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SYSTEMATIC REVIEW

Mapping risks and harms of eXtended reality (XR) technologies – A scoping review and novel typology

[version 1; peer review: 1 approved with reservations]

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Abstract

This article uses a scoping review method to extensively map risks and harms related to the design, development and application of XR technologies (VR, MR, AR, virtual environments, and metaverses). Through the application of qualitative content analysis, thematic categories emerged which were developed into a novel typology of risks comprising of six main themes and 19 sub-themes: 1) health and wellbeing (cognitive, psycho-emotional, socio-relational and physical), 2) autonomy (privacy, self-sovereignty, surveillance, authenticity), 3) epistemic and scientific (epistemic uncertainty, scientific uncertainty, algorithmic imperfection, manipulation), 4) normative (norm violations, rights violations), 5) structural (socio-political, economic/financial, legal), and 6) technical safety and security (security, dual use). Further considerations identified were risks pertaining to special populations (vulnerable groups), unknown risks and long-term use effects. A subsidiary aim was to map risk mitigations. Other key findings, such as geographical distribution of sources, and use cases, among others, are featured, lending to a robust discussion on the state of XR risks, potential motivators for development of XR harm mitigation-strategies, and key knowledge gaps.

Keywords

Immersive technologies, virtual reality, augmented reality, mixed reality, harm, risks, ethics

Open Peer Review

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Any reports and responses or comments on the article can be found at the end of the article.

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1. Introduction

1.1 Background and rationale

This article's primary motivation is to provide a comprehensive mapping and examination of potential risks and harms relevant to the creation, development and use of eXtended reality technologies (XRTs), also called immersive technologies. XRTs are growing increasingly ubiquitous across sectors, and there have been several calls for close examination of these technologies.[1–3] This work not only contributes to illuminating potential risks, but allows for an informed building of normative frameworks, approaches, or tools which may adequately address or mitigate these issues. A robust examination of risks also allows for researchers and policy makers to make informed decisions not only about design but also about the safe and ethical dissemination of XRTs to the wider public.

This article is a key research output of the Horizon Europe project, XR4Human,[4] which will develop ethics and interoperability guidance documents for developers and users of XRTs in Europe. Specifically, the article supports the work of Work Package 2, which is tasked to map, examine, and evaluate the ethical, philosophical and risk-related issues of XRTs. Through this scoping review and the subsequent typologies developed, the article contributes to the WPs task of developing a normative framework which forms as the foundation for the Code of Conduct for the Human-Centered and Ethical Development of Immersive Technologies. While the project focuses primarily on European contexts, the findings presented here also have global relevance.

1.1.1 eXtended reality (XR)

XR is an all-encompassing term commonly used to represent:

technology-mediated experiences enabled via a wide spectrum of hardware and software, including sensory interfaces, applications, and infrastructures. XR is often referred to as immersive video content, enhanced media experiences, as well as interactive and multi-dimensional human experiences.[5]

In essence, XR is a fusion concept capturing "all the realities": augmented reality (AR), virtual reality (VR) and mixed reality (MR).[5] The meaning and usage of XR and its modes/forms have evolved over time (see[6–8]). These terms remain in flux, expanding as new infrastructures, affordances and trends emerge. AR places digital information on top of a user's physical environment; MR is an active blending of digital and physical, wherein changes to, or interactions with, the digital object would occur as if it existed in physical space; VR is a completely digitized interactive environment which can give the user the experience of complete immersion.[5] Immersion is a complex concept which may refer to the physics or technical abilities offered by a device (measured quantitatively), but may also refer to a user's subjective experience of feeling "present" in a virtual environment (qualitative).[4] These environments, commonly characterized in literature as virtual environments (VEs) (sometimes "virtual worlds"), are a primary affordance of XR. These can be understood as a network of persons represented as avatars, interacting in synchronicity.[9,p.2] Often considered as the apex or ultimate goal of XR, the interconnection and expansion of virtual environments would culminate in a Metaverse, a digitized parallel of reality itself which persists over time, is interoperable, and is immersive.[a].[10]

1.1.2 Risk and harm

As XRTs become more widely adopted across various disciplines and applications, more attention has been placed on the associated risks and harms. There have been a number of governmental, non-governmental agencies and individual interest in examining what constitutes a risk or harm in various technologies. The Institute of Electrical and Electronics Engineers (IEEE) has been one of the key standards agencies to play a significant role in examining risks of technologies, as evidenced by the series of white papers they published on the ethics of XRTs.[11]

According to the IEEE, a "risk" is "an unwanted event that may or may not occur".[12] The International Organisation for Standardization (ISO), another key agency, notes that a risk is a "combination of the probability of occurrence of harm and the severity of that harm".[13] Given that risks are directly connected to an unwanted event or probability of harm, it would be prudent to examine what constitutes harm.

IEEE defined harm as "any unwanted occurrence which ends in some sort of "value damage or loss" to a person.[14] This very broad interpretation presents the opportunity to capture a wide range of unwanted events in the XR literature. However, it may also present a significant challenge in contextualising what harms ought to be considered by developers.

[a]Persistence, here, means virtual objects continue to exist even when the user is not in the digital world.

Harm has been a concept that has been debated extensively in philosophical, sociological, and jurisprudential academic literature.[b][15–17] Acknowledging the nuanced understanding of harm and how the probability of harm (i.e., risks) may be represented in literature, it was important to examine what may already be broadly categorised as risks and harms of XR to facilitate a foundational awareness of various risk/harm descriptors and how they are used in relation to XR.

In 2020, the Cyber XR Coalition published what is described as a framework for XR risk assessment.[18] It was emphasised that the risk categories in the report were a "work in progress", which could be interpreted as an acknowledgment of the challenge of attempting to map risks and harms. The reported risk categories in this framework were human, financial, legal, information, and societal.[18] They note harms such as physical, psychological, misuse of data, privacy violations, manipulated social discourse etc. societal.[18]

Others have similarly sought to identify risks associated with XR, often focusing on a specific type of XR, application, or user. For example, XRSI released a publication focused on the privacy risks of XR and proposed mitigation measures.[19] The Rathenau Institute publication, *Responsible VR: Protect consumers in virtual reality,* is another example, identifying risk clusters that are relevant to consumers: physical and mental risks; social risks; abuse of power; and legal risks.[20] Likewise, the IEEE embarked on what they described as the "Global Initiative on Ethics of Extended Reality" which yielded several publications on challenges with various applications (use cases) of XR.[21] The European Union, as part of its Web 4.0 and virtual worlds strategy, has also begun to reflect on "opportunities, pitfalls and potential solutions" of XR technologies, with a focus on virtual worlds/metaverses.[22] Noting that the global market for XR, particularly, virtual worlds should reach over 800 billion by 2030, it is imperative that developers are not only aware of the risks and harms but to ensure that the development of the technology is co-creative, human-centric, inclusive, considers and is respectful of fundamental rights, and avoids risk of harm to users.[4,16,22]

1.1.3 Aim and objectives

This article aims to contribute to any knowledge gaps in the existing literature by applying the scoping review method for obtaining a comprehensive mapping of XR risks and harms related to design, development and use. A scoping review is a type of systematic knowledge mapping in which findings are to be summarised and presented *as described in the literature.*[2,3] This mapping spans across disciplines and methodologies.

The specific objectives are:

1. To identify and describe the various forms of risks and harms associated with the design, development and use of XR technologies.

