainment content, playing games, taking virtual tours, training, medical rehabilitation, and inspecting structures from cars to buildings [11]. The emergence of XR has begun to blur the boundaries between the physical and digital worlds by creating a sense of presence, immersion, and realism for users [11].

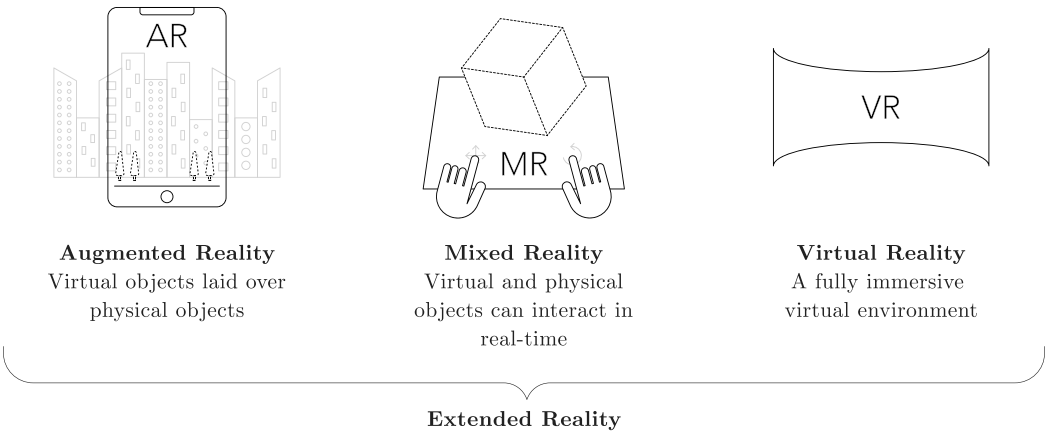

Fig. 1. Extended Reality Technologies

According to Statista, the Business-to-Consumer (B2C) revenue for the AR and VR market is predicted to reach 31.12 billion USD with an estimated user penetration of 28.8% in 2023. The market is projected to grow at an annual rate of 13.72% from 2023 to 2027, resulting in a market volume of 52.05 billion USD by 2027 [62]. Major corporations such as Google, Alibaba, Warner Bros, Coco Cola, McDonald's, and Disney are heavily investing in promising XR companies and applications [11]. Furthermore, PwC's "Seeing is Believing" report claims that AR and VR have the potential to drive business, improve technology, enhance user experience, and increase global GDP up to 1.5 trillion USD by 2030 [54]. This has led to explosive growth in XR applications, technical advancements, and research activities in various fields such as entertainment, education, healthcare, gaming, manufacturing, and tourism [11, 68].

VR refers to a synthetically constructed 3D environment that users can interact through display screens or wearables like Head-mounted Displays (HMD) [26]. VR can be broadly divided into two categories - Immersive and Non-immersive. In Immersive VR, HMDs track user movements and display VR information, creating a fully immersive experience. On the other hand, Non-immersive VR uses multiple screens to present virtual information [26]. VR technology was first introduced in the 1960s, but it took 50 years to become mainstream. The creation of Oculus and its acquisition by Meta in 2014 were key events that led to the rapid growth of VR devices for personal and home use [26]. As a result, VR has now become popular, accessible, and affordable, with many players entering the market like HTC Vive, Samsung VR, Valve Index, Google Cardboard, and others [26]. According to Statista, the global VR market size is expected to grow rapidly from less than 12 billion USD in 2022 to a whopping 22 billion USD by 2025 [64]. Although initially, VR was mainly focused on the gaming industry, it has the potential for innovative applications in various sectors,

including industrial simulations, design and prototyping, education, healthcare and medical training, fitness and sports, meditation and rehabilitation, social interaction, entertainment, and many more [26].

AR, unlike VR, enriches and augments the real world by overlaying digital or virtual information onto physical objects in real-time [8, 9]. The term "Augmented Reality" was coined by Boeing employees Tom Caudell and David Mizell, who highlighted its advantages over VR in terms of power and pixel consumption [8]. To provide an immersive experience, AR requires key devices such as displays, input devices, tracking, and computers. With modern-day smartphones, which come equipped with powerful CPUs, high-quality cameras, GPS, accelerometers, and gyroscopes, AR has found a promising platform that is ubiquitous and portable [8]. According to Statista, by 2024, there will be 1.7 billion active mobile AR users worldwide [63]. Studies conducted by Carmigniani et al. [2011] and Chen et al. [2019] showcases that AR has immense potential to create innovative applications that can be used across various domains and contexts, including advertising and commerce, entertainment and leisure, art, education, healthcare and medical treatment, engineering and manufacturing, tourism, and archaeology [8, 9].

MR technology, a relatively new development in XR, is a hybrid that combines the best aspects of AR and VR [11]. While VR completely blocks out the physical world, AR solves this problem by superimposing digital content onto real-world objects. However, AR still has limitations as there is no interaction between real and virtual objects [20, 56]. This is where MR excels, as it merges the real and virtual worlds in a way that allows for real-world objects to interact with virtual objects in real-time, creating practical scenarios for MR users [56]. One example of this technology is the Microsoft HoloLens, an untethered MR headset that has been used to solve various challenges faced by organizations in sectors such as manufacturing, engineering, construction, healthcare, and education [28].

2.2 Importance of Ethics in Emerging Technologies

XR technologies have experienced a significant economic and adoption boom in recent years and this growth trend is expected to continue in the future [62–64]. The technology's versatility and innovative modes of interaction make it a powerful tool. Its widespread adoption in various domains including healthcare, education, entertainment, and gaming highlights its immense impact [8, 9, 26, 28]. With these features, XR technologies have sparked a technological revolution capable of generating ethical problems [47].

A technological revolution is a gradual process and can be divided into three stages: the introduction stage, the permeation stage, and the power stage [47]. During the introduction stage, there are fewer users and use cases, resulting in a smaller social impact and fewer ethical issues. In the permeation stage, the technology becomes more integrated into society, with more users and use cases. This increased integration leads to more ethical issues. In the power stage, the technology has a significant impact on society, resulting in a multitude of ethical issues problems [47].

The main focus of this study is not to determine which phase of the tripartite model XR technologies fall into, but to pursue James H. Moor's [2005] proposition that technological revolutions are directly correlated with their social impact and ethical problems [47]. The emergence of new opportunities due to technological advances inevitably leads to ethical issues, but there are rarely any well-thought policies in place to address these issues [47]. These ethical issues are not only abundant but also complex packaged, requiring significant effort to comprehend and establish good ethical guidelines [47]. This served as a motivation to investigate the ethics of XR, to gain a comprehensive understanding of the ethical landscape surrounding these emerging technologies.

2.3 Previous Studies on the Ethics of XR Technologies

Before conducting the actual review, a literature search was conducted to gain an understanding of the ethical concerns of XR. XR technologies are widely used in interdisciplinary contexts and have various use cases, which has resulted in a substantial amount of research being conducted. However, the studies are scattered across different fields. There is a significant focus on VR, AR, and MR technologies individually, with studies exploring ethical concerns with fields and applications such as healthcare [52], rehabilitation [13, 61], gaming [12], education [66], and the technology [6, 7, 42, 70] itself. Additionally, some studies have addressed safety concerns for children [33], women [49] and Aged people [71] in virtual environments.

There are few studies that discuss the ethical issues related to the umbrella term "XR" [11, 38, 60]. Chuah [2018] conducted a study that identified various risks associated with XR technology, including psychological, time-loss, physical, financial, and performance risks [11]. He also urged future researchers to examine the negative aspects of XR, such as motion sickness, cognitive overload, distracted attrition, and increased stress [11]. Slater et al. [2020] investigated the ethical problems and implications of superrealism. They concluded their research by outlining some general principles for mitigating superrealism issues in the context of XR [60].

In response to these ethical concerns, IEEE formed a multidisciplinary group consisting of industry professionals, ethicists, researchers, educators, and technology enthusiasts to be a part of their IEEE Global Initiative on Ethics of XR [1]. This group focuses on addressing issues of discrimination and inequity among XR users, and they recommended measures to make the technology more inclusive and unbiased [18]. Several other discussions centered around the challenges of XR usage in various scenarios like medicine, education, social spaces, business, and the metaverse are also carried out [1].

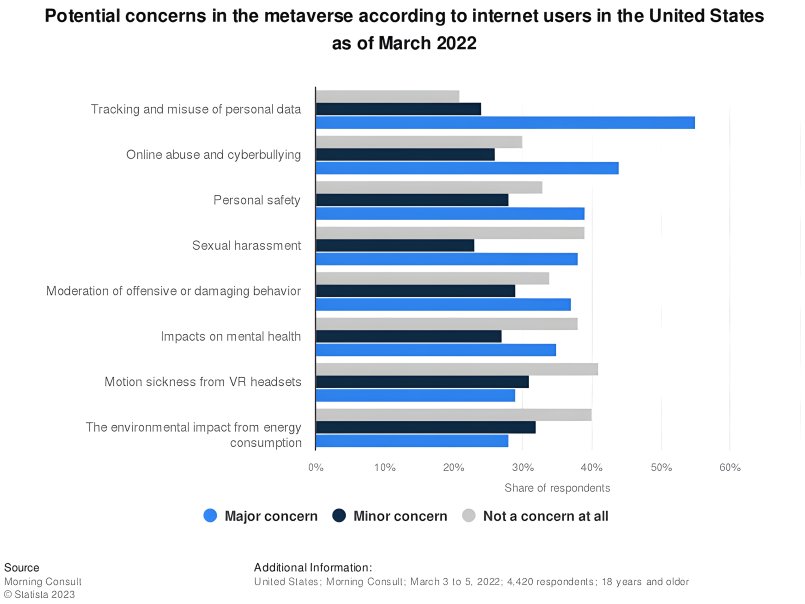

Fig. 2. Potential concerns in the Metaverse identified in [65]

The Metaverse is a recent innovation of the fourth wave of computing that has the potential to revolutionize education, business, remote work, and entertainment by incorporating spatial and immersive technologies over the internet [48]. However, this new paradigm comes with various challenges related to its embedded AR and VR technologies. According to Mystakidis [2022], these technologies are inherently persuasive, as they can influence the user's cognition, emotion, and behavior [48]. Furthermore, there are several risks associated with AR and VR, such as attention distraction, data privacy concerns, information overload, motion sickness, violent representations, identity theft, among others [48]. To identify potential threats in metaverses, an online survey was conducted among internet users in the US in March 2022 [65] and the survey results are shown in Fig 2.

In order to guarantee a safe and secure experience for users engaging with XR technologies, it is imperative to identify and address the challenges and risks associated with their usage. The objective of this study is to comprehensively examine the current ethical landscape of XR technologies by employing a systematic approach to analyze existing literature. This approach will provide practitioners, including those in the HCI domain, with reliable evidence to understand potential threats linked to the utilization of XR and create ethical solutions to mitigate them in future designs.

2.4 Scope and Limitations of This Study

The terminology used for XR is often ambiguous, with various names such as cross-reality [68], X-reality [43], or Mixed Reality [26] being used interchangeably. According to the study by Mann [2018], XR has three possible definitions: 1) as a larger category that includes mixed reality, 2) as synonymous with mixed reality, or 3) as a subclass of mixed reality [43]. As this is a debated issue in and of itself, this study did not attempt to establish a definitive definition for XR. For the purpose of this study, the most common definition was considered, which deems XR as a catch-all phrase for AR, VR, and MR [11, 68] as shown in Fig 1. Other definitions and understandings were not focused upon.

Apart from the nomenclature, there is also confusion surrounding the taxonomy of XR. While it is referred to as a collective term for AR, VR, and MR, some studies include other realities under the XR banner, claiming that it is an umbrella term for any immersive technology that merges physical and virtual environments [21, 43]. Mann [2018] identifies other realities such as Phenomenal Reality, Mediated Reality, Quantimetric Reality, and finally, All Reality which is a unified framework for numerous realities and meta-realities that exist and has both artificial and real-world components [43]. However, this study does not aim to prove which taxonomy is correct or what technologies are classified under XR. Instead, the focus is on the most common classification, which includes AR, VR, MR, and limits the study to these technologies [11, 68]. This study collectively refers to these as XR and conducts the review based on this classification.

XR technologies, such as AR, VR, and MR, are used in different domains such as gaming, healthcare, art, education, sports, entertainment, engineering, construction, among others [8, 9, 26, 28]. While ethical issues can emerge within these specific domains, the goal of this study is to take a broader perspective and explore the overall ethical landscape of XR. Consequently, this research does not focus on any specific context but instead adopts a comprehensive search strategy that encompasses studies from diverse domains, applications, and use cases.

Although this systematic review study followed a rigorous and well-defined methodology to maximize validity and minimize researcher bias, it is important to acknowledge the inherent challenge posed by publication bias, which may be present in the primary studies included in the review. Publication bias refers to the tendency for studies with positive results to be published more frequently than those with negative results. Failure to address this bias could introduce distortions in the systematic review findings and questions its rationale [35]. Although it is beyond the scope

of this study to independently assess the validity of the primary studies, certain measures have been taken to mitigate this issue. For instance, including articles from conference proceedings and journals helps address publication bias as they undergo peer review by a panel of researchers before being accepted for publication [32, 35]. These steps aim to increase the reliability of the systematic review findings.

To summarise, this study is limited to the following aspects:

- The study considers XR as an umbrella term encapsulating AR, VR, and MR.
- The study is restricted to examining AR, VR,and MR.
- The study examines XR technologies without focusing on specific contexts.
- The study includes peer-reviewed articles from conference proceedings and journals.

3 METHODOLOGY

Systematic literature review, is a research methodology that involves a systematic and thorough search, evaluation, and synthesis of the existing literature on a particular research topic or question [35]. SLRs are often used in various disciplines including HCI to provide a comprehensive overview of a specific research area or phenomenon for the following reasons [35]:

- To summarise the available evidence concerning a topic area or technology or phenomenon.
- To identify any gaps in current research and find potential areas for future investigation.
- To provide an overall framework or background in order to design future research activities.

In contrast to traditional literature reviews, SLRs follow a fair, transparent, and well-defined methodology [16, 35]. SLRs investigate clearly articulated research question(s) by employing a predefined systematic process that identifies, selects, and retrieves all relevant studies, which are then interpreted and used to answer the research questions [16]. The review protocol is discussed openly so that anyone can replicate the study on their own. As a result, SLRs provide solid and reliable evidence that is robust and has the potential to transfer inferred knowledge across various contexts [16].

For this SLR, guidelines proposed by Kitchenham and Charter [35] were referred as they are generic guidelines which can be adapted to align with a broad research objectives. These guidelines have been implemented in earlier SLR studies that focused on XR and Ethics (Eg. [3], [40], [58], [22], [50], [44], [34], [17]), and it served as a motivation to apply it for this study and prior works served as a guidance.

There are three key phases in a SLR process: planning the review, conducting the review and reporting the review [35]. Each phase, as shown in Fig 3, included several stages that guided the review process, keeping it relevant, rigorous, and unbiased. Several iterations were necessary at various stages. Upcoming sections will explain each phase in detail.

3.1 Planning the Review

The planning phase began with recognising the importance of conducting this research followed by formulating the research question and developing the review protocol. A pilot study was performed to evaluate and refine the review protocol before conducting the actual review.

3.1.1 Rationale for the Review. Before taking up a systematic review, it is critical to ascertain why one is required in the first place [35]. Previous studies, as discussed in section 2.3, have concentrated on the ethics of a individual XR technology or certain specific context, rather than the ethics of the broad XR spectrum. An SLR study is appropriate for understanding the current state of ethics in XR technologies across various domains and contexts because it has the

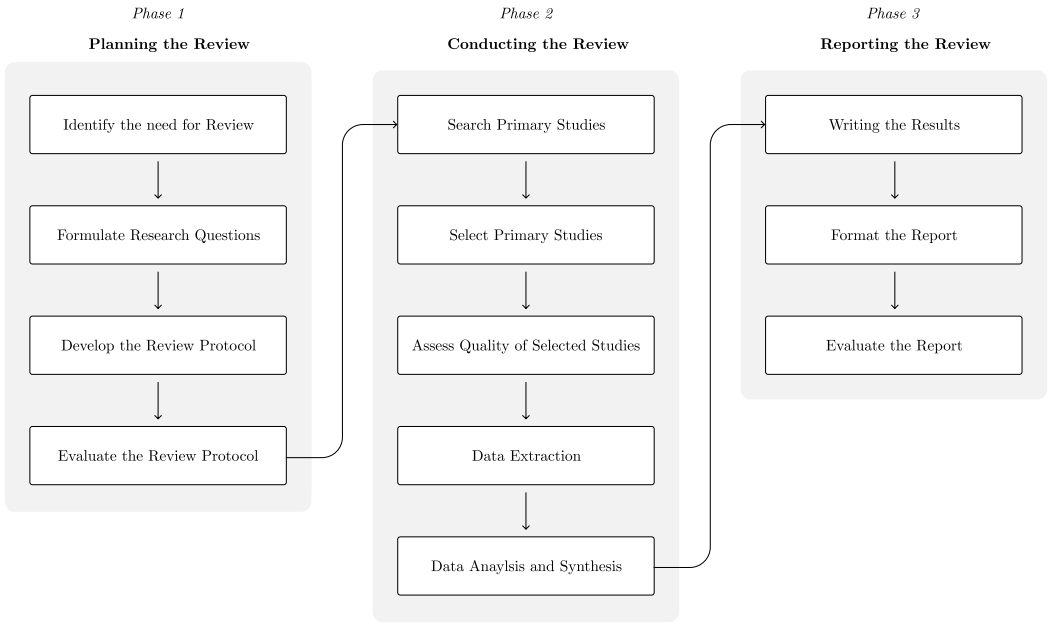

Fig. 3. Steps of the SLR process

ability to summarise all available evidence about a specific phenomenon, in this case ethics, by thoroughly reviewing existing literature and providing a comprehensive overview of it. With this information, gaps in existing research can be identified and explored further in the future.

3.1.2 Research Question. Formulating appropriate research questions (RQs) is crucial for driving the entire SLR methodology, as it sets the direction for the study [35]. In line with the research goal of understanding the current state of ethics in XR technologies, the following research questions were formulated:

RQ1: What are the various ethical issues and related concerns that arise as a result of the use of XR technologies?

RQ2: What are the adverse effects and barriers caused by the issues faced when using XR technologies?

RQ3: What solutions and recommendations are offered for addressing the challenges encountered in XR technologies?

To address these RQs, this study performed a systematic review of existing research on XR technologies, encompassing AR, VR, and MR. The review process followed a well-defined protocol specifically designed to address these research questions and gather pertinent insights to answer them. The details of the review protocol will be discussed in the subsequent section.

3.1.3 Developing a Review Protocol. A review protocol serves as a blueprint by outlining the methods used to conduct a SLR study. It provides guidance for the researchers to take the study in the right direction [35]. The protocol is defined before performing the review to avoid any possibility of researcher bias. Failing to do so reduces the study's repeatability as the selection of studies and subsequent analysis might have been influenced by the researchers' beliefs [35].

The review protocol provides all the necessary details to plan, execute, and report an SLR study. It includes the following crucial information [35]:

- Rationale for the study
- Research questions to be answered
- Search strategy including search terms and data sources
- Study selection criteria and procedure
- Study quality assessment procedure
- Data extraction technique
- Data synthesis method
- Reporting format
- Project timetable

3.1.4 Evaluating the Review Protocol. Prior to conducting the actual review, it is critical to evaluate the review protocol using pilot studies to ensure the effectiveness of the chosen strategy and to validate it to reduce any potential bias [35]. A minimal sample set of 12 articles was retrieved using the search strategy to conduct a pilot study, and the screening process was initiated. The first stage of the screening process qualified 9 articles, and the second stage qualified 6 articles as final studies. The articles that did not pass the screening were thoroughly examined to determine why they appeared in the search results and why they were deemed unsuitable for this study. Before conducting the actual review, the learning and insights from the pilot studies were used to refine and strengthen the review protocol. To reduce researcher bias and improve internal validity, the pilot study results were also shared for review and criticism with the project supervisor, who is an expert in this field. After they gave their approval, the actual review was conducted.

The sections that follow go into detail on the search strategy, study selection approach, quality appraisal, and finally data analysis and synthesis techniques.

3.2 Conducting the review

3.2.1 Search Strategy. The RQs formulated in the earlier section supported in the development of the search strategy for this study. While conducting an SLR, it is critical to follow a search strategy, which is typically developed through an iterative process involving knowledge from previous SLRs, preliminary searches, and input from field experts such as supervisors [35]. The same conditions aided in the development of an effective search strategy for this study, which resulted in the finding of appropriate studies to answer the RQs.

The search strategy was developed by first identifying relevant keywords and search terms based on the research objective and also analyzing previous SLR studies related to XR and ethics. To obtain relevant results, search terms related to XR technology, ethics, ethical and other related issues had to be included.

To obtain results about XR technologies, the terms "Extended Reality," "Augmented Reality", "Virtual Reality", and "Mixed Reality" were included. Abbreviations as well as alternate spellings such as "Extended-Reality" and "Mixed-Reality" were also included to broaden the scope of the search. The term "Metaverse" was also included as recently published research studies used it to refer AR, VR, and MR technologies in different contexts such as social networks, education & training, gaming platforms, healthcare and so on [14].

Terms such as "ethical concern", "ethical frameworks", "societal implication", and "privacy implication" were used to find studies on ethical concerns, considerations, and other related issues. Possible synonyms of "issues" were added to

Key Word in the Research Question	Relevant Search Terms
XR Technology	Augmented Reality, Virtual Reality, Mixed Reality, Mixed-Reality, Extended Reality, Extended-Reality, XR, AR, VR, MR, Metaverse
Ethics	Ethics, Ethical
Ethical and Other Related Issues	Ethical Issue, Ethical Problem, Ethical Limitation, Ethical Challenge, Ethical Concern, Ethical Implication, Ethical Consideration, Ethical Risk, Ethical Framework, Ethical Guideline, Ethical Reflection, Ethical dilemma, Social Implication, Societal Implication, Privacy Implication

Table 1. Relevant search terms

broaden the search parameter. During preliminary search, it was discovered that several papers contained the terms "Ethics" and "Ethical" in the author keywords and abstract. As a result, the search query included the term "ethic*".