2. To identify and describe the mitigation strategies/redress proposed in literature for identified risks and harms.

1.1.4 Previous systematic reviews and research gap(s)

A preliminary search in January 2023 identified only a few systematic/scoping reviews reporting harms and risks related to the use of XR technologies.[23–26] These, however, were narrow in disciplinary scope i.e., mainly relating to a specific domain or specific scenarios (health or construction), or one type of XR technology or experience (ex: VR only).[23–26] A gap, therefore, exists in the XR literature for reviews that comprehensively map risks and harms related to XR technologies and experiences. This expanded mapping of risks and harms is building on the findings of an initial mapping of ethics guidelines for XR technologies conducted early 2023, where various ethical issues with the use of the technology were identified.[27]

2 Method

Considering the broad nature of the research questions, a scoping review, following the seminal review framework of Arksey and O'Malley[28] and the Johanna Briggs Institute (JBI) Manual for Evidence Synthesis[29] was selected as the methodological approach. This article's method, additionally, adheres to the reporting standard, the Preferred Reporting Items for Systematic Reviews and Meta-Analysis extension for scoping review (PRISMA-ScR).[30]

Sources covering risks and harms of XR are not homogenous, thus a scoping approach allows for the inclusion of literature from various domains, traditions, study designs and methodological approaches.[28,31] The method is also

[b]For example: how does environmental harm relate to a loss for the person, and does it have to?

Table 1. Search string. Search string used for search in the databases Scopus and IEEE Xplore, with number of retrieved documents for each database.

Databases	Search string	Number of retrieved documents
Scopus	(TITLE-ABS-KEY ((safe* OR harm* OR danger* OR abus* OR hazard* OR secur* OR "adverse effect" OR "adverse vents" OR risk OR risking OR risks OR benefit* OR privacy OR wellbeing OR "well-being")) AND TITLE-ABS-KEY (ethic* OR bioethic* OR philosoph* OR integrit* OR moral* OR "human centred" OR "human centered") AND TITLE-ABS-KEY ((interactive W/2 (media* OR experience*)) OR metaverse OR xr OR xr4* OR (immersive W/2 (technolog* OR environment*)) OR (virtual W/2 (realit* OR environment*)) OR ((virtualis* OR virtualiz*) W/2 (technolog* OR network*)) OR (augmented W/2 realit*) OR (mixed W/2 realit*) OR (extended W/2 realit*)))	1768
IEEE Xplore	((((interactive NEAR/2 (media OR experience OR experiences)) OR metaverse OR xr OR xr4* OR (immersive NEAR/2 (technology OR technologies)) OR (immersive NEAR/2 (environment OR environments)) OR (virtual NEAR/2 (reality OR realities OR environment*)) OR (virtuali* NEAR/2 (technology OR technologies OR network*)) OR (augmented NEAR/2 (reality OR realities)) OR (mixed NEAR/2 (reality OR realities)) OR (extended NEAR/2 (reality OR realities))) AND (safe OR safety OR harm OR harming OR harms OR danger* OR abuse OR hazard* OR security OR secure OR "adverse effect" OR "adverse events" OR risk OR risking OR risks OR benefit OR benefits OR privacy OR wellbeing OR "well-being") AND (ethic OR ethical OR ethics OR ethically OR bioethic OR bioethical OR philosophi* OR integrity OR integrities OR moral OR morals OR morality OR moralities OR "human centred" OR "human centered")))	513

appropriate to finding potential knowledge gaps.[28,31] Scoping reviews are primarily descriptive endeavours, meaning that "findings" (i.e., risks and harms themselves) are reported as written within the included sources.[29] Although the PRISMA-ScR review guidelines note a critical appraisal of literature as an optional part of the scoping process.,[30] this review did not include a critical appraisal of source quality, specifically regarding empirical rigor or methodological validity. Given the diversity and technical complexity of the included literature, and in keeping with the descriptive aim of scoping reviews, the reviewers considered that critical appraisal would not have been appropriate and could introduce bias. A straightforward presentation of findings was therefore judged the most practical and methodologically sound choice.[29]

The following sections will provide an overview of the review protocol, search strategy, source inclusion/exclusion criteria, the process of selecting sources of evidence, as well as data mapping and reporting.[31]

2.1 Team and expertise

The review team comprises of CD (ethicist/methodologist), LC (vision scientist), SO (ethicist/pharmacist), and RK (research ethicist).[c] Additionally, members of WP2 acted as experts providing guidance throughout the research. These members include philosophers, technology experts and practitioners, vision scientists, psychologists, and other social and natural scientists.

2.2 Review protocol

Reviewers CD, LC, SO prepared a protocol based on JBI standards for scoping review protocols.[32] This protocol served as the roadmap for how to approach this review. However, while the protocol itself was not registered, the data charts which present extracted findings will be uploaded to the XR4Human Community in Zenodo.org.[33]

2.3 Information sources and search strategy

The search strategy comprised of an inductive search using databases followed by citation chaining and manually inputted sources. This design allows for an iterative process that brings in more sources as reviewers become familiar with appropriate literature, widening the breadth of the mapping.[31]

In January 2023, the search string was constructed after several meetings. The final search string (Table 1) was submitted to a University of Oslo librarian who executed a search in the databases, IEEE Xplore and Scopus. These databases

[c]Initials have been changed such that authors cannot be identified.

provide a wide range of technical literature from multidisciplinary sources. The search yielded 2281 records, which were then uploaded to the management software Rayyan.[34] After deduplication, 1939 sources remained and were considered for eligibility. See Table 2. for details.

Citation chaining of the included database sources was also performed. Reviewers CD, SO and LC systematically searched the reference lists of the full-text database articles deemed appropriate for data extraction. This process yielded 111 additional sources, which were then screened for eligibility using Rayyan. In addition to citation chaining, further publications were identified for screening through manual input from the XR4Human consortium members.

2.4 Inclusion and exclusion criteria

All included sources referred either in the title or abstract to XRTs, including virtual reality (VR), augmented reality (AR), mixed reality (MR), the Metaverse, virtual worlds, or virtual environment, or to recognized synonyms such as "immersive technologies" (see Table 3 for an overview of the type of sources considered and the eligibility criteria used). The

Table 2. Overview of number of retrieved records from database search and after deduplication.

Database	Number of retrieved records
Scopus	1768
IEEE Xplore	513
Number of records before deduplication:	2281
Number of records after deduplication:	1939

Table 3. Overview of the type of sources considered, and the eligibility criteria used.

Screening	
Sources considered	**Types:** Academic/scientific literature, book chapter, guidelines, recommendations, policy documents, regulations, framework, official standards, can be either journal articles or grey literature (report, working paper, policy paper, etc.) from government, non-governmental organisations, or industry.
	Authors: Academic researchers, institutions, government and affiliated agencies, non-governmental organisations, professional societies, non-profit organisations.
	Must be full text.
	Language: English only.
Sources excluded	Conference summaries, videos, images, podcasts, blog articles, news articles, syllabi, books.
Eligibility	
Sources included	Explicitly referred in title and/or abstract to "immersive technologies" or extended reality (XR) or virtual reality (VR) or mixed reality (MR) or augmented reality (AR) or virtual environments (VEs) or virtual worlds or Metaverse. Publications that mentioned specific XR-related artifacts/devices/platforms were also included.
	Referred in title and/or abstract to harm or risk. "Risk" and "harm" encompasses a wide umbrella of meaning, including synonyms (i.e. danger, abuse, etc.), hence words highly associated with risk and harm such as "well-being" or "safety", etc were considered.
	Date range: 2000–2023 (database literature, citation chaining), 2000–2024 (manual input)
Sources excluded	Did not mention immersive technologies, XR or its constituents (VR, AR, MR), virtual environments or virtual worlds, or the Metaverse.
	Did not identify any form of risk or harm or synonym arising from the design/use/implementation of XR in the title or abstract.
	Mentioned XR very generally or broadly but did not engage with the technology specifically (for example, as part of "digital technologies").
	Languages outside of English.

approach was to specify which terminology (e.g., AR, MR, VR) was used in each source, along with the applications of the technology (use cases) and the accompanying output devices or platforms (see Table 4: Data charting categories).