To obtain a diverse set of studies from various disciplines utilizing XR technologies, a preliminary search was conducted in seven data sources, including ACM Guide to Computing Literature, Scopus, IEEEXplore, Springer Link, PubMed, Web of Science, and Google Scholar. These databases, digital libraries, and search engines were discovered while investigating on previous SLRs in the context of ethics and XR. These data sources supported the "Advanced Search" feature, which allowed to search complex queries built with Boolean operators such as AND, OR, as well as wildcard operators such as Asterisk (*). To narrow down and achieve the best results, filters were used to focus the search on fields like Title, Abstract, Keywords and Full-text. To retrieve studies, customized search queries with the same set of search terms were used because each of these data sources used a different search mechanism and had different field filter names. Since data sources like Google Scholar and Springer Link did not support field level filtering, a "All fields" search was carried out. During the preliminary search, these seven sources yielded nearly 24,521 (as on March 16, 2023) relevant documents. Appendix A contains a detailed table with information about the data source, search query, and search hits.

```
Abstract:("Augmented Reality" OR "Virtual Reality" OR "Mixed Reality" OR
"Extended Reality" OR "AR" OR "VR" OR "MR" OR "XR" OR "Metaverse" OR
"Mixed\-reality" OR "Extended\-reality") AND (Fulltext:("ethical issue"
OR "ethical problem" OR "ethical limitation" OR "ethical challenge"
OR "ethical concern" OR "ethical implication" OR "ethical consideration"
OR "ethical risk" OR "ethical framework" OR "ethical guideline" OR
"ethical reflection" OR "ethical participation" OR "ethical design"
OR "ethical protocol" OR "ethical dilemma" OR
"social implication" OR "societal implication" OR "privacy implication")
OR Keyword:(ethic*))
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Listing 1. Search Query used in ACM-GCL

Following careful consideration of the time constraints and scope of this thesis study, the focus was narrowed down to ACM guide to computing literature (ACM-GCL). The motivation behind concentrating on this data source is that ACM-GCL is a comprehensive database that includes ACM full-text articles as well as articles from over 6500 other publications, including IEEE Computer Society and Springer-Verlag [30, 37]. This would be sufficient to obtain articles from various perspectives on the ethics of XR. With the help of the search query shown in Listing 1, 78 studies (as on March 16, 2023) were retrieved from ACM-GCL. The search query focused on the Abstract, Keywords, and Full-text fields, using the search terms shown in table 4. The retrieved studies were stored to *Zotero Reference Manager* with the help of *Zotero Browser Connector*.

3.2.2 Selection of Studies. After retrieving and storing the studies in a reference manager, the screening phase began to select the studies that are relevant to answering the RQs. The study selection criteria were applied in two stages to obtain the final set of studies.

Before conducting the actual review, inclusion and exclusion criteria for screening must be established. This ensures that any potential bias is eliminated and that the study's internal validity is improved [35]. The inclusion and exclusion criteria for this study were determined based on the RQs and were refined iteratively with the help of preliminary searches and a pilot study.

To investigate the ethics of XR, studies that discuss XR technologies such as AR, VR, or MR must be included. Metaverse studies were also relevant in this case because it is used as an extended term to refer to XR technologies in certain contexts. It is also critical that the retrieved studies address ethical concerns, considerations, or other related issues concerning XR technologies, either throughout the article or in a specific section. Some articles that came up in the search had a brief mention of XR technology or ethical issue related search terms, but they didn't provide any evidence on the ethics of XR technology or discussed the ethics of other technologies. The study did not include these articles.

To improve the quality of the retrieved data, the focus was narrowed to research articles and short papers published as conference proceedings and journal articles, which provide detailed empirical evidence and discussion about the phenomenon. Other types of content, such as abstracts, extended abstracts, workshop papers, panel discussions, magazine articles, and posters, were not considered for this study.

The full-text of the article must be available to support a thorough screening [35]. Sci-hub or ResearchGate can be alternatively used to retrieve articles that are locked and has no free-access. In the case of this study, all full-texts were available. It was also critical that the papers retrieved be published in English in order to maximise the efficiency of the qualitative data analysis. This study did not include any other language publications.

Screening was done in two stages in this study. The first stage of screening included a review of the title, abstract, and keywords, as well as content skimming in some cases to understand the context well, and the second stage included a full-text screening. Only 42 of the 78 articles were research articles or short papers. As a result, only those 42 articles were considered for first stage of screening as per the study selection criteria shown in table 2. The title, abstract, keywords, introduction, and conclusion were read during the first stage of screening to determine whether the article complies with the selection criteria and was relevant to the study's objective. 29 articles (69%) qualified to the second stage of screening, while 13 articles were rejected. While investigating the rejected articles thoroughly, it was discovered that they were discussing the ethics of the process or experiment rather than the ethics of XR technologies. Certain articles appeared because they contained the search terms but were unrelated to the study. For example, the search term

Inclusion Criteria	Exclusion Criteria
• The article must be written in English • The article must discuss any XR technology, such as AR, VR, MR, Metaverse or its application. • The article discusses ethical concerns, considerations, or related, issues concerning XR technology throughout the article or in a specific section. • Research articles and short papers published as conference proceedings and journal articles. • The full-text of article must be available.	• Articles that do not discuss XR technology but provide a brief reference of the search terms. • Articles that discuss ethics but do not discuss about any XR technology. • Content types like Abstracts, Extended Abstracts, Workshop Papers, Magazine Articles, Panel Discussions, Posters, Work in Progress, Books, Book Chapters and Book Reviews.

Table 2. Selection criteria used to screen the studies

"AR" brought up a paper focusing on Action Research, which was not relevant for this study and was thus excluded. There was also a paper published in French which was excluded from this review.

The remaining 29 articles were subjected to a second stage of screening in which the full-texts were thoroughly read to determine whether the articles met the selection criteria and could provide relevant evidence to answer the research questions. With a 79% qualification rate, 23 of 29 articles qualified as final studies. The analysis of the six failed articles revealed that they did not provide relevant evidence to answer questions about the ethics of XR. These studies were published between 2012 and 2023 as seen in the histogram visualisation in figure 4. The 22 research papers and 1 short paper published as conference proceedings and journal articles focused on XR technologies such as AR, VR, and MR, their applications in different contexts and addressed the ethical concerns and implications in a way that can be utilised to answer the RQs.

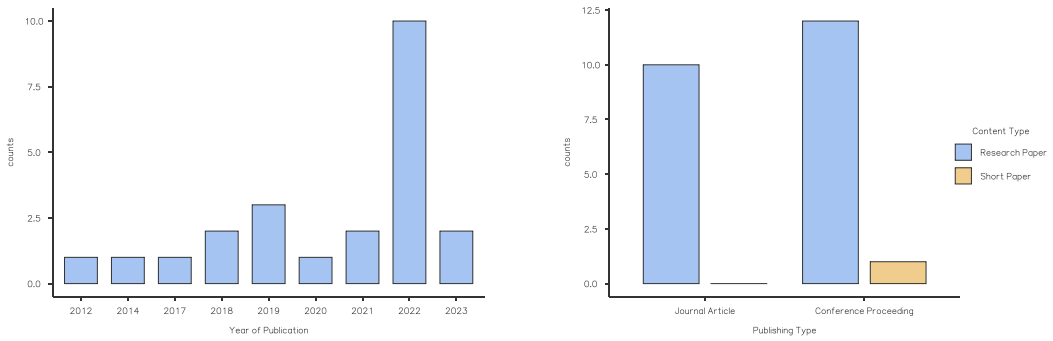

Fig. 4. Descriptive Statistics of the Finalised Studies

3.2.3 Quality Appraisal of Studies. Apart from implementing the selection criteria, it is also crucial to appraise the quality of the final set of studies chosen for the SLR in order to avoid biases and maximise the study's validity [35]. The quality of this study was assessed by thoroughly reviewing each finalised study and determining whether it contains the relevant keywords, adheres to the inclusion and exclusion criteria, and, finally, whether it contains relevant information that can help answer the research questions. It also aided in identifying strong inferences and recommendations that can reflect the current state of ethics in XR by comprehending different research design and discussions in each publication.

All 23 finalised studies were deemed suitable for this review. Although there was some overlap in the subject matter, each study offered distinct perspectives that contributed to answering the RQs. For instance, [69] discussed cybersickness caused by desktop VR while used by generic users, whereas [23] discussed cybersickness related to the use of VR HMDs specifically among individuals with Autism Spectrum Disorder. Table 3 lists the final studies and their meta information. The studies were all carried forward to the next step of data analysis and synthesis.

Reference	**Authors**	**Year**	**Article**	**Form of XR**	**Application Area of XR**
[4]	Berret et al.	2022	Augmented Assistive Technology: The Importance of Tailoring Technology Solutions for People Living with Dementia at Home	AR	Assistive technology for people with Dementia
[27]	Heimo et al.	2014	Augmented Reality: Towards an Ethical Fantasy?	AR	Generic Usage of AR
[10]	Chow et al.	2019	Challenges and Design Considerations for Multimodal Asynchronous Collaboration in VR	VR	Collaborative Virtual Environments
[15]	Degado Rodriguez et al.	2022	Challenges in Virtual Reality Studies: Ethics and Internal and External Validity	VR	VR Research Studies
[57]	Scahper et al.	2022	Computational Empowerment in Practice: Scaffolding Teenagers' Learning about Emerging Technologies and Their Ethical and Societal Impact	AR	Education
[33]	Kaimara et al.	2022	Could Virtual Reality Applications Pose Real Risks to Children and Adolescents? A Systematic Review of Ethical Issues and Concerns	VR	VR Applications for children and adolescents
[69]	Vinson et al.	2012	Cybersickness Induced by Desktop Virtual Reality	VR	Desktop VR
[31]	Jicol et al.	2022	Designing and Assessing a Virtual Reality Simulation to Build Resilience to Street Harassment	VR	Stress Innoculation Training used for simulating Street Harassment

[41]	Luro et al.	2017	Ethical Considerations for the Use of Virtual Reality: An Evaluation of Practices in Academia and Industry	VR	VR usage in Academia and Industry
[24]	Greene	2023	Ethical Design Approaches for Workplace Augmented Reality	AR	Workplace AR Systems
[45]	Mhaidili and Schaub	2021	Identifying Manipulative Advertising Techniques in XR Through Scenario Construction	XR	XR Advertising
[59]	Simeone et al.	2022	Immersive Speculative Enactments: Bringing Future Scenarios and Technology to Life Using Virtual Reality	VR	Speculative Enactments
[2]	Baker et al.	2019	Interrogating Social Virtual Reality as a Communication Medium for Older Adults	VR	Social VR for Older Adults
[23]	Glaser et al.	2022	Learner Experience and Evidence of Cybersickness: Design Tensions in a Virtual Reality Public Transportation Intervention for Autistic Adults	VR	VR based training for people with Autism Spectrum Disorder
[19]	Fominykh et al.	2022	Model Augmented Reality Curriculum	AR	AR Curriculum
[14]	De Felice et al.	2023	Physical and Digital Worlds: Implications and Opportunities of the Metaverse	AR, VR	Metaverse
[39]	Lovregilio et al.	2018	Prototyping Virtual Reality Serious Games for Building Earthquake Preparedness: The Auckland City Hospital Case Study	VR	VR Serious Games
[71]	Waycott et al.	2022	The Role of Staff in Facilitating Immersive Virtual Reality for Enrichment in Aged Care: An Ethic of Care Perspective	VR	VR for Aged Care
[46]	Millard et al.	2019	The Unethical Future of Mixed Reality Storytelling	MR	MR based Storytelling
[29]	Huynen et al.	2018	Towards Design Recommendations for Training of Security Critical Agents in Mixed Reality Environments	MR	MR based training for Security Critical Agents
[53]	Popoveniuc and Vatavu	2022	Transhumanism as a Philosophical and Cultural Framework for Extended Reality Applied to Human Augmentation	XR	Human Augmentation
[36]	Lavoie et al.	2021	Virtual Experience, Real Consequences: The Potential Negative Emotional Consequences of Virtual Reality Gameplay	VR	VR Gaming

[55]	Ramirez et al.	2020	What It's like to Be a _____: Why It's (Often) Unethical to Use VR as an Empathy Nudging Tool	VR	VR-based Empathy-Enhancing Nudging

Table 3. Final set of studies included for SLR

3.2.4 Data Analysis and Synthesis. The review phase concludes with the crucial steps of data analysis and synthesis. A 6-phase thematic analysis approach formulated by Braun and Clarke [2006] was implemented to discover patterns and themes hidden in the rich qualitative data of the finalized studies. Thematic analysis is a popular qualitative analysis method which is acclaimed for its accessibility and flexibility, making it appropriate for this study as well. It enabled the identification of recurring themes or patterns by labelling, organizing, analyzing, and interpreting qualitative data from the studies selected for this SLR [5]. The entire analysis was carried out using the qualitative analysis software called MAXQDA.

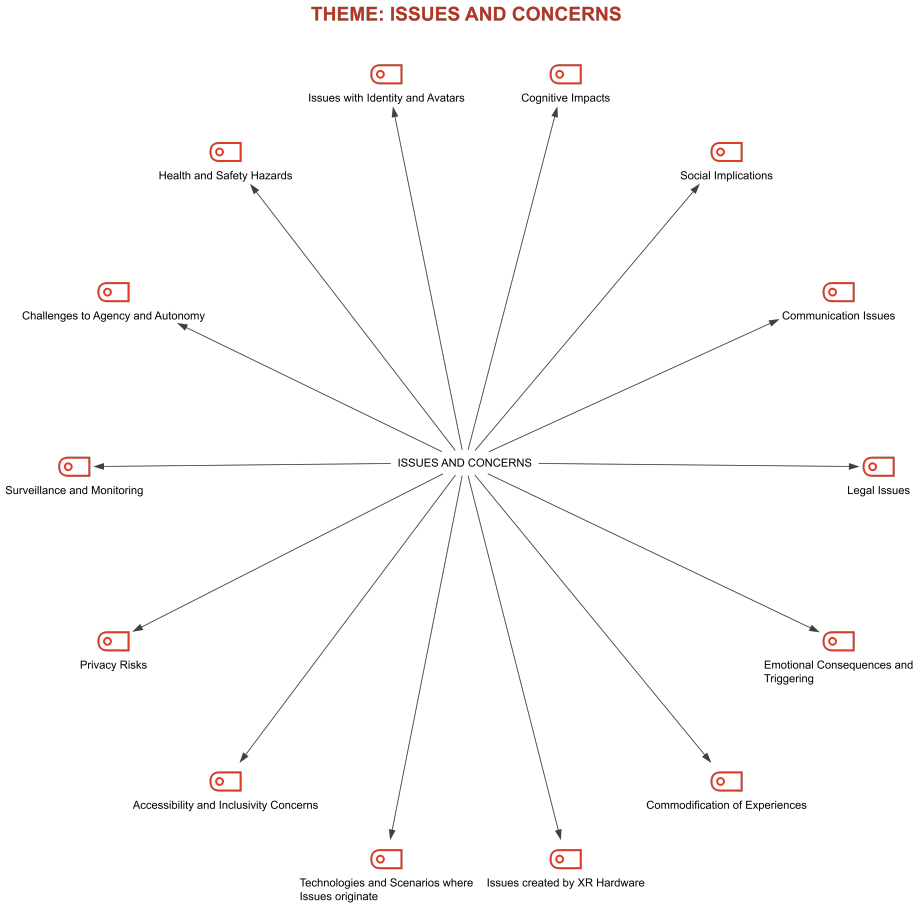

Fig. 5. Relationship between the theme "ISSUES AND CONCERNS" and its codes

The thematic analysis process began with familiarising the data set [5]. Each of the finalised study was read repeatedly to get a better understanding of what XR technology is being discussed, ethical concerns and related issues being outlined and finally any potential solutions discussed to mitigate them. This immersive and iterative reading helped to identify some patterns across different studies and gave a clue of how the coding can be done [5]. Memos were added in the MAXQDA software to note down the meta information and other relevant information that can help further in the thematic analysis. Once this was done, a formal coding process was initiated.

Codes are fundamental piece of data that represent a block or segment of qualitative information that can be later synthesised to get a meaningful inference [5]. These codes can be generated in two ways: either through an inductive approach or a deductive approach. For this study, a data-driven inductive coding approach was chosen so that the codes can be generated without any preconceived theory and lie close to the data. The themes emerging will be determined based on the codes and its relationships [5]. Descriptive code names where added to help get a better understanding the code.

Once the initial coding was done, the codes where collated in the MAXQDA code system. There they were carefully sorted, combined and thoughtfully categorized into different candidate themes [5]. This process was done in several iterations until the themes and their codes were found logically relevant. Each identified themes contains several codes and sub-codes associated to them. This was due to numerous codes being generated from analyzing 23 final studies. Visualization features in MAXQDA, such as MAXmaps (shown in Figure 5), were useful for visualizing and refining the code relationships.

After a day's break, the candidate themes were reviewed, modified and refined. Few theme names were modified and some were combined to bring more coherence to the themes [5]. Three themes were defined: ISSUES & CONCERNS, NEGATIVE EFFECTS & BARRIERS CAUSED and SOLUTIONS & RECOMMENDATIONS. These three themes helped to answer the research questions of this SLR study and give a detailed understanding of the ethical landscape of XR technologies. Other codes and information collected were used to strengthen the background and discussion sections. Once the themes were reviewed and finalized it was used to report the findings of the study.

3.3 Reporting the Review

The reporting phase is the final phase of the SLR. The findings and inferences are written down during this phase [35]. Figure 6 depicts the flow of information across the various phases of this SLR investigation using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram. It additionally indicates how many records have been identified, reviewed and finally included in the study [51].

The finalized themes and findings are discussed in depth in the following sections, answering the RQs.

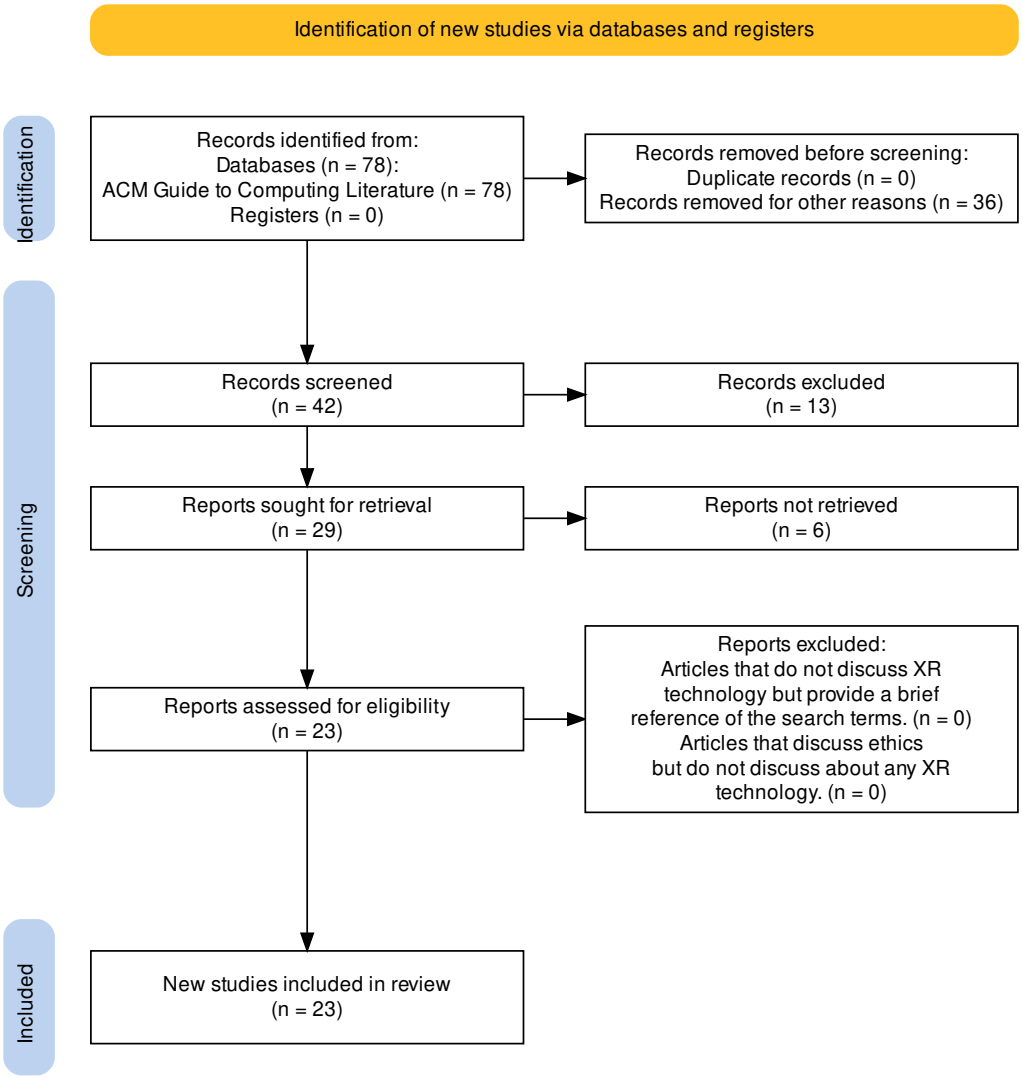

Fig. 6. PRISMA Flow diagram of this SLR study. Adapted from [51] and generated using [25]

4 FINDINGS

The three themes which emerged from systematically reviewing 23 articles are discussed in length in this section. These interpretations are the answers to the RQs about what possible ethical issues and associated concerns are found with XR technologies, the negative impacts and barriers they create, and lastly the different approaches by which the issues can be addressed and managed. Answering these three questions provides a comprehensive picture of the ethics of XR. Furthermore, these findings can assist future researchers identify the gaps that need to be filled in order to address these challenges and make XR technologies safe and ethical to use.

4.1 Issues and Risks of XR

The thematic analysis revealed a multitude of issues and concerns associated with the usage of XR technologies across various contexts and applications. These issues raise profound ethical challenges, encompassing social implications, privacy risks, and other moral problems. It is noteworthy that many of these issues are interconnected, emphasizing the need for a comprehensive and critical approach to address them, as resolving one issue often necessitates addressing others in tandem.

4.1.1 Health and Safety Hazards. Applications and benefits of XR are plentiful yet serious ethical dilemmas emerge from these interventions as it is found XR technologies are responsible for causing several health issues and risks for the safety of the users. Commonly found health and safety hazards are discussed here.

One of the most prevalent issues observed in XR technologies is the occurrence of sickness induced by VR, which encompasses cybersickness, simulator sickness, and motion sickness. While these issues have distinct names, their symptoms and associated problems are closely related, warranting a comprehensive discussion. Cybersickness affects both neurotypical and neurodivergent individuals who engage with VR technologies [15, 23, 33, 36, 39, 41, 45]. Symptoms commonly experienced due to cybersickness include dizziness, vertigo, eye strain, headache, blurred vision, nausea, sweating, postural instability, and general discomfort [15, 23, 33, 36, 41, 69]. It's important to note that these symptoms are temporary and typically subside shortly after the VR experience has ended [15]. Various factors contribute to and influence the severity of cybersickness, including exposure time, vection and sensory conflicts, lags and jitters caused by VR devices, and individual differences [39, 41, 69]. Additionally, there may be miscellaneous factors that contribute to cybersickness, as the exact causes are not yet fully understood [23, 69]. Cybersickness gives rise to significant ethical and legal concerns [69]. Contrary to prior assumptions, Vinson et al. [2012] conducted a comprehensive study on cybersickness and discovered that even desktop VRs can induce this condition [69]. The researchers emphasized that cybersickness undermines the beneficence of VR studies, as the detrimental symptoms and effects experienced by study participants diminish the potential benefits. Consequently, this poses a potential challenge for conducting VR-based research in countries like the USA, Canada, and Australia, where research projects are required to adhere to ethical guidelines and demonstrate a commitment to beneficence. Glaser et al. [2022] investigated whether people with autism spectrum disorders (ASD) will still find immersive VR beneficial, despite worries about HMDs causing cybersickness. According to the study findings, people with ASD experienced dizziness and disorientation which were symptoms of cybersickness [23]. Although the effects were mild for the majority of participants, two of them scored highly on the Motion Sickness Assessment Questionnaire (MSAQ). This suggests that individual differences may aggravate these symptoms [23]. Prolonged exposure was also discovered to affect ASD people more than others [23].

In addition to cybersickness, the usage of VR technology for gaming, as discovered by Kaimara et al. [2022], has been found to have adverse effects on children's physical development and health [33]. Prolonged periods of gaming

can negatively impact the development of visual pathways and contribute to visual problems. The blue light emitted by VR device screens poses a potential risk to visual receptors. Furthermore, excessive VR gaming can reduce physical activity among children, increasing the likelihood of obesity [33]. The emission of blue light is also associated with decreased secretion of melatonin, a hormone essential for sleep, leading to disruptions in the sleep cycle and sleep deprivation [33]. Additionally, Lavoie et al. [2021] highlighted that VR, with its immersive nature, can impact vitals like heart rate, blood pressure, and stress levels, potentially posing risks to participants' overall health [36]. In certain cases, XR technologies have even resulted in situations where participants were at risk of falling, raising concerns about the safety aspects of the technology [15, 46].

The presence of health and safety risks is a concern in any VR study, and these risks are further amplified in remote VR experiments [15]. One of the ethical challenges arising from remote experiments is determining the responsible party for providing assistance to participants in the event of health or safety issues. With no researcher physically present, concerns arise regarding the proper conduct and support of such experiments [15].

4.1.2 Cognitive and Psychological Impacts. Immersion and experience of realism in XR technologies have been revealed to cause many cognitive and psychological side effects in both neurotypical and neurodivergent users.

Overdependence and addiction to XR technologies are the most common adverse effects. Though this also plays a role in agency manipulation, multiple symptoms have been found in affecting a user's cognitive and psychological capabilities. Mhaildi and Schaub [2021] addressed how XR technologies might cause a variety of consumer implications, including mental harms such as addiction and behavioral changes. This is most likely due to consumers believing that alternate realities are safer and better than the real world [45]. Thoughts like this encourage them to believe that such virtual realities are real, causing them to become distressed over what is happening there, which could lead to them developing anti-social traits by engaging in aggressive acts or even murdering someone in these virtual environments. Such activities have a huge impact on their mentality, which may have repercussions in their actual lives [45]. Addiction to virtual worlds has also been observed in children and adolescents. In their study, Kaimara et al. [2022] discussed past studies, emphasizing that VR technologies, in addition to causing addiction, induced cognitive impacts, anxiety, and confusion between real and virtual realities [33]. Popoveniuc and Vatavu [2022] discovered that when XR was utilized for Human-Augmentation, it increased the dependence on virtual worlds among the users [53].

The second major concern is the loss of ability to distinguish between realities. De Felice et al. [2023] highlighted the metaverse's ability to completely eliminate distance between people by placing them together in a virtual world despite them being in different places in the real world. Though this has social benefits, their growing engagement and presence in the virtual world causes individuals to disconnect from reality, resulting in them to lose their ability to differentiate between what is real and what is virtual [14]. According to Popoveniuc and Vatavu [2022], living in such blended reality causes users to fall in love with these environments for their realistic aspects while forgetting that they are artificially built [53]. According to Delgado Rodriguez et al. [2023], VR poses temporal mental health hazards such as derealisation and depersonalisation. This is worsened when people with mental health problems or disorders interact with XR technologies [15]. Baker et al. [2019] emphasized one of their participants, Cleo's, feedback that Social VR could be unfavorable for those with dementia because they are already living in their own reality [2].

Overload of capabilities was another prevalent issue for those with mental health issues. Hyper-realistic experiences in metaverse have been shown to cause sensory overload in those with photosensitive disorders such as epilepsy [14]. Despite their capacity to encourage people with cognitive impairments, AR technologies have been shown to increase cognitive load [4]. Berret et al. [2022] discovered that when they tested the benefits of AR technology on patients with

dementia, AR interfered with their established usage patterns. Introducing AR into their lives for the first time resulted in a learning curve and a lot of information recalling, creating an unbearable cognitive load for them [4]. When it comes to virtual environments, imagination is an important feature, yet it has been shown to cause confusion, sensory and cognitive overload in children [33]. According to Luro et al. [2017], humans have restricted information processing skills that, when exceeded, result in confusing and behavioral disorders. Information overload is facilitated by VR content, tasks, and interaction [41].

Other adverse effects of XR technologies includes decreased cognitive performance, loss of attention and focus, including distraction [33, 36, 53].

4.1.3 Emotional Consequences and Triggers. Beneficial characteristics which contribute to the success of XR technologies, such as immersion, presence, and realism, have been found to be the same factors that can increase negative emotions and induce traumatic experiences for users.

Lavoie et al. [2021] confirmed this in their study by emphasizing that, when compared to laptop gamers, VR gamers reported a high level of absorption during gameplay, which eventually amplified negative emotional responses [36]. This raises concerns since increasing levels of negative ruminations, such as harmful thoughts or unpleasant feelings, can lead to anxiety or depression and make VR games harmful if not handled properly [36]. Lavoie et al. provided empirical evidence that the nature of virtual reality content, such as frightening incidents and characters, caused viewers to experience intense and enduring negative emotions through surveys and experiments. The results of their second experiment revealed that when compared to those who played 2D games, 3D VR games triggered more negative experiences [36]. Delgado Rodriguez et al. [2023] carried out a study that confirmed same. Since VR enhanced absorption, gamers felt more humiliated by their actions in the game. This points to circumstances in which VR gaming can be stressful [36]. When players were exposed to violent VR games, their levels of hostility and agression intesified [15]. VR's realism and absorption capacities are nearly equal to real-world events such as real-life battlefields, capable of generating extreme traumatic reactions and PTSD [36, 55].

The blurring of moral values with respect to aggression and violence, as well as the acceptance of such conduct, constitutes a threat to one's experience in the Metaverse. According to De Felice et al.[2023], if users could be anyone, including demoralized people, in public virtual environments like Metaverse, it will be difficult to safegaurd the vulnerable population [14]. Participating in violent VR experiences desensitizes people, and the same attitude may be displayed in their actual life, and those on opposite sides might encounter traumatic circumstances and possible trauma triggering in the future [14].

Similar ethical and moral ramifications were observed in VR simulations designed for sensitive and dangerous training situations. When Lovereglio et al. [2018] simulated virtual earthquakes for evacuation training purposes, they discovered that users became immersed due to the realism of the experience, which could elicit negative emotions such as fear or even trigger past trauma if they had previously experienced real earthquakes [39]. Likewise, Jicol et al. [2022] believed that simulating street harassment was risky since it might stir up emotions and bring up past suffering [31]. Their participants advised the same due to the simulator's realism and ecological validity, which can put participants with PTSD related to harassment encounters at risk because they do not want to re-experience that traumatic occurrence even for training purposes. They anticipated it to trigger an overwhelming amount of negative emotions [31]. During the experiment, they discovered that the virtual harasser's realism and resemblance to a real-world counterpart induced discomfort and, in some cases, emotional triggering [31].

4.1.4 Challenges to Agency and Autonomy. The functioning of several XR technologies and their applications have been found to have profound consequences on a user's agency and autonomy. This section discusses a few of the manipulative and influential characteristics.

While Delgado Rodriguez et al. [2023] attempted to highlight moral implications in VR experiences that were discovered to trigger negative emotions and aggression-causing capacities of VR, they also discussed how VR has the potential to alter a person's belief, change emotions, and blur their moral standards [15]. This demonstrates that VR as a technology has the power to control autonomy within virtual settings and influence their behaviors [15]. Similarly, Greene [2023] investigated the capabilities of Workplace AR systems and discovered that the powerful data collection and processing capabilities can basically characterise the workers biologically to a situation in the future where the organization can take advantage of influencing the worker's agency or even assessing their emotional state without their knowledge [24]. This raises severe concerns about one's agency in their workplace.

While it is obvious that XR technologies have the ability to deceive users, they also turn out to be the ideal instrument for advertisers and marketers to target customers and use their vulnerabilities to their advantage [45]. In their study, Mhaidli and Schaub [2021] listed several characteristics of manipulative XR advertisements. Emotional persuasion, deception, illogical reasoning, and false advertising were among them [45]. These characteristics can be achieved using articulated textual and photo-realistic graphical content that can use a consumer's emotions, reasoning, and desires to sell products that they may not even need at that moment [45].