Having established earlier that sources use multiple and sometimes divergent understandings of what constitutes a risk and harm, or sometimes use synonymous terms, a broad inclusion strategy for terms was employed. Selected publications were required to refer to harm, risk, or their synonyms, or to related terms (e.g., well-being, security, etc.) in the title or abstract.

Sources that did not identify any risk/harm arising from the use and/or application of XR were excluded. Additionally, sources that only mentioned XR very generally (as part of "digital technologies", for example) but did not engage more specifically with XR-related risks/harms were excluded. Further inclusion criteria required full texts to be available in English. The database search covered publications from 2000 to January 2023, although some 2023 and 2024 publications were manually added. Practical reasons motivated these language and timeframe preferences: English was the common language among the reviewers, and while discussions of XR risks and harms predate 2000, earlier publications were considered likely to be outdated.[d] Due to project timelines, reviewers were unable to conduct a database search inclusive of 2024.

Strictly peer reviewed publications were not required, as doing so would have limited the range of sources. However, due to time constraints, sources such as blogs, vlogs, conference summaries and podcasts were excluded. There were no restrictions regarding context, population, research methodology, or disciplinary background in keeping with the goal of identifying a broad range of XR-related risks and harms. The final inclusion/exclusion criteria were developed iteratively, with significant refinements made following the pilot phase.

2.4 Source selection process

Reviewers (SO, CD, LC) conducted an initial screening of each database source according to the aforementioned inclusion criteria using the software Rayyan.[34] This review was a "first pass", focusing on title and abstract. Disagreements were discussed and settled during our weekly meetings. Reviewer RK independently reviewed any conflicts. After this process, 145 database sources remained and were uploaded to NVivo 14[35] for data extraction.

To ensure that sources aligned with the research question, and to further refine both inclusion criteria and the draft charting table (section 2.5), twenty-five pilot articles were selected for full-text reading by reviewers CD, SO, and LC.[30] This led to clarifications of eligibility criteria, refinement of the categorization process, and the addition of new categories to the data chart. After the pilot stage, it was agreed that each source would be reviewed by one reviewer, instead of the recommended two, complemented by weekly discussions to address any uncertainty/ambiguity.[29] This was a practical decision, as the expected number of included sources after citation chaining and manual input would be high. This approach both reinforced the appropriateness of included sources and facilitated continued refinement of the data items and charting process. Of the 145 database publications read in full, 100 were assessed as suitable for final inclusion.

Citation chaining commenced on these included articles mid-2024, while manual input was ongoing. The same inclusion and exclusion criteria applied to citation-chained sources. This process yielded 111 eligible texts. Combined with manual input of 12 publications, a total of 125 non-database sources were screened, of which 30 were excluded for not meeting eligibility criteria. The final number of publications included across database search, citation chaining, and manual input was 195 (see Figure 1 Prisma flow chart).

2.5 Data charting, coding and theme identification

2.5.1 Data charting

Following Aromataris et al.,[29] the approach to data charting was primarily descriptive. Source data were classified into several categories and presented in a table or chart format (the "charting" method). The purpose of data charting is to organise information systematically, which aids in the synthesis of findings and the identification of commonalities and differences across sources. Charts were discussed between reviewers at weekly meetings, and individual charts were also accessible to each team member. These meetings facilitated a deeper understanding of how categories were defined and enabled the identification of additional items to be charted.

The categories included title, author, year published, type of publication, country, method (s) used, units of analysis, output device or platform mentioned, use cases, risks or harms discussed, and recommended strategies for risk mitigation

[d]See Table 3 for an overview of the type of sources considered and the eligibility criteria used.

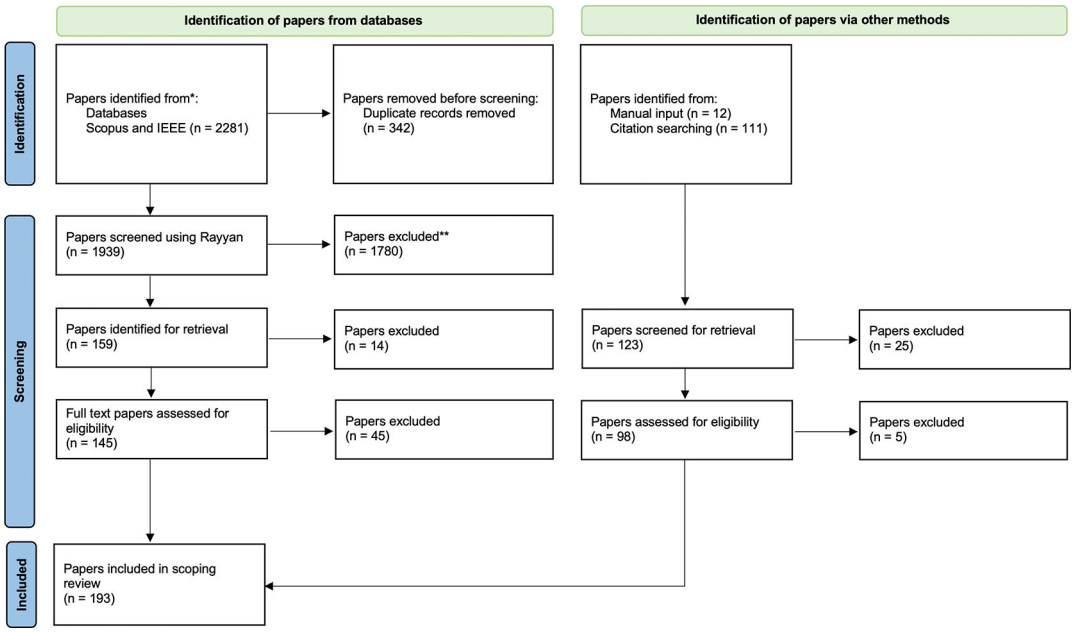

Figure 1. The PRISMA flow diagram. The PRISMA flow diagram[36] illustrating the selection process of publications, with the number of publications identified, screened, assessed for eligibility and included in the review. The search process comprised of database search, citation searching, and manual input. The final number of publications included in the scoping review was 195.

or redress for harms. "Unit of analysis" refers to the specific experience described by the authors; "use case" refers to the specific areas of application; and "device" refers to the hardware components or systems enabling the experience being analysed, as described by the source. This categorization helps to narrow down the type of experience to which the identified risks and harms were connected. (See Table 4).

2.5.2 Coding, analysis, and theme identification

In addition to data extraction and presentation through the charting method, qualitative descriptive content analysis was used as an analytic tool to synthesize findings.[37] Due to the large volume and wide range of risks and harms mapped, it was critical to present the data in a way that was understandable to the reader. Descriptive content analysis is a method that uses codes to group and classify text, allowing themes to emerge inductively.[28]

Reviewers CD, SO and LC used NVivo 14 to assign codes to the risks and harms identified within their respective sources.[31,32] Codes with conceptual or practical similarities were placed together. During pilot testing it was recognized that the way "risks" and "harms" were framed—whether from a quantitative, qualitative, or philosophical point of view—varied widely between sources. Furthermore, many sources used synonyms or related concepts instead of the explicit terms "risks" and "harms". As a result, some interpretation was necessary.[31] For conceptual clarity, expansive definitions for risks and harm were established a priori (as described in Section 1.3). If sources indicated that an unwanted event may occur, the described event was classified as a risk. If sources indicated an actual event had taken place, it was classified as a harm. In other words, harms were coded as events that have taken place, while probable, implied, or speculative occurrences were coded as a risk. Although the reviewers acknowledged conceptual slippage between risks and harms (i.e., sources might refer to a "risk of harm"), a deliberate distinction was maintained between events that had occurred and those that might occur, to support future analyses of XR vulnerabilities.