VR is also being used as an empathy nudging tool, where it is used to nudge users to consider adopting new behaviours by putting them in the shoes of others and experiencing it for educative or explorative purposes (for example, nudging towards healthy food choices, experiencing the life of a Jewish person in a Nazi camp, living the life of a black person through various stages of life) [55]. According to Ramirez et al. [2021], this approach is unethical since nudging alters users' behavior and influences their choice-architecture by affecting three moral values: autonomy, transparency, and welfare [55]. Such VR empathy simulations not only present ethical challenges, but also mislead and manipulate users by instilling incorrect notions in them as a result of their experiences as "someone else" or "something else" in such empathy-enhancing VR simulations. They also believe that such a noble approach is likely to backfire because it is impossible to provide the experience of "what it's like to be" due to different issues produced by perspective-taking and semantic variances [55].

4.1.5 Privacy Risks. XR technologies are powerful technologies that use several sensors and computational techniques to offer immersion, presence, realism, and a variety of additional benefits. These capabilities necessitate the collection of huge amounts of personal and environmental data, which raises novel and potentially dangerous privacy concerns when an individual uses XR technologies [45].

The collection of personal and biological data from consumers raises significant privacy concerns. During their investigation of different challenges in VR, Delgado Rodriguez et al. [2023] discovered that personal information potentially gathered by VR technologies such as eye movement patterns, motor responses, and reactions can generate a unique kinetic fingerprint of a user [15]. VR can record information such as user behaviors, habits, interests, and preferences. Such information, which is stored in a vendor's or software company's cloud, can be accessed by government and commercial agencies and abused, such as being hacked or enabling identity theft [15]. In addition to these issues, the research team discovered other privacy concerns when carrying out remote VR studies. Transmitting the remote session recording over the internet may put the privacy of the research participants at jeopardy, allowing them to be identified if it falls into the hands of people with malicious intentions [15].

Greene [2023] raised similar issues during their examination of workplace AR systems. Personal information acquired by wearable devices, such as vital signs and galvanic skin responses, can be fed into algorithms that can predict a worker's emotional state and any subsequent changes to it [24]. With such sensitive biological data, organizations would be able to characterize a worker's biological behavior over time, giving companies an edge at the expense of workers' privacy [24].

Metaverse takes these concerns to the next level by incorporating Brain-computer Interface (BCI) capabilities. According to De Felice et al [2023], BCIs are capable of monitoring brain waves and potentially deduce one's thoughts [14]. This poses major risks to metaverse users who accept privacy without questioning how their data will be processed and used. With such enormous potential, there is some concern regarding data security and protection in the event of hacking attempts or data leaks resulting in data misuse [14].

Mhaildi and Schaub [2021] discovered that advertisers can use personal data obtained through various sensors to perform unique XR advertising tactics capable of manipulating consumers' perceptions [45]. Taking it a step further, XR advertisers can recognize users' emotional states and recommend things based on their vulnerabilities and emotional needs. When compared to conventional advertising strategies, XR advertising poses unforeseen harms with a large scale impact [45].

Finally, Heimo et al. [2014] discovered that AR technologies such as glasses or smartphones pose serious privacy concerns to individuals, particularly seniors or the general public, who can be recorded without their knowledge or consent (since many countries allow filming in public) [27]. The recorded data can be used in unintentional ways by the person using AR technology, such as streaming live video or edited content to the internet, committing identity theft, peer surveillance, selling the data to government bodies that can tag and frame people for crimes they did not commit, or even developing a social credit system [27]. Leaving aside these adverse effects, Heimo et al. question the problems concerning data security and protection as it is unclear who is going to safeguard such sensitive data. What rules should be put into effect to control such databases? [27].

4.1.6 Surveillance and Monitoring. Wearable and mobile AR technologies have the potential to be invasive and exploitative due to their capacities like tracking, facial recognition and collecting user data [24, 27]. These capabilities give rise to ethical issues like surveillance and monitoring which can also be used in unintended ways.

Heimo et al. [2014] investigated the development of AR solutions from an ethical viewpoint and discussed about the direct and indirect consequences of AR developments which also enables surveillance of users. Technologies like smartphones with high quality cameras or AR glasses, which at a glance looks like normal glasses, are capable of recording subjects in public without their consent as many legal structures and countries allow it [27]. Though this matter of privacy was discussed in the previous section it also adds more layers of ethical issues and discourses like what happens to the recorded footage? Who has access to it? How will it be used? Commercial or private purposes?

In modern times where government and non-government organisations are involved in widespread surveillance, AR technologies with the help of smartphone cameras or AR glasses can help perform coordinated peer surveillance or sousveillance where any member of the public can record an activity [27]. Though it has several benefits, such as allowing the public to keep an eye on those in positions of power, it also has shortcomings for the general public. AR users can utilize these recordings to verify, identify, and rank individuals [27]. The data can also be sold to government or commercial security agencies, who can use it to perform surveillance by identifying citizens in public places, controlling or harming them, and even assisting in the development of a social credit system that can treat certain citizens differently by using existing biases or creating new ones within society [27].

Similarly, Greene [2023] investigated the promotional material of the Vuforia Expert Capture system to analyze the tranhumanist discourses around Workplace AR system. Vuforia claimed that its workplace AR solution empowers employees by innovating employee training, boosting peer-to-peer communication, enhancing workers' agency, and fostering efficient organizational processes [24]. Though this appears to be advantageous to both the worker and the organization, the transhumanist rhetoric fails to address how workers will be monitored and exploited in order to gather data from them to power these AR systems [24]. Greene anticipates that workplace AR systems would employ wearables' invasive bio-technical capabilities to monitor users by recording every action they do, such as capturing retina movements, gazes, facial movements, verbal inflections, and vital signals like heart rate or galvanic skin responses. Companies will be able to characterize the biological behaviours of users using this sensitive and personal information in order to monitor and influence them for organizational advantages [24].

4.1.7 Issues with Identity and Avatars. In some cases, XR technology users suffer identity related concerns in these computer-generated realities. To begin, AR applications such as ZombieBooth or AR filters in social apps enable modification of their identity. Using real-time image processing techniques, users alter their faces by zombifying them, changing their clothing, or even removing them completely [27]. These modified visuals can then be easily shared on internet-powered social media platforms, where users may face privacy risks as well as social repercussions such as cyberbullying, humiliation among friends and family, and even a rupture in interpersonal relationships [27]. In the worst-case scenario, it may even result in the loss of employment opportunities. These strong identity-altering technologies have the potential to cause ethical dilemmas such as identity theft, impersonation, and can enable someone to intentionally frame users with artificially generated pictures [27].

De Felice et al.[2023] raised similar concerns regarding authenticity of user identity while exploring the ethical implications of Metaverse. Metaverses allows users choose an avatar to showcase their authentic identities using a Non-Fungible Token, an unique cryptographic code securely stored on a blockchain. Though these avatars are intended to be a "digital twin" of a user's identity, an ethical dilemma arises as to whether users will choose their original identity or be a different individual in the metaverse [14].

Avatars, the digital representations of users, allow interaction between various elements of a virtual environment, including other users. Most virtual worlds start by asking their users to design an avatar for themselves. Users can then customize their avatar to fit their real-life identity or choose any other imagined personality [2]. Baker et al. [2019] addressed several concerns regarding avatars raised by older people who participated in the study which investigated the communicative abilities of Social VR. The majority of it revolved around the realism and appearance of the avatars [2]. Older participants thought the avatars they created resembled androids and behaved in the virtual world like mechanical puppets. Despite the fact that participants chose to reflect their own characteristics, avatars lacked vitality and distinct personalities. They thought the avatar appeared unhappy and not enjoyable [2]. The lack of facial and emotional expressions hampered the immersive experience and diminished the advantage of social interactions in VR. Though avatar designing abilities are restricted by software capabilities, the lack of avatar realism and emotional expressions has significant social consequences [2].

User identities are likely to cause discrimination in XR technology [27]. Camera systems have often failed to recognise non-Caucasian faces, facial features, and expressions. This is also true for AR systems, as AR technologies utilise the same camera systems and facial recognition algorithms. As a result, it can be discriminating and racist based on a user's identity[27]. This can result in technology excluding users of specific identities — whether done consciously or

unknowingly — and raises moral questions about whether an identity is "person enough" for the company or individuals who developed the AR systems [27].

4.1.8 Social Implications. Aside from the social implications caused by a user's identity or avatar, XR technologies have a number of other social repercussions for their users, including children.

Kaimara et al. [2022] carried out a systematic review to identify the ethical issues and concerns associated with VR applications that may endanger children and adolescents development. After reviewing 85 studies, they discovered that VR technologies and interventions serve as a potential risk to children's psychosocial development, which encompasses aspects such as emotions, personality, and interpersonal connections [33]. Parents, educators, and academic professionals are concerned about the features of VR, with evidence suggesting that it can lead to a decrease in prosocial behavior, impact social skills, and promote social isolation while playing VR games [33]. The immersive and social aspects of these virtual worlds enable gamers to transfer their social lives from the real world to these simulated worlds. Though games such as MMORPG have been found to enhance relationships and social interactions among gamers, they also have the potential to cause addictive gaming disorders, which have a direct impact on real-world social skills and disrupt personal, familial, and societal relationships [33]. The lack of social skills can also lead to isolation, as children spend more time with digital devices than they do engaging in everyday interactions and activities. Spending longer time playing games has also been proven to significantly reduce children's prosocial behaviour, making them to perform less beneficial activities for other people as compared to children who played for less than an hour [33].

Platforms powered by XR technology, such as metaverse, offer several kinds of risks to their users' social relationships and well-being [14]. De Felice et al. [2023] discovered that, in addition to interfering with a person's capacity to do physical activities or spend quality time in nature, the metaverse has an adverse effect on a person's social interactions [14]. The metaverse improves relationships by eliminating the distance between people and allowing them to interact from within their own place and space. This is supported by the brain's immediate adaptation process and altering the perception, which leads users to believe the illusory world of metaverse is real [14]. Though it might seem beneficial, the detachment from reality and constructed social abilities can be used by individuals to alleviate loneliness. If ignored for an extended period of time, this might have major psychological consequences for the user [14].

Through the act of bullying, hate speech, and other related societal issues, social networks on the internet often hinder one's freedom of speech and expression. Similar problems are expected to arise in the metaverse, where people can indulge in such heinous behaviour by hiding behind their avatars [14]. Similarly, the real-time facial modification capabilities of AR technologies might lead to cyberbullying when the altered images are shared on social media platforms, causing humiliation or rupturing the social image and connections of a user [27].

4.1.9 Commodification of Experiences. XR technologies and their applications in entertainment such as gaming, digital narratives, and storytelling are becoming increasingly popular [46]. As they gain popularity, it becomes apparent that they possess the potential to cause harm to those who use them or to offend the sentiments of others who indirectly take part in such digi-physical encounters [46]. The root cause of such problems is the commodification of experiences. Though commodification aids business growth and commercializing the technology in cosumer markets, it takes a negative turn when creators attempt to commodify experiences they do not own [46].

While researching the ethics of MR storytelling, Millard et al. [2019] uncovered new ethical issues that could endanger participants' lives. One such example is the StoryPlaces MR project, which deployed 20 different locative literature experiences in different parts of UK [46]. One particular locative experience in Bournemouth got damaged and fell into the sea during the winter. Being unaware of this damage, the MR experience continued to direct users along dangerous

cliff-top coastal trails, accidentally directed them to go past the caution signs, temporary fencing, and get close to the cliff's edge putting their lives at risk [46].