Notably, the codes were kept as close in meaning to the source as possible (31, Ch.11.2.8) For example, sources describing risk of "cybersickness" were assigned the code "cybersickness" and grouped accordingly. This process led to the emergence of several broad themes (e.g., "physical risks", under which cybersickness and other risks pertaining to physical well-being were classified). The reviewers then compared the emerging themes, reflected on the appropriateness of each code within its assigned theme, and discussed the potential establishment of new themes. Eventually, this iterative process led to the collective development of a novel typology of risks comprising six main risk themes (i.e., health and

Table 4. Data charting categories as presented in section 2.5.1.

Category	Description	
Title of publication	Extracted as written in the publication	
Author	The names of the authors in the order as written in publications	
Year of publication	As reported	
Type of publication	Journal article, book chapter, conference paper, report, pre-print	
Country	The country or countries where the authors' research institution or organization is/are located, as given in the publication	
Methods	Empirical	Experimental, quasi experimental, survey, observational, case study, mixed method
	Non-empirical	Reviews, theoretical, philosophical, commentaries/opinion pieces, book reviews, conceptual, policy, historical
Unit of analysis (Type of XR experience mentioned)	XR, AR, MR, VR, virtual worlds, virtual environments (VEs), Metaverse(s)	
Output device or platform mentioned	"Wearables" such as head-mounted displays (HMD), glasses or goggles, haptic gloves, vests and suits. Virtual environment platforms (VEs; can be desktop), mobile devices and platforms, desktop, 360 video, CAVE. If the source is about a *particular* VE platform or device, this will be specified (ex: sources analysing VE platform, Pokemon GO, etc.).	
Use cases	General application, industry/manufacturing, commerce, healthcare, education/training, entertainment, journalism, governance/law, urban planning, socializing, research	
Meets inclusion criteria (Include)	Yes	
	Reasons	
Risks noted	Risk is to be coded only when there is mention of the likelihood of harm to individual or society	
Harms noted	Harm is to be coded if there are explicit examples of harm that occurred during exposure to/with use of XR, and if there was an explicitly stated harm	
Mitigations measures/ recommendations	Measures proposed by authors on how to address various risks or harms noted in the publications	

wellbeing; autonomy; epistemic and scientific; normative; structural; technical safety and security) and 19 sub-themes (described further in Section 3).

3. Findings

The following sections present the mapped data, which will form the basis for the subsequent discussion. This includes an overview of the characteristics of the source material (as charted), as well as a report addressing the primary research question: "what are the risks and harms of XR technologies?"

3.1 Source characteristics

3.1.1 Characteristics of publications

The findings of this review were extracted from the 195 included publications, with date range from 2000–2024. Most sources were published between 2016 and 2022. Since the database search covered publications from 2000 through January 2023, and only manually selected publications were added for 2023 and 2024, Figure 2 reflects only the period from 2000 to 2022. The manually inputted sources for 2023 and 2024 are excluded from the figure, as they do not represent a comprehensive output for those years. The types of sources included were journal articles, book chapters, conference papers, pre-prints, and reports.

3.1.2 Geographic distribution of authors

The included sources represented a broad geographic range of authors (see Figure 3). Note that the number of countries listed surpass the number of sources due to multi-authored publications with affiliations across multiple countries. Most

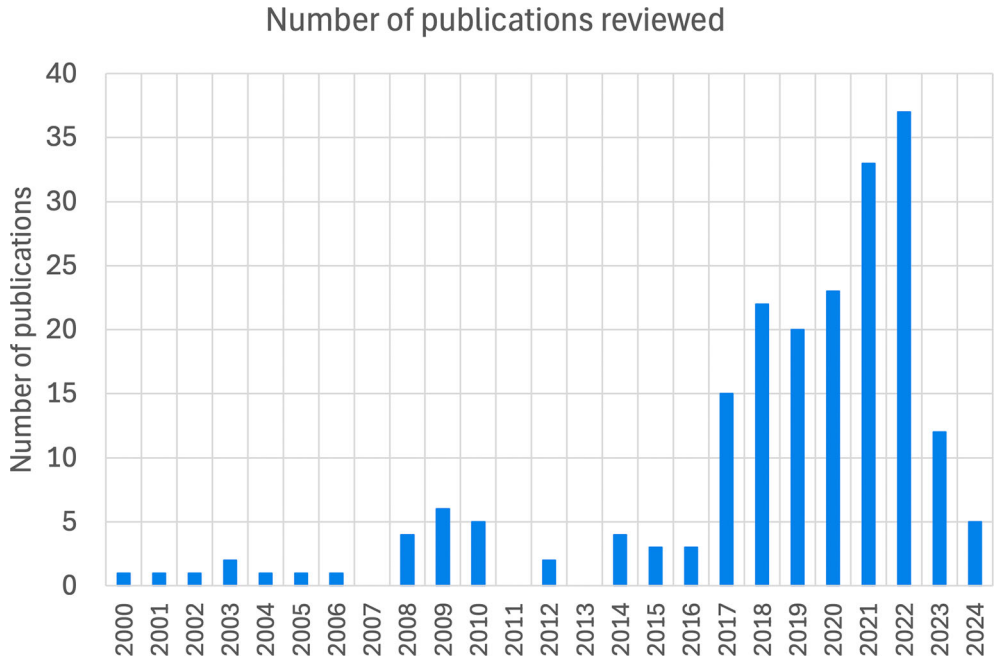

Figure 2. Number of publications from year 2000 to 2022 included in the review. Since database search was performed in January 2023, the number of publications from year 2023 (n = 12) and 2024 (n = 5) were not included in the bar chart.

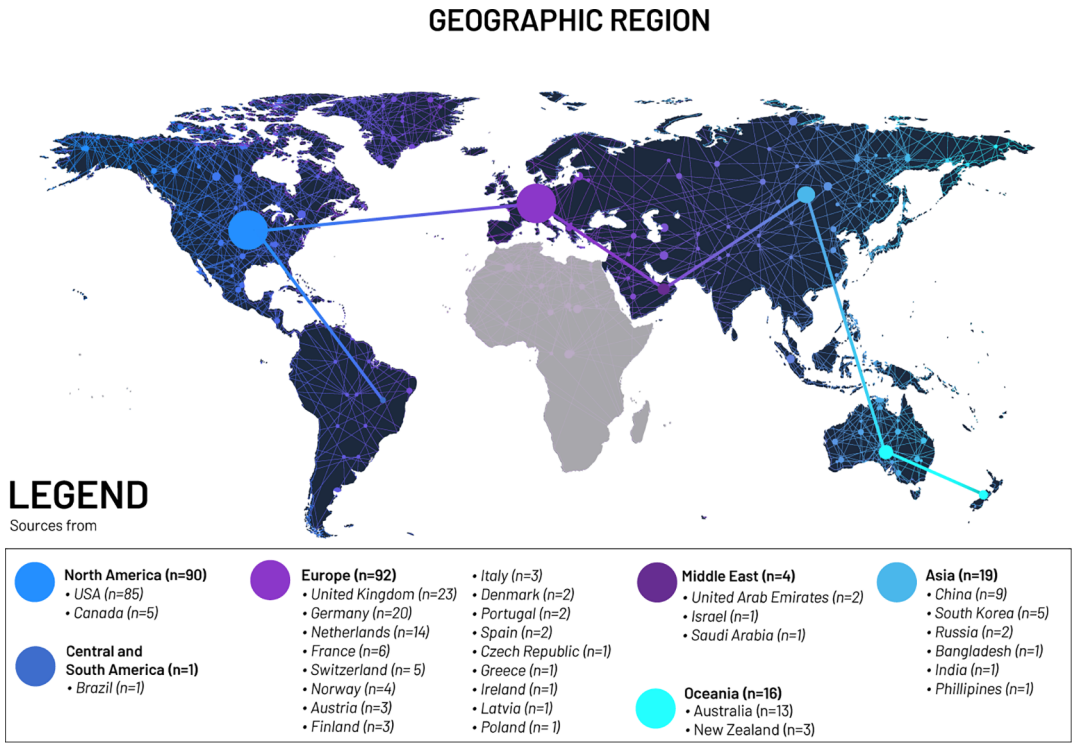

Figure 3. Geographic distribution of source authors. Note that the number of countries listed (n = 222) exceeds the number of publications reviewed (n = 195) due to multi-authored publications with affiliations from multiple countries.

authors originated from North America, largely the United States (n = 90). European contributions comprised 92 publications, with the majority from UK (n = 24) and Germany (n = 20). Nineteen sources were from Asia and 16 from Oceania (Australia and New Zealand). A smaller number of sources originated from the Middle East (n = 4) and South and Central America (n = 1). No sources were identified from African or Caribbean countries, although it is possible that some were filtered out due to English-language restrictions or excluded source types.