Furthermore, VR experiences can be deliberately designed for the purpose of Dark Tourism, which involves commercial touristic ventures taking people to sites associated with death or tragic events [46, 67]. Aligning with ethical principles that discourage the exploitation of violence for mere spectacle or entertainment, it is crucial that Dark VR experiences must refrain from commodifying the suffering of individuals without their informed consent or knowledge [46]. Conversely, this highlights the inherent potential of Dark VR to generate unethical scenarios, emphasizing the need for critical examination.

Pokémon Go, an AR game from Nintendo, faced similar allegations when the newspapers reported that players were able to capture Pokémon creatures including the one has the ability to defend itself with the help of poisonous gas in a place like Auschwitz [46]. Though the game creators cannot be held liable, this demonstrates their lack of awareness of the geographical significance and sentiments attached to it. Such interactions in games would affect the emotions of related people who are caught in the crossfire between game interactions and its commercial aspects [46].

The commodification of non-owned experiences raises serious ethical considerations for the designers and developers of these XR systems, which have the potential to harm participant life and other feelings. The ethical challenges seen in such scenarios are more akin to those encountered with gentrification or place branding than to those encountered in games [46].

4.1.10 Issues created by XR Hardware. XR technologies have been found to improve and enrich the lives of children, elderly people, as well as people suffering from medical conditions such as dementia and ASD [2, 4, 23, 33]. However, XR devices such as HMDs, AR Glasses and Smartphones present challenges for such users, interfering with the immersive experience, risking their privacy, causing health hazards thus reducing the benefits of technology and solutions.

The most common criticism is the discomfort of using XR hardware. Baker et al. [2019], when investigating the potential of Social VR as a communication medium, discovered that one of their participants stated that prolonged use of HMD caused discomfort and distraction [2]. They also noted that the tracking errors and jitters created by the Kinect sensor used in their avatar creation workshop left their older participants unsatisfied, annoyed, and lacking control over their avatars [2]. AR HMDs were also proven to be unsuitable for those suffering from dementia [4]. Current AR HMDs are heavy and uncomfortable, according to Berret et al. [2022]. The Microsoft HoloLens, which weighs 579 grams, requires many strap adjustments, making it uncomfortable for any user to use for extended periods of time. Attempting to adjust the HMD increases the cognitive burden of people with dementia because they require assistance as they are are unfamiliar with the technology [4]. Glaser et al. [2022] also discovered that HMDs have some issues with comfort when their participants with ASD reported straining their arms while trying to carry a strapless HMD like Google Cardboard. Even a participant wearing the Oculust Rift in their study expressed discomfort because the headset was loose and didn't for their head comfortably [23].

HMDs were also a major problem for individuals who wear glasses [2]. In the study done by Baker et al. [2019], Sally, an elderly woman wearing eyeglasses, removed them to wear the HMD, but she later regretted doing so because the visuals appeared soft and it was difficult for her to obtain a precise focus causing more strain to her eyes [2]. HMDs such as the Microsoft HoloLens have also been linked to eye strain and other visual discomforts. These discomforts cause postural instability, which ruins the experience of using it [4].

XR hardware was also discovered to be hazardous to one's health. Aside from causing cybersickness and symptoms like dizziness and nausea in patients with ASD when they used HMDS [23], extended use of screens and HMDs caused

difficulty in sleeping leading to children become obese [33]. Blue light from screens influenced the photoreceptor systems, resulting in visual symptoms. It was also discovered to disrupt the circadian rhythm, which disturbs the sleep cycle and causes irregularities and poor habits that contribute to obesity [33].

XR hardware design and engineering also raise a few ethical and social issues. AR glasses that are made to seem like normal eyeglasses can be mistaken by people and this design feature may be misused by the person wearing them to record footage of others without their knowledge [27]. VR HMDs confront engineering hurdles as well, as the current design makes it difficult to read or monitor facial movements, which are required in social VR to power the expressions of avatars [2]. Most HMDs did not allow users to see their bodies in virtual worlds, ghost experiences were created. Limitations with current HMD technology cannot address these difficulties unless external sensors are used [39].

4.1.11 Accessibility and Inclusivity Issues. XR, like any emerging technology, has certain accessibility and inclusion concerns. A few of them that were uncovered during the SLR investigation are discussed here.

The accessibility of the XR devices was causing major problems. According to the findings of Baker et al. [2019], HMDs do not perform well with persons who wear glasses, causing them physical and visual discomfort. This hightlights the issue of HMD accessibility for those with visual impairments such as poor vision, myopia or hyperopia, or even colorblindness, as they typically wear glasses to correct their vision [2].

People with ASD who participated in the Glaser et al. [2022] study similarly reported accessibility concerns with VR HMD controllers. Due to their psychomotor limitations, a participant named Evan struggled to navigate and control their avatar using the Oculus Rift's hand control devices. Keith, who experienced no such troubles, likewise encountered difficulties while attempting to rotate their avatar. These problems were discovered to occur when participants attempted to use both controls at the same time. Jonah, a participant with severe cognitive impairments, also had difficulty using controllers and was assisted by the research team during the session [23]. The requirement to employ VR controllers for interactivity is an open challenge to immersive VR systems [39]. This raises the question of whether such a VR intervention would be effective for everybody on the autism spectrum. People with ASD along with comorbidities such as psychomotor and cognitive deficits, necessitate more complex and accessible VR solutions [23]. Aside from the HMD issues, Hyper-real XR experiences and visuals have been found to induce seizures and cause sensory overload in users who suffer from epilepsy [14, 45]. This accessibility concern may cause people suffering from photosensitive seizures to reconsider utilizing XR technologies or engaging with metaverses.

AR systems that were shown to be racist and discriminatory had challenges with inclusivity. In various instances, these systems have been found to not recognize certain genotypes, such as non-caucasian races, or to perform poorly in certain lighting circumstances but well for fair-skinned persons [27]. This may result in the segregation of technology, which may make it inaccessible to a broad grouping of people with different genotypical backgrounds.

4.1.12 Communication Issues. During the analysis of issues and risks in XR technologies, an interesting set of issues emerged which highlighted the communication gap between the stakeholders. This section addresses some instances in which a lack of communication between technology creators (Vendors, Developers, Designers,...) and end users (research subjects, consumers, public,...) causes ethical dilemmas to arise.

In the previous sections, it was highlighted how older participants who wore eyeglasses in a study conducted by Baker et al. [2019] encountered certain difficulties when attempting to use HMDs. This occurred because they were unclear about whether to wear or remove their glasses while using the headset [2]. Despite the fact that researchers were there to assist users, it is unsure if important information on how to participate in such scenarios was given to those wearing glasses, or would it have been considered prior to the study. This failure to provide relevant helpful

information, combined with the limitations of HMD technologies, might have worsened the issue for older individuals wearing glasses and possibly impeded the study's findings.

Similarly, while researching how VR is used in public areas, Luro et al. [2017] noticed that some mishaps in the VR demo space may have been prevented if the exhibitor had notified visitors about the potential risks of playing with VR technology [41]. In some situations, purposeful attempts were made to evoke fear among participants, which could explain why safety guidelines were not shared with the visitors. The VR safety and health guidelines were not showcased in the demo space and were not given to visitors to read [41]. To add to that, Luro et al. discovered a lack of information communicated about VR in general. Perhaps they assumed the guests would be familiar with the technology [41]. As it is not recommended to utilize VR, such assumptions and a lack of expressing safety guidelines can threaten the lives of visitors with pacemakers [41]. In this scenario, a moral dilemma arises as to who is liable if electromagnetic radiation from the VR headset interferes with pacemakers and pose risk. Is it the visitor's responsibility to disclose that they wear a pacemaker, or is it the responsibility of the exhibitor to discuss such risks? In addition to these concerns, the noisy settings in public locations made communication difficult, necessitating a separate audio channel between visitors and exhibitors [41].

When examining the various issues highlighted by Heimo et al. [2014] in AR applications, a recurring theme emerges regarding the responsibility to disclose the information about capabilities and risks associated with the technology. This raises important ethical considerations and prompts speculative questions: Should AR users proactively inform the public that they are wearing AR glasses capable of recording, or is it the public's responsibility to inquire? Should the AR user explicitly communicate how the recorded video will be used, or should the public seek clarification? Should the vendor be responsible for explaining how the captured data will be protected, or should the AR user be knowledgeable about the specifics of data processing? These inquiries fuel discussions that challenge the ethical accountability of all stakeholders involved, extending beyond the realm of technology alone.

4.2 Negative Effects and Barriers Created

Upon closer examination of the aforementioned issues and concerns, it becomes evident that the symptoms and risks associated with XR technologies can have a significant impact on users. These effects range from compromising their overall experience to potentially causing harm or creating a general aversion towards XR technologies. This section aims to delve into specific negative effects and barriers that arise as a result of the issues and concerns discussed in the previous section. By exploring these aspects, a comprehensive understanding of the challenges and obstacles faced within the XR landscape can be attained.

Cybersickness is a prevalent issue experienced by users of VR technologies. In addition to its negative impact on user health, there have been instances where it has compelled individuals to abandon the VR experience altogether to avoid the severe discomfort caused by its symptoms [23, 69]. Such incidents can serve as potential barriers in research studies, as participants' well-being is compromised, thereby affecting the study outcomes [69]. Moreover, it can generate a sense of aversion among general users, making them cautious and uncertain about potential harm caused by VR technology. Cybersickness poses significant barriers for individuals using XR technologies for educational purposes. It has the potential to disrupt the user's sense of presence, thereby impeding their learning experience and resulting in a negative transfer of knowledge [23]. These issues stemming from cybersickness become significant hurdles for individuals engaging in VR-based educational programs, as it hampers their ability to effectively learn and complete their courses [23]. Moreover, cybersickness also has negative implications for vendors and creators, as the reluctance of users to invest in technologies that cause discomfort and raise legal concerns can lead to decreased sales and reduced

production of VR devices and applications [69]. Consequently, cybersickness emerges as a critical barrier that impacts both the production and adoption of technology, thus affecting business perspectives in the XR industry [69].

While XR technologies have shown promise in cognitive training, treatment and aged care, it is important to acknowledge the adverse effects associated with such applications. In the previous section, it was revealed that individuals with dementia and severe ASD faced challenges with cybersickness, discomfort caused by XR hardware, and accessibility issues when engaging with AR and VR technologies [2, 4]. Consequently, these barriers prevent these individuals from fully experiencing and benefiting from the technology as intended for others. Beyond functional barriers, people with dementia encounter additional challenges when adopting novel technologies like XR. Assistive technologies, while designed to support individuals with disabilities, often inadvertently draw attention to their limitations, impacting their self-image and confidence [4]. Moreover, these individuals feel that the assistive technologies neglect their emotional and social needs, perceiving them as monitoring tools rather than tools they can control to meet their specific requirements [4]. The complexity of AR technology poses a challenge for individuals with dementia, as it requires them to navigate a new and sophisticated interaction system. This learning process can be physically and cognitively demanding, making it difficult for people with dementia to use the technology effectively [4]. This presents a barrier for both the creators of AR solutions and the end users, as there is a need for a balance between simple, user-friendly interaction and powerful capabilities that can truly assist individuals with dementia. Additionally, some older adults who seek to be independent in their own homes often encounter stigmatizing and patronizing forms of assistive technologies, which hinder their desire for autonomy. Such negative emotions can discourage individuals from embracing useful technologies that can improve their lives [4]. The study conducted by Baker et al. [2019] revealed ceratin barriers encountered during the use of social VR among older adults. One notable barrier was due to unrealistic avatars and technical errors faced with the tracking software, which had significant social implications. These technical issues and limitations created barriers for users, as they caused misunderstandings and anxieties [2]. For instance, a participant named Carl experienced jitters caused by the Kinect sensor, leading him to believe that he had Parkinson's disease and lost control of his body. Such fears and anxieties cast doubts on one's perception of aging and can have a profound impact on the individual's overall experience [2]. Additionally, tracking errors in social VR mediums hindered effective social interaction, as non-verbal cues were not accurately conveyed. Older participants, who are often sensitive to social cues, could interpret these errors as personal mockery of their aging bodies, reinforcing negative social stereotypes. This, in turn, negatively impacted the older adults' social VR experience [2]. Ignoring these ethical considerations can serve as a significant barrier to the adoption of such technologies [4].

The cognitive impacts and emotional consequences of XR simulations may create certain barriers. Jicol et al. [2022] highlighted the emergence of barriers resulting from facing street harassment. The fear and anger generated by such an event can significantly impact individuals' lives and hinder their ability to enjoy public spaces. In some cases, women may constantly change their routes or confine themselves to their homes in an attempt to feel safer [31]. These barriers not only limit their physical movements but also affect their mental well-being. They may feel a loss of control over their lives, experience a decrease in self-esteem, and become subjected to self-objectification, which can lead to physical and mental health issues [31]. Simulated street harassment in XR scenarios has the potential to reproduce these barriers by leveraging the realism and immersive capabilities of XR technologies.

4.3 Solutions and Recommendations

During the data analysis, a several codes surfaced, carrying a wide range of solutions in the form of ethical frameworks, considerations, design guidelines, and stakeholder responsibilities. The synthesis and interpretation of these codes

yielded valuable insights that can establish a robust foundation for researchers and industry practitioners to refer and integrate into their studies or commercial ventures. By leveraging these findings, XR creators can effectively build safer and more ethical XR solutions and platforms. These solutions and guidelines serve as invaluable resources, empowering professionals in the field to navigate the intricate landscape of XR technology, which is filled with issues and concerns, and make concious decisions that prioritize user safety and ethical considerations.

4.3.1 Mitigating Cybersickness in XR Experiences. Various studies conducted by Vinson et al. [2012], Luro et al. [2017] Lovreglio et al. [2018], Glaser et al. [2022] and Delgado Rodriguez et al. [2023] provide valuable recommendations to mitigate its risk among participants. Delgado Rodriguez et al. propose improving VR hardware as a means to prevent factors contributing to cybersickness. They suggest using VR devices with reduced lag, minimal flickering, and error-free tracking capabilities for conducting VR studies and trials [15]. Lovreglio et al. highlight the optimization of the VR experience based on GUI and CPU capabilities of the hardware to alleviate lagging issues. They emphasize that since there is no universal solution for cybersickness, suitable approaches should be devised on a case-by-case basis [39].

In addition to hardware considerations, cybersickness can also be triggered by self-motion in virtual environments, leading to sensory conflicts [69]. Lovreglio et al. recommend VR designers to employ navigation techniques such as teleportation in open VR worlds. This approach allows users to move between locations without physically walking. While it may slightly disrupt the realism of the virtual world, they propose an alternative technique where users can navigate by clicking a button on the controller, enabling better control over body movements and reducing cybersickness while preserving ecological validity and realism [39].

Furthermore, Vinson et al. [2012] suggest that individual susceptibility plays a role in cybersickness. They propose implementing a screening process before and after the trials by using self-reported tests to identify individuals prone to cybersickness [69]. Tests such as the Simulator Sickness Questionnaire (SSQ), Motion Sickness Assessment Questionnaire (MSAQ), and Virtual Reality Symptom Questionnaire (VRSQ) can be utilized for participant assessment. While the SSQ is commonly employed in research studies, the MSAQ has proven to be a suitable choice for assessing cybersickness symptoms in individuals with ASD [23, 41].

These recommendations provide valuable guidance for researchers and practitioners on how to minimize the risk of cybersickness in VR experiences. Implementing these suggestions will improve user comfort, research beneficence and trial quality, while creating more enjoyable XR experiences.

4.3.2 Enhancing Privacy Protection in XR. XR technologies that incorporate sensing technologies, such as those found in Workplace AR systems, raise significant privacy concerns for users, particularly regarding biotracking capabilities and their possible influence on user agency [24]. This issue is not limited to Workplace AR systems but extends to other XR interventions that utilize similar technologies to deliver functional benefits. In the study conducted by Greene [2023], who investigated the Workplace AR system called Vuforia Expert Care System, a set of ethical design recommendations was proposed, drawing from the principles of Value Sensitive Design and Ethically Aligned Design [24]. The aim of these recommendations was to empower designers to create equitable AR applications specifically for industrial workplace contexts. However, the relevance of these recommendations extends beyond the workplace, as the narratives surrounding AR technology (possibly the whole XR spectrum) and its potential align with transhumanist ideas that are prevalent across various sectors [24].

Greene [2023] proposed a speculative ethical design framework consisting of four interconnected design layers, each addressing different aspects of workers' autonomy, privacy, and well-being [24]. Most of the guidelines seems to emphasize privacy concerns, informed consent and improving autonomy. In the first design layer, the interface

layer, recommendations revolve around UX/UI display features in the AR HMD. Greene suggests giving users control over data collection and monitoring features, displaying regular privacy setting updates, and incorporating UI and designer features that provide alerts when monitoring features are active and maintains user privacy [24]. The second layer, the monitoring layer, focuses on design recommendations for tracking capabilities. Notably, the guidelines emphasize avoiding the default enabling of biotracking features to address privacy concerns and also limit the data collection capabilities of the system [24]. Moving on to the third layer, the documentation layer, designers are advised to create comprehensive technical documentations that clearly explain the data collection procedures within the system. These materials should also outline individuals' rights to view, modify, and own their workplace data [24]. Greene recommends keeping automated features and decision-making processes transparent so that it can easily be accessible for modification. Additionally, Greene suggests the creation of a standalone document that highlights exploitative and improper usage of the technology in various workplace contexts [24]. Finally, the context layer suggests creating rules and policies for collecting anonymous data from workers, explain how the AR system has been designed to influence behaviours, and offering workers the choice to opt-out from using certain featuers like gamification [24].

While these design guidelines primarily focus on enhancing the ethical aspects of AR systems with tracking capabilities, the principles can be applied to the design and communication of similar invasive and exploitable characteristics in other XR technologies that may or may not use sensing technologies, like in the case of surveillance problems highlighted by Heimo et al [2014]. By incorporating these guidelines, XR designers can create user-centered solutions and ecosystems that respect individual privacy rights. Moreover, these recommendations create awareness among users, empowering them to make informed decisions about their privacy and usage. Embracing these ethical design principles enables creators to tackle privacy concerns, uphold user agency, and strive towards the development of XR technologies that are both functional and ethically aligned with societal values.

4.3.3 Promoting Accessibility and Inclusivity in XR Technologies. Throughout the analysis, various challenges related to accessibility and inclusivity were identified. These challenges encompassed issues such as the technology being unsuitable for individuals with Dementia or ASD, older individuals feeling that the technology does not cater to their specific needs, and instances of racism and discrimination within AR technology. It is crucial to develop systems that are fair and unbiased in order to effectively serve a diverse range of individuals with different capabilities. This section briefly discusses a selection of recommendations picked from studies conducted by Heimo et al. [2014], Baker et al. [2019], Berret et al. [2022], and Glaser et al. [2022].

To begin, Berret et al. [2022], who examined assistive AR technology for dementia patients, believed that using a Human-Centered Design (HCD) approach would be the most effective strategy because it helps identify individual needs and provides an easier way to introduce technology to dementia patients living in their homes [4]. They favoured HCD above other approaches because such actions were not widely discussed. When introducing new technology to people with dementia, it is critical to consider ethical considerations such as autonomy, privacy, and vulnerability [4]. Dementia persons and their needs are distinct and different, thus personalized solutions are required. Personalisation increases the individual's engagement with technology while enhancing the usability and accessibility of the solutions. It improves the user experience and makes the assistive technology enjoyable to use [4]. HCD also simplifies understanding a dementia patient's demands and challenges with acceptance and interaction with technology. Considering the emotional and social needs of dementia patients from early on helps to develop optimal solutions and achieve high technology adoption rates [4]. Berret et al. were able to include stakeholders such as the patient and support person, location, activities, and technical assistance in their research by using an HCD strategy. Aside from the patients' involvement,

their support person or caretaker's feedback on the design was also critical in personalizing the technology [4]. Berret et al. indicated that having multimodal interactions with both audio and visual was preferred by people with dementia when coming up with design recommendations [4]. People require a wide range of design solutions based on their needs, interests, and capacities due to the various stages of dementia[4]. Such highly customized solutions necessitate ethnographic methodologies and close engagement with dementia patients, necessitating repeated visits and observations to understand their routines and needs. A firm bond between the patient and the researcher is essential for this to happen [4]. Baker et al. used a participatory approach to investigate social VR for elderly people for social objectives in their study. They appreciated the participatory methodology since it enabled participants to make their own decisions and engage the researchers closely with them throughout the research [2].

Various technical and design considerations were also shared to enhance the usability and user experience of the technology. In the context of social VR, it was recommended to eliminate tracking errors as they significantly impacted the participants' experience. Employing error-free technology and precise adaptive body tracking were identified as crucial elements for maximizing the overall experience [2]. Avatars were found to be beneficial in improving social interactions among older adults. To meet the communicative preferences of older individuals, avatars should be realistic and exhibit behavioral anthropomorphism, allowing them to establish a sense of genuine connection with others [2]. To achieve this, the implementation of advanced technologies such as lip syncing and simulating eye movement is essential. These technologies ensure that facial movements are accurately captured and conveyed when viewed through a HMD. Enhancing facial expressions in avatars emerged as a unanimous request from older adults, as it helps foster a more authentic sense of connection [2]. Furthermore, the findings from Baker et al. highlighted the emergence of a novel form of interaction through non-verbal, gesture-based interactions [2]. Therefore, it is suggested to design VR experiences with hand controllers that support hand gestures, facilitating the building of social rapport with others. Providing hand controllers also enables older adults to interact with virtual objects, enhancing their overall engagement and immersion in the virtual environment [2]. Likewise, Berret et al. also provided several design recommendations of future AR technology. Their suggestions primarily revolved around adopting a minimalist design approach and unobtrusive setups. This includes incorporating voice-based interaction to activate the device or prompt interactions, presenting content with high contrast visibility in various lighting conditions, and avoiding the need for additional mediating devices [4]. By following these design suggestions, AR technology can become more accessible, inclusive and user-friendly, allowing a wider range of individuals to engage with it effectively [2].

Lastly, in addition to collecting design requirements and developing solutions, Heimo et al. propose the importance of conducting extensive user testing. They emphasize the need to include individuals with diverse capabilities and feature (eg. genotypes) during these tests to ensure the development of inclusive XR technologies that do not discriminate or exclude anyone from the XR experience [2].

The aforementioned study methodologies, design principles, technical suggestions and considerations can guide new XR technologies and research studies to follow in their footsteps, ensuring an accessible and inclusive future for XR technology.

4.3.4 Reinforcing Participant Safety and Ethical Practices in XR Experiences. It has been observed that Institutional Review Boards (IRBs) take various measures to ensure the protection of research participants. These measures include establishing protocols, addressing ethical concerns prior to the commencement of the study, screening participants, and implementing necessary remedies if participants experience any discomfort [41]. IRBs also require informed consent, which informs participants of the implications and provides the option to withdraw from the study. Research

experiments are conducted in controlled environments, and researchers are available to provide assistance in case of emergencies [41]. However, these practices are not often seen in industrial and public VR experiences, which lead to risks such as injuries, violation of safety guidelines, and privacy concerns [41]. Luro et al. [2017] emphasizes the importance of bridging the gap between industry practitioners and academia. They highlight the need for collaboration and knowledge sharing between the two parties to improve research practices and enhance user experiences, ultimately resulting in the development of high-quality XR experiences [41].

5 DISCUSSION