3.1.3 Distribution of use cases

The included sources reflected a variety of use cases, i.e., the domain to which the XRTs were applied (Figure 4 and Table 5, the latter specifying references). The majority of sources focused on general use or application (n = 94). Other

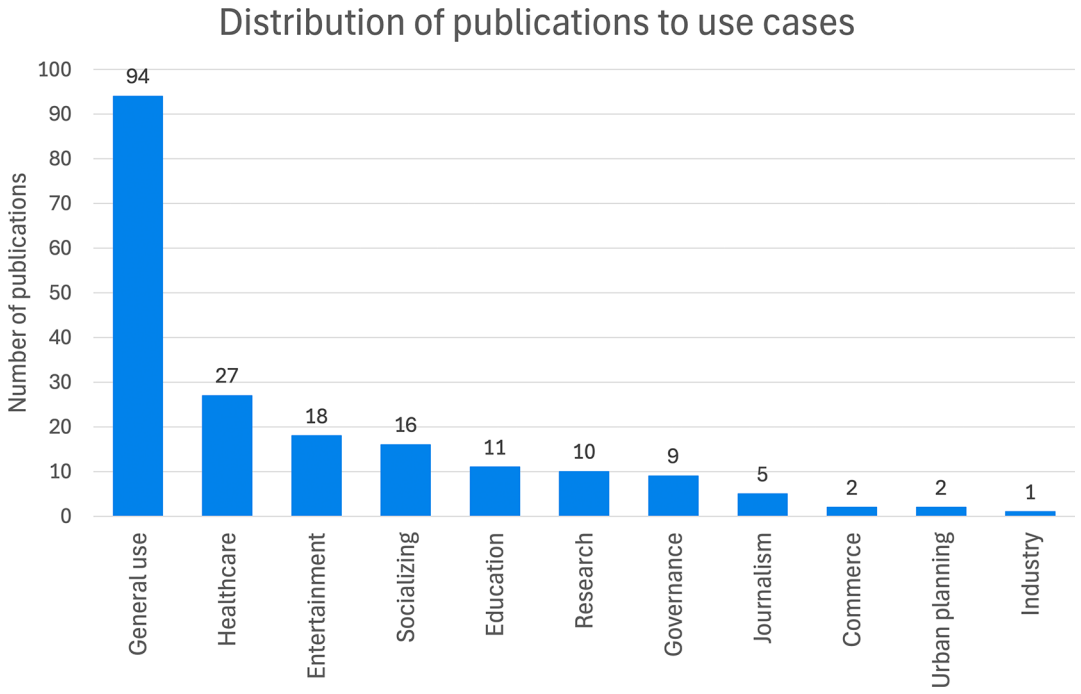

Figure 4. Distribution of all included publications (n = 195) to use cases; the specific areas of application as presented in the literature.

Table 5. Use cases, number of publications, and corresponding references.

Use cases	Number of publications	References
General use	94	1–3,23,24,38–126
Healthcare	27	127–153
Entertainment (gaming)	18	154–171
Socializing	16	172–187
Education/training	11	188–198
Research	10	199–208
Governance, law/legal	9	209–217
Journalism	5	218–222
Commerce	2	20,223
Urban planning	2	224,225
Industry e.g., manufacturing, logistics	1	226

publications focused on healthcare (n = 27), entertainment (n = 18), socializing (n = 16), education (n = 11), research (n = 10), governance (n = 9), and journalism (n = 5). The use cases least represented were industry, commerce, and urban planning.

3.1.4 Distribution of units of analysis

In terms of charted unit of analyses (Figure 5), 84 publications pertained to VR only, 46 to virtual worlds, metaverses or virtual environments, and 29 to AR. An additional 18 publications focused on XR or immersive technologies more generally. MR was relatively underrepresented, with only 6 publications identified.

We observed conceptual differences in how terms such as VR, "virtual environments", "virtual worlds" and the "Metaverse" were utilized between 2000–2024. Changes were also noted in the types of output devices and platforms discussed over time. Publications from earlier years (2000–2012) discussed virtual environments or virtual worlds, with particular attention to desktop platforms such as Second Life, Habbo, LambdaMOO, among others, as well as to avatars.[104,114,117,170,175,176,209,215,217] These platforms were variably described as virtual environments, virtual worlds, or "metaverses," and in some cases, also classified as VR technologies.[23,104,117,132,170,208] More recently, there has been an uptick in references to virtual environments under the terminology of the Metaverse (see discussion section for more).[60,102,107,128,194,211,212] After 2012, the focus shifted towards various output devices, particularly wearables such as head mounted displays (HMDs).[101,181,182]

There were inconsistencies regarding the meaning of or how VR was understood over time. We note a shift where the authors start to consider "immersion" (quantitatively understood) as a critical component of VR. Therefore, while many sources identified HMDs as primary facilitators of VR and bracketed desktop platforms as non-VR. However, some recent sources still referenced desktop platforms as examples of VR.[111,148,184] These sources use rather broad definitions, such as describing VR as a "close to perfect simulation of the real-world including representations of oneself and other persons," where the most convincing simulations are "fully immersive".[148,p.574] In this interpretation, desktop simulations would be a less convincing type of virtual reality, but nevertheless VR. Notably, many publications did not define their unit of analysis.[101,152,183,195,207]

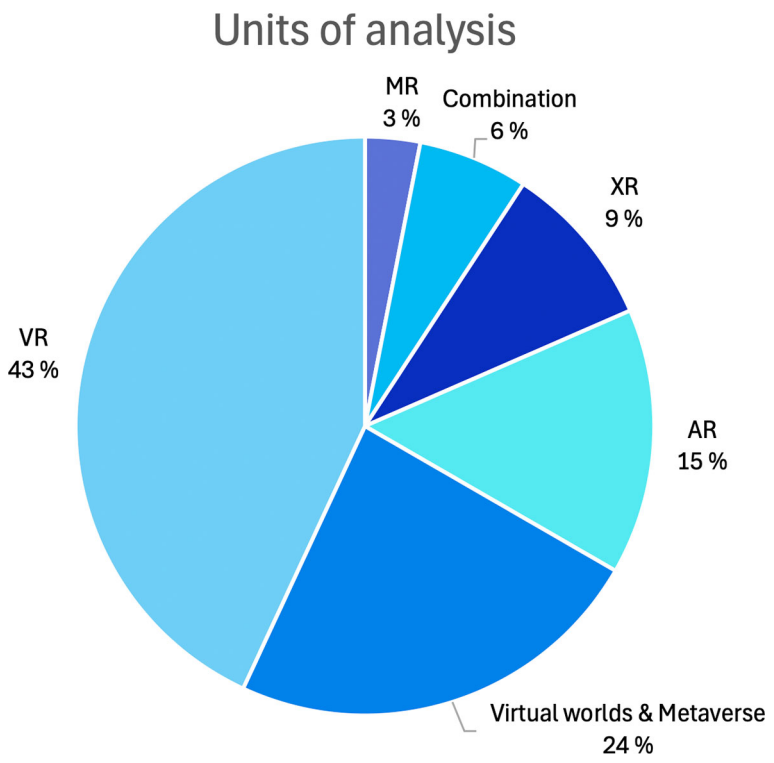

Figure 5. Distribution of units of analysis with number of publications in parentheses. Publications with more than one unit of analysis (e.g., AR and MR) are categorized as "Combination".

Additionally, there were inconsistencies in how the terms Metaverse, virtual worlds, and virtual environments were used, with some sources referring to them interchangeably.[153] "Virtual environments" were often defined through their immersive aspects, e.g., a virtual environment is an "immersive, interactive, multi-sensory, viewer-centered, three-dimensional computer-generated environment" (Cruz-Neira in[1,p.9]). How "immersive" was interpreted, and whether this definition would limit virtual environments to devices offering quantitatively immersive experiences (like HMDs), remained unclear. Another definition framed virtual environments more broadly describing them as attempts "to create a replica of an object of experience in a way for a human to understand".[126,p.550]

AR applications in the form of wearables (e.g., glasses or goggles), as well as mobile devices and their associated platforms, were the third most discussed unit of analysis. Of note, the mobile platform Pokemon GO was the AR application with the highest number of mentions in the literature.[2,108,154,158,160,164,171] While HMDs are frequently associated with VR, recent discussions increasingly address AR and MR applications that utilize passthrough technology.[53,78,89,98]

Finally, disciplinary scope and aims should be mentioned. The sources come from a wide range of disciplines, and similarly purport a variety of aims. These sources went about achieving their aims through various methods, from offering a critical discussion, to philosophical argumentation, to mixed methods and proof of concepts/experimental work. Discussions and evidence of risks and harms are not siloed to a narrow disciplinary or methodological tradition. Though these findings are not summarized in an accompanying table, they are available in the reviewers' data charts.

3.2 Typology of risks and corresponding harms

The main purpose of this review was to map risks and harms of XR. The process of coding and subsequent iterative classification of codes allowed for reviewers CD, SO, and LC to develop a typology of risks. What emerged after this process included six major themes and 19 sub-themes: 1) health and wellbeing (cognitive, psycho-emotional, socio-relational and physical), 2) autonomy (privacy, self-sovereignty, surveillance, authenticity), 3) epistemic and scientific (epistemic uncertainty, scientific uncertainty, algorithmic imperfection, manipulation), 4) normative (norm violations, rights violations), 5) structural (socio-political, economic/financial, legal), and 6) technical safety and security (security, dual use).

Developing a typology was a practical approach for presenting a large dataset with large variation in *types* of risks and harms.[227] Some themes were inherently more concrete (like health & well-being risks), while others more abstract (autonomy risks, normative risks, epistemic risks). (See Figure 6) Additionally, the codes are not mutually exclusive and may overlap between thematic categories. The typology should therefore operate mainly as a revisable, heuristic mapping for risks. A substantial number of codes were associated with each risk and harm category and are listed in tables 6–11 alongside the thematic elaborations.

The following section is a reporting of the risks and harms based on the typology. Note that written sections will not present all the codes, but rather the codes that the reviewers had in common or were frequently discussed. Later discussion will then reflect upon and use evidence to contextualize both the charted findings as well as the findings classified within the typology.

3.2.1 Health and well-being risks

Risks to health and well-being encompass "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity".[228]

3.2.1.1 Cognitive

Cognitive impacts are those to the brain's conscious activity: to think, understand, learn, remember, and make decisions about, among other things. Here, the affordances of XR – particularly immersive VR – offered several unique risks. Immersive VR can convincingly simulate new environments, leading users to experience sensations similar to those outside VR and may potentially even influence their behaviour.[126] These behavioural changes can be limited to the virtual environment itself, where the participant takes on associated behavioural traits of their avatar representation ("proteus effect"), or may extend virtual activities into extra-virtual spaces.[1,109,123,148]

The combination of immersion and presence (a user feeling like they are in a virtual environment) can contribute to the unique difficulty of separating virtual and physical "realities".[73,78,126,132,194,210] This is not only a problem for immersive XR; AR may also cause confusion, as digitally over-laid information could be mistaken for real-world/physical information.[122] This may mean that some persons may confuse the two realities (virtual and non-digital realities), or

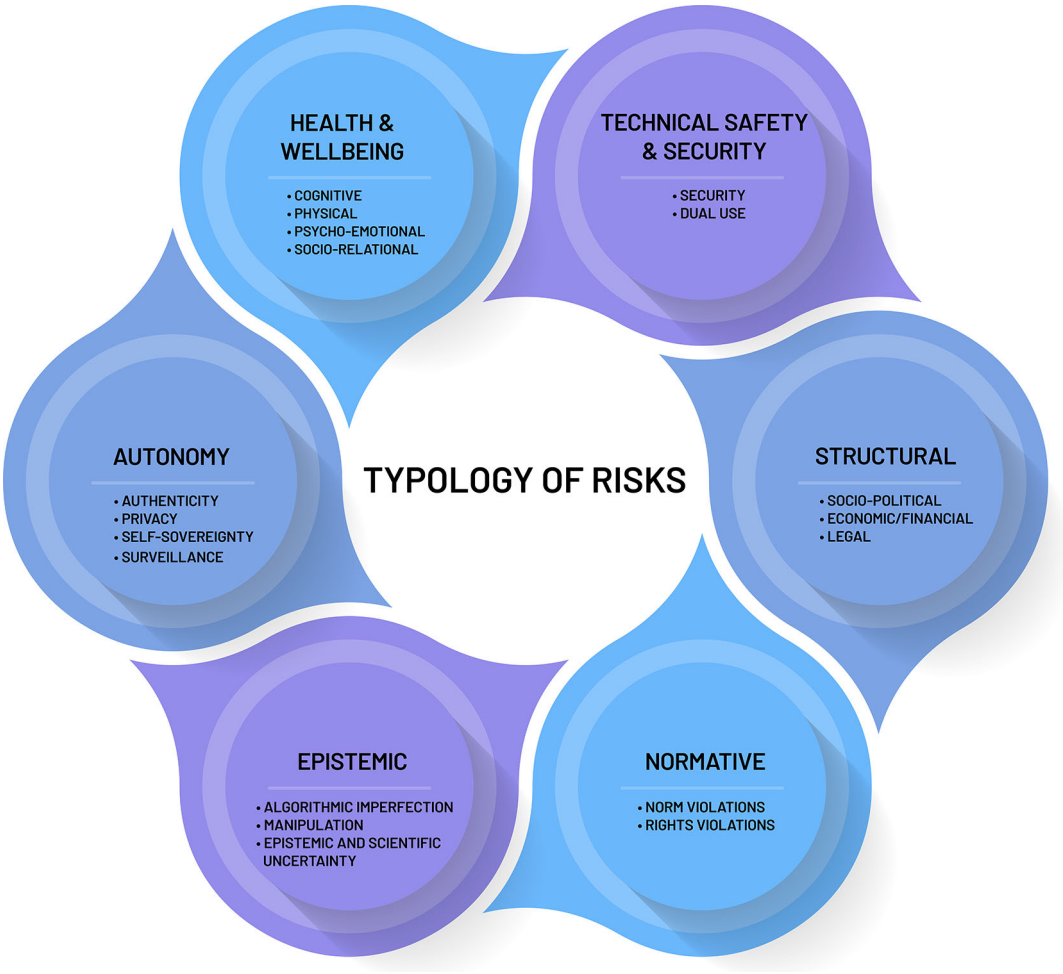

Figure 6. Risk typology. Risk typology developed by the reviewers from the iterative classification of codes for risk and harm. The typology includes six major themes and 19 sub-themes. See further details in Section 3.2.

even obtain false memories from a VR experience, a problem especially for children who are not as capable as adults in distinguishing between imaginary and real.[3,24,144,207]