In this study, a comprehensive investigation was undertaken to explore the ethical aspects of XR technologies and their applications. The focus was on investigating the emerging issues and concerns associated with the use of these technologies in various contexts, as well as understanding the negative effects and barriers that arise from these issues. The study also aimed to identify potential solutions that can effectively address these risks and promote the ethical use of XR. A rigorous systematic review methodology was employed to ensure a robust and reliable analysis. The findings were qualitatively interpreted through a thematic data analysis process, which facilitated the identification and synthesis of various ethical concerns, social implications, privacy risks, and moral dilemmas associated with different XR technologies, such as AR, VR, MR, and metaverses. In various industrial, commercial, and research usescases, these technologies have been found to have a broad collection of problems, allowing for extensive investigation of their ethical implications.

Numerous issues and concerns have emerged in relation to the use of XR technologies, encompassing the domains of health, cognitive capabilities, emotions, privacy, autonomy, and social relationships. It is noteworthy that these issues often exhibit intricate interrelationships, with some acting as causative factors while others manifesting as subsequent effects. Health-related problems present significant challenges to users' physical well-being, as certain XR applications have the potential to cause falls or result in injuries during interaction [4, 46]. Moreover, cognitive and psychological impacts have been observed to generate negative emotional consequences, and in some instances, they can even trigger past traumas or contribute to the development of post-traumatic stress disorder (PTSD) [31, 39]. Furthermore, the sensing and tracking capabilities inherent in XR technologies raise concerns regarding privacy, as they introduce the possibility of surveillance and monitoring that can infringe upon individuals' personal autonomy [24, 27]. These features provide avenues for the gathering of extensive user data, potentially enabling governmental or commercial entities to exploit vulnerabilities such as emotional changes for deceptive and manipulative purposes [24, 27].

XR technologies, particularly VR, have exhibited significant potential for social implications. VR games, known for their addictive nature, have led children and adolescents to become deeply immersed in virtual worlds, often to the extent of neglecting their real-life responsibilities [33]. This behavior not only poses health risks but also directly impacts their interpersonal relationships with friends, family, and the society in which they live [33]. While many of the health issues, cognitive impacts, and privacy concerns associated with XR technologies have been previously identified in literature reviews, the emergence of issues related to commodification is both new and alarming. These issues highlight how commercial motives can give rise to moral problems, such as disregarding someone's sentiments or exploiting their non-existence for personal gain [46]. It is important to acknowledge that XR hardware plays a significant role in facilitating these issues by providing the features and functionalities that enable such experiences. However, the sophisticated design of these hardware devices can also become a limitation, leading to accessibility concerns for certain individuals [4]. Lastly, it is important to highlight the communication issues that exist between stakeholders on both the production and consumption sides of XR technologies. Failure to effectively communicate

critical information from XR producers to consumers or vice-versa was found to put stakeholder's well-being and safety at risk.

The identified issues have had detrimental effects on both users and XR technology, leading to various barriers in XR interventions. For instance, the prevalent problem of cybersickness poses a threat to the quality of educational programs and research studies conducted in virtual reality, hampering their effectiveness [23, 69]. This, in turn, hinders the adoption rates of XR technologies for such purposes, ultimately impacting the production of technology and applications in this domain. Cybersickness has found to be a liability for XR businesses [69]. Moreover, while features like immersion and realism in XR are often hailed, they also come with their own drawbacks. These features can negatively impact the lives of older adults, dementia patients, and individuals with ASD, despite their potential positive applications [2, 4, 23]. However, through the systematic review, some design recommendations and frameworks were identified to address concerns related to cybersickness, privacy, accessibility, and participant safety. These insights can help mitigate the adverse effects of these issues and guide the development of more human-centered and ethically aligned XR solutions.

Moving forward, it is essential to address these issues in order to establish the ethical and safe use of XR technologies, such as AR, VR, and MR, across various contexts. By doing so, we can foster business growth and unlock numerous opportunities where XR technologies can enhance quality of the human life. Unlike previous studies that focused on individual XR technologies or specific use cases, this comprehensive investigation delves into the ethics of XR, presenting clear findings that outline the identified issues, their effects, and potential solutions. This study opens doors for researchers to explore these issues, effects, and use cases in a detailed manner. Each issue and its corresponding effect serves as an avenue for in-depth examination. The findings highlight the importance of recognizing that despite the beneficial purposes for which XR applications are built, they still carry ethical implications that need to be addressed. For practitioners, the listed solutions provide a solid starting point to consider how the discussed considerations and frameworks can be applied to different XR use cases. Furthermore, practitioners can identify additional considerations necessary for effectively implementing XR interventions and catering to the needs of participants.

This review has certain limitations that should be acknowledged. Firstly, in order to manage the scope of the study, only the ACM Guide to Computing Literature database was considered, while other relevant data sources such as Scopus, IEEE Xplore, SpringerLink, PubMed, Google Scholar, and Web of Science were initially included in the pilot studies but later excluded. The inclusion of these additional data sources could potentially provide valuable insights that were not captured in this review. Furthermore, the review focused exclusively on research papers and short papers, omitting other content types like review papers, extended abstracts, panel discussions, magazine articles, and books. Incorporating these alternative formats could have enriched the findings of the review.

It is important to note that the review specifically centered on XR technologies such as AR, VR, MR, and Metaverse, omitting other computer-generated realities. Broadening the search query to include additional relevant terms could have yielded further insights. Lastly, the data analysis and interpretation relied on a data-driven inductive coding approach. While this approach allows for flexibility and novel insights, it also introduces subjectivity as the interpretation of the relationship and links between the data, codes, and themes is dependent on the researcher's understanding [5]. The absence of a predefined theory or pre-existing frameworks and codebooks may impact the synthesis and findings. Reproducing the SLR by other researchers might yield different interpretations based on their own preconceived notions [5]. Despite these limitations, the review provides valuable findings within the defined scope and serves as a foundation for further research and exploration in the field of XR technologies and Ethics.

Addressing all the complex issues and concerns simultaneously can be challenging due to their interrelated nature. This study has made an effort to discuss the ethical implications in a comprehensive manner. By building upon the

insights of this systematic review study, researchers can take a vertical approach, focusing on specific ethical aspects in-depth or can also take a horizontal approach, exploring ethical aspects across the broad spectrum of XR. By pursuing both vertical and horizontal directions, researchers from the domains of HCI, XR and Ethics can contribute to the ongoing discourse on ethics in XR and pave the way for the design and development of ethically aligned XR technologies.

6 CONCLUSION

In the rapidly evolving landscape of XR technologies, including AR, VR, and MR, this study aimed to gain a comprehensive understanding of the current state of ethics in XR. Through a rigorous systematic review, this study confirms that the usage of XR technologies raises several ethical issues and related concerns, such as social implications, privacy risks, and moral dilemmas. These issues have profound impacts on various aspects of human life, encompassing health, privacy, autonomy, emotions, and cognitive capabilities.

Moreover, this study revealed the existence of adverse effects and barriers experienced by users across diverse application domains, including education, training, rehabilitation, medical treatment, and entertainment. These barriers pose significant threats not only to consumers but also to the XR industry as they hinder adoption rates and impact business outcomes. However, it is noteworthy that the analysis of multiple studies uncovered valuable insights in the form of ethical frameworks, design guidelines, and key recommendations aimed at mitigating these ethical issues and improving the overall XR experience.

The chosen SLR methodology proved to be an effective approach, enabling the identification of articles that not only discussed the impacts by XR technologies but also shed light on stakeholder perspectives, industry and academic processes, as well as emerging issues like commodification and communication challenges. The inclusion of additional data sources and content types could further enrich the insights obtained through this SLR methodology.

The insights derived from this study provide a wealth of opportunities for future researchers to explore. Three overarching themes, namely Ethical Issues and Related Concerns, Adverse Effects and Barriers, and Ethical Solutions and Recommendations, offer valuable avenues for deeper investigations. Researchers can delve into specific phenomena within these themes through targeted studies, enabling a more nuanced understanding of the ethical landscape. Furthermore, a broader exploration of XR ethics across the wide spectrum of XR technologies can uncover further related phenomena and expand the knowledge base. Given the diverse sub-topics within each theme, the scope for future research in the field of XR ethics is vast, offering the potential to contribute meaningful knowledge to the XR community and society at large. Addressing the limitations outlined in the discussion section provides opportunities for extending this study.

This research highlights that despite the immense positive potential of XR technologies, there remain significant ethical issues and concerns that must be addressed. While tackling these issues comprehensively poses a considerable challenge due to their interrelated nature, doing so is essential to cultivate safe and ethical XR ecosystems that enhance the capabilities of humans.

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A SEARCH RESULTS

Table 4: Search Results

Data Source	Search Hits	Search Query Used
ACM Guide to Computing Literature	78	Abstract:("Augmented Reality" OR "Virtual Reality" OR "Mixed Reality" OR "Extended Reality" OR "AR" OR "VR" OR "MR" OR "XR" OR "Metaverse" OR "Mixed-reality" OR "Extendedreality") AND (Fulltext:("ethical issue" OR "ethical problem" OR "ethical limitation" OR "ethical challenge" OR "ethical concern" OR "ethical implication" OR "ethical consideration" OR "ethical risk" OR "ethical framework" OR "ethical guideline" OR "ethical reflection" OR "ethical participation" OR "ethical design" OR "ethical protocol" OR "ethical dilemma" OR "ethical issue" OR "social implication" OR "societal implication" OR "privacy implication") OR Keyword:(ethic*))
Scopus	897	ABS ("Augmented Reality" OR "Virtual Reality" OR "Mixed Reality" OR "Extended Reality" OR "AR" OR "VR" OR "MR" OR "XR" OR "Metaverse" OR "Mixed-reality" OR "extended-reality") AND (TITLE-ABS ("ethical issue" OR "ethical problem" OR "ethical limitation" OR "ethical challenge" OR "ethical concern" OR "ethical implication" OR "ethical consideration" OR "ethical risk" OR "ethical framework" OR "ethical guideline" OR "ethical reflection" OR "ethical participation" OR "ethical design" OR "ethical protocol" OR "ethical dilemma" OR "ethical issue" OR "social implication" OR "societal implication" OR "privacy implication") OR KEY (ethic*))
IEEEXplore	76	("Abstract":"Augmented Reality" OR "Abstract":"Virtual Reality" OR "Abstract":"Mixed Reality" OR "Abstract":"Extended Reality" OR "Abstract":"AR" OR "Abstract":"VR" OR "Abstract":"MR" OR "Abstract":"XR" OR "Abstract":"Metaverse" OR "Abstract":"Mixed-reality" OR "Abstract":"extended-reality") AND (("Full Text Only":"ethical issue" OR "Full Text Only":"ethical problem" OR "Full Text Only":"ethical limitation" OR "Full Text Only":"ethical challenge" OR "Full Text Only":"ethical concern" OR "Full Text Only":"ethical implication" OR "Full Text Only":"ethical consideration" OR "Full Text Only":"ethical risk" OR "Full Text Only":"ethical framework" OR "Full Text Only":"ethical guideline" OR "Full Text Only":"ethical reflection" OR "Full Text Only":"ethical participation*" OR "Full Text Only":"ethical design" OR "Full Text Only":"ethical protocol" OR "Full Text Only":"ethical dilemma" OR "Full Text Only":"ethical issue" OR "Full Text Only":"social implication" OR "Full Text Only":"societal implication" OR "Full Text Only":"privacy implication") OR ("Author Keywords":ethic*))

Continued on next page

Table 4: Search Results (Continued)

Springer Link	1697	"Augmented Reality" OR "Virtual Reality" OR "Mixed Reality" OR "Extended Reality" OR "AR" OR "VR" OR "MR" OR "XR" OR "Metaverse" OR "Mixed-reality" OR "Extended-reality" "ethical concern"
PubMed	76	("Augmented Reality"[Title/Abstract] OR "Virtual Reality"[Title/Abstract] OR "Mixed Reality"[Title/Abstract] OR "Extended Reality"[Title/Abstract] OR "AR"[Title/Abstract] OR "VR"[Title/Abstract] OR "MR"[Title/Abstract] OR "XR"[Title/Abstract] OR "Metaverse"[Title/Abstract] OR "Mixed-reality"[Title/Abstract] OR "extended-reality"[Title/Abstract]) AND (("ethical issue" OR "ethical problem" OR "ethical limitation" OR "ethical challenge" OR "ethical concern" OR "ethical implication" OR "ethical consideration" OR "ethical risk" OR "ethical framework" OR "ethical guideline" OR "ethical reflection" OR "ethical participation" OR "ethical design" OR "ethical protocol" OR "ethical dilemma" OR "ethical issue" OR "social implication" OR "societal implication" OR "privacy concern") OR (ethic*[Other Term]))
Google Scholar	21,500	"Augmented Reality" OR "Virtual Reality" OR "Mixed Reality" OR "Extended Reality" OR "AR" OR "VR" OR "MR" OR "XR" OR "Metaverse" OR "Mixed-reality" OR "Extended-reality" "ethical concern"
Web of Science	197	AB=("Augmented Reality" OR "Virtual Reality" OR "Mixed Reality" OR "Extended Reality" OR "AR" OR "VR" OR "MR" OR "XR" OR "Metaverse" OR "Mixed-reality" OR "Extended-reality") AND (TS=("ethical issue" OR "ethical problem" OR "ethical limitation" OR "ethical challenge" OR "ethical concern" OR "ethical implication" OR "ethical consideration" OR "ethical risk" OR "ethical framework" OR "ethical guideline" OR "ethical reflection" OR "ethical participation" OR "ethical design" OR "ethical protocol" OR "ethical dilemma" OR "ethical issue" OR "social implication" OR "societal implication" OR "privacy implication") OR AK=(ethic*))
Total Documents	**24521**	