In addition to its immersive and presence-inducing properties, XR offers a sense of embodiment, where the user perceives their virtual body as their own.[146] This phenomenon can affect/distort users' perception of 3D space (impeding or inhibiting spatial understandings), and their physical bodies.[116] Reported effects include changes in body image, self-objectification, issues in how persons remember their body, as well as perception that the virtual body is "more real" than the biological body, potentially contributing to various disordered behaviours and emotional difficulties.[98,116,145]

Related to how persons may understand virtual environments is how they interpret virtual entities, avatars, or objects. Users may anthropomorphize, or add human characteristics, to virtual entities, which can lead to interacting with an avatar as if it were "capable of empathy, individual perspective, and rationality. As a result, they may place undue confidence, trust or expectations in these agents".[1,p.37]

Several authors noted the addictive potential of XR: the more immersive the artifact, the more potentially addictive.[1,107,144,145,186,208,221] Although the exact mechanisms are debated, many posit that a strong sense of presence, coupled with compelling virtual experiences, contributes to addictive behaviors.[1,181,196] The virtual environments themselves can be voluminous and complex to the point of overwhelming users' ability to process, resulting in information overload.[116,207] Sources also describe XR as capable of reducing cognitive performance, including poor decision making within intra-virtual task assignments, reduced concentration, and difficulties with attention.[107,116,122,146,168,197]

Table 6. Health and well-being risks.

HEALTH & WELLBEING RISKS			
COGNITIVE	**PSYCHO-EMOTIONAL**	**SOCIO-RELATIONAL**	**PHYSICAL**
Addiction Anthropomorphizing virtual objects Avatar proteus effect Creation of false memories Difficulty concentrating Difficulty distinguishing real and virtual realities Embodiment illusion and body memory Incongruent perception/ understanding of self to 3D space and physical surroundings Information overload Manipulation Negative effect on child cognitive development Negative effects on users with pre-existing cognitive conditions Perceptual changes and unconscious influence on cognition leading to: • real life immoral actions • real world behaviour transfer from virtual • dangerous behaviour Poor decision making from visual fatigue Problems with attention Lack of awareness over surroundings Reduced cognitive performance Unknown cognitive effects from general or long-term use to wider population and vulnerable groups	Agential uncertainty Aggression Anxiety Attachment to avatar/ virtual beings Body dysmorphia Brainwashing Deception Depersonalisation and derealisation Desensitization & decreased empathy Exacerbation of pre-existing conditions Detachment and Escapism Exposure trauma Intensification of experience Nudging Violent propensity Reduced inhibitions Re-traumatisation Self-consciousness Self-objectification Technostress Withdrawal symptoms Unknown psycho-emotional effects from general or long-term use to wider population and vulnerable groups	Abuse of power Assault Bystander haptic proxy Controlling vulnerable persons Defamation Harassment False attribution towards specific groups based on XR experience Impersonation of others Impoverished inter-personal relationships Griefing Groping Manipulative advertising Radicalization and extremist recruitment Remote work gender disparities Reputational damage Self-censorship Social engineering Social isolation or asocial Social exclusion Socially unacceptable use of device Stalking Surveillance & Sousveillance Threat misidentification Third party avatar modification Trolling Virtual graffiti Work-life imbalance Unknown socio-relational effects to wider population and vulnerable groups from general or long-term use	Auditory occlusion Cybersickness and discomfort Dizziness and postural instability Ergonomic issues Fatigue Strain Headache Infections - (microorganisms) Increased reaction time Falls, injuries, life threatening situations & death for user and bystander. Manipulated and limitations of movements Nausea Neglect of well being Obesity Seizures Sensorimotor after-effects Unspecified adverse effects on minority users Sweating Visual disturbances and asthenopia Unknown physical effects from general or long-term use to wider population and vulnerable groups

3.2.1.2 Psycho-emotional

Psycho-emotional risks pertain to psychological and/or emotional states. XR's capacity to construct immersive environments raises concerns about triggering or intensifying emotional states such as anger (aggression) and anxiety, as well as dissociative conditions like depersonalization and derealization.[1,3,144,223] Related to this is a feeling of agential uncertainty, i.e., "the risks of no longer perceiving oneself as the author of one's own action".[148,p.579]

XR use may also contribute to desensitization, reduced empathy,[24,112] and trauma-like responses to offensive, immoral or violent virtual experiences.[100,107,140,148,151,196,206,219] XR's highly realistic graphic and haptic capabilities may make violations of personal space feel more distressing.[196] Some authors argue that this heightened realism could facilitate aggression in real life or serve as a space for radicalisation and violence.[102,181] This realism may also facilitate a preference for virtual experiences over extra-virtual ones, which may lead to escapism.[107,116,208]

Table 7. **Autonomy risks.**

AUTONOMY RISKS			
PRIVACY	**SELF-SOVEREIGNTY**	**SURVEILLANCE**	**AUTHENTICITY**
Biometric psychography Breach of privacy • Associational • Informational • Physical De-anonymising data of user/bystander Location registration Lack of or limited awareness of privacy risks Third party identification of user/bystander Traceability of avatars Tracking of user/bystander Unintentional sharing of sensitive (intimate) data Violation of the principle of purpose limitation Unspecified AI influenced novel privacy threats Unknown privacy threats	Confusing choice architecture Compromised consent Inability to opt-out Lack of or limited control of virtual environment Lack of transparency Manipulation of persons to act as robots Misuse of data Problems with data control Poor comprehension of terms of use and privacy agreements Over-trust	Enhanced data capture Sousveillance (Inter-Citizen) Surveillance (Government/ Workplace) Live mapping World scraping	Conformism and homogeneity Instrumentalization of user and bystander for data Inauthenticity of avatar or user Reduced authenticity

Table 8. **Epistemic risks.**

EPISTEMIC RISKS			
EPISTEMIC UNCERTAINTY	**SCIENTIFIC UNCERTAINTY**	**ALGORITHMIC IMPERFECTION**	**MANIPULATION**
Avatar Identity Biased immersive Journalism Difficulty distinguishing between real and simulation Superrealism Inherent uncertainty Immersive experiences become beliefs	Diminished objectivity Difficulty to test all aspects of technology Questionable ecological validity Questionable empirical evidence Lack of or limited assessment tools for usability of device Lack of or limited research on long-term cognitive and psychological impact Overstating benefits Clinical and research issues: • Contraindication to participate in XR • Consent issues • Hasty use • Paternalism • Therapeutic misconception • Unsafe application of XR in treatment • Lack of training • Lack of established standards for medical or research	Algorithmic bias Algorithmic miscategorization Facial recognition incongruency Misuse of augmented intelligence	Cyberbalkanization Dark patterns Deepfakes Digital deception Fake news Filter bubbles Gatekeeping Fabricated visual or auditory information Malevolent creativity Misinformation and disinformation Misleading or manipulative design Paranoviruses

3.2.1.3 Socio-relational

Socio-relational risks affect interpersonal relationships, group dynamics, and/or family bonds. Following psycho-emotional impacts, escapism may also negatively affect real-world relationships.[116] Time spent with the technology may serve to isolate and disconnect users from families and friends, a reduction in physical or social contact, and difficulty

Table 9. Normative risks.

NORMATIVE RISKS	
NORM VIOLATIONS (Moral & Conventional)	**RIGHTS VIOLATIONS**
Crossing respected legal, social, cultural and ethical boundaries Changing beauty norms to align with avatars Dignity violations Deepfakes of the dead Exposure to immoral or offensive content Encouraging immorality and unethical behaviour Legitimation of immersive technology as weapon of war Loss of cultural diversity Moral damage Private spaces become non-existent Reversal of the relationship between man and technology Shift in values Surveillance as new normal Inappropriate behaviour due to unclear norms in virtual environment Unknown norm violations from general or long-term use to wider population and vulnerable groups	Accessibility issues Discriminatory or un-inclusive design Expansion of digital divide Gatekeeping Stigmatisation Marginalisation Replication of real-world inequities in virtual environments Exposing people to simulated acts without their consent

Table 10. Structural risks.

STRUCTURAL		
SOCIO-POLITICAL	**ECONOMIC/FINANCIAL**	**LEGAL**
Algorithmisation Authoritarianism Creation of panopticon "Data violence" Datafication Democratic decay Limited potential for socio-political solutions to risks Perpetuation of biases or power-structures Perpetuation of colonising ideals Privatization of social and political thought Social control Surveillance capitalism	Attention economy Creation of market monopoly Difficulty managing virtual assets Gambling Gentrification Higher cost of living Increased cost of healthcare Unemployment Harvesting in game currency eg gold farming Replacement costs for personal glasses	Copyright violations Defamation of character Exploitation of legal rights Fraud and scams Geolocating user to target for crime Identity theft Intellectual property theft Lack of governance/regulations Potential violations of data protection law Pyramid and ponzi schemes Taking advantage of lawless VR Trespassing in real life for game purposes Unclear legal responsibility Unconventional uses of VR as evidence in court Unregulated banking and gambling Unspecified breaking of law

forming relationships.[113,115] Further, social interactions within XR can be fraught with harmful behaviours, including harassment and assault in the form of defamation, griefing, groping, modifying user avatars, stalking, trolling, and virtual graffiti.[78,178,183,185,196,214,216,221] These environments may also serve as conduits for control or exclusion, where users feel the need to conform or self-sensor in order to fit in.[115] In addition to personal relationships, professional relationships may also be impacted. XR has the potential to increase remote work, which may lead to heightened workplace surveillance, as well as difficulties balancing between work and life.[1]

3.2.1.4 Physical

Physical risks associated with XR design or use have been noted by several sources. A primary risk is that of cybersickness, sometimes called simulation sickness, characterized by negative symptomatology including, but not limited to: "nausea, vomiting, eyestrain, disorientation, ataxia, and vertigo".[208,p.1044–46,50,52,54,55,59,127,129,130,169,200]; HMD users face additional issues with reduced user stability, where balance and orientation may be affected.[54,197]

Table 11. Technical safety and security risks.

TECHNICAL SAFETY AND SECURITY	
SECURITY	**DUAL USE**
Attacks - Chaperone attack - Data scraping bot - Disorientation attack - Hack controls app in real time - Hacking - Human joystick attack - Implanting virtual eavesdropping - Keystroke inference attack - Overlay attack - Shoulder surfing - System becomes owned by attacker - Using sensors to extract information from user Exploits - Malicious apps altering digital object - Malware Negligence - Breaches via 3rd party apps - Data leaks - Difficulty authenticating information - Shared security problems between software or hardware Unspecified security threats Unknown security vulnerabilities	Empathy increaser to empathy decreaser Illicit applications Unspecified harms due to dual use

Use of these devices also have impacts on the visual system, from discomfort, blurred vision, and eye strain (asthenopia), to worsening of stereoacuity and other oculomotor effects.[52,59,191] Some of the adverse effects may be a consequence of the vergence-accommodation conflict, an unnatural disruption between vergence and accommodation that occur in a typical stereoscopic HMD.[52,54,124] HMDs that are not properly aligned in front of the eyes may also lead to perceptual distortions and worsening of the discomfort.[59] Uncomfortable and poor fit of the headset is more common in those with smaller head size and shorter interpupillary distances, such as in females and children (see section 3.3. for more on this).[59,191] Correct vision prescription is important for comfortable use,[124,198] although not all headsets allow users to wear glasses underneath.[43,124] Moreover, individuals lacking stereovision (~30% of the population) may have significantly diminished VR experience.[124,150]

Ergonomic issues associated with XR use include fatigue due to hardware weight, strain from requiring more head movement, and movement limitations.[122,197] The possibility of injury is frequently mentioned across units of analysis and output devices. These injuries may be minor but at times be life-threatening or even result in death.[166] Injuries may arise due to several issues: from hardware or game design to malfunction and manipulation.[53,171] When it comes to HMDs, visual and auditory occlusion may lead to self-injury or collisions with bystanders or objects.[219] HMDs also have a small field of view that contributes to inhibited spatial understanding, compromising a user's ability to navigate spaces safely.[98]

Game design in AR, particularly with mobile AR games like Pokémon GO, are frequently cited as facilitators of "distraction"-related injuries, including accidental death when a user pays closer attention to the AR display than their physical environment.[142,158,159,167,171,196] It has also been reported that AR-playing individuals have been killed for trespassing.[196] Some other effects include headache, auditory occlusion, seizures and infections secondary to sharing devices.[73,136,208,226] Finally, authors write about how the cognitive, psycho and socio-appeal of virtual environments may lead some individuals to neglect their real-world needs, preferring virtual engagement over bodily self-care.[116]

3.2.2 Autonomy Risks

This category addresses risks related to the ability to "govern oneself, to be directed by considerations, desires, conditions, and characteristics that are not simply imposed externally… but are part of what can somehow be considered one's authentic self".[229,p.1] This definition was selected for its broad scope and is reflective of issues identified by authors, which have been grouped into the following sub-themes: risks to privacy, to self-sovereignty, risk of surveillance, and risks to authenticity.

3.2.2.1 Privacy

Privacy is both a state and a protective mechanism, creating a space in which people may "direct their lives as they see fit irrespective of social and political pressures".[230,p.118] Privacy was one of the most frequently cited concerns, across all units of analysis, devices and platforms.[39,53,62,68,72,73,76–78,80,84,86,88,91,194,211,212,218] Privacy discussions centre around data – how it is ascertained, aggregated, analysed, shared, controlled, and what that means for the average user. XR is changing and expanding in terms of data collection possibilities, alongside acquiring "greater contextual awareness" through the analysis of bystander and environmental data.[193,p.4] This means that XR is growing better equipped to make predictions about personal location habits (where a user goes, when, and how often).[193]

Mobile AR platforms and devices, despite not collecting unconscious biometric data like gait or eye tracking, nevertheless pose significant issues when it comes to environmental or spatial data and are prevalent as geolocating and potential recording devices. Privacy, therefore, is a significant problem for AR, where Global Positioning systems are heavily relied upon, as well as user information.[167]

Moreover, the discussions point to a uniqueness of XR technologies, particularly immersive XR, in exacerbating the privacy issues already present with other forms of technology. Some consider digital technologies to be inherently privacy-reducing, especially in the linking of social networks and VR where data capture and interpretation will take on novel dimensions.[181,p.6] Indeed, enhanced data capture is a notable feature of XR technologies.[1,2,62,108,111,115,181]

XR makes it easier to classify and track both users and bystanders, whereby bystanders cannot necessarily consent or opt out.[108,109,111] The ease with which users and bystanders can be de-anonymized due to highly capable environmental sensors and efficient machine learning is also a concern.[100,111,142] Additionally, some authors discuss how users may lack an understanding of these risks, not fully comprehending the privacy and terms of use agreements offered by companies.[2,62] These threats are further complicated by the increasing incorporation of artificial intelligence (AI), which, combined with sensor data, may lead to hitherto unknown privacy threats.[61,96] Authors describe violations of informational, associational, emotional, and physical privacy.[108,215] XR can more easily reveal who one associates with, user's emotional or affectional states, as well as where they are.[58,181] It may do this through unexpected or novel means such as through reflections on a user's pupil which indicate their location.[121]

3.2.2.2 Self-Sovereignty

Self-sovereignty can be understood as the ability to govern oneself, and one's information, deciding upon and pursuing a self-selected course of action without interference. XR has unique implications on user's ability to self-govern. Data, again, is a critically discussed issue.[100,111,170,223] Not only does XR have access to intimate data; it can also share that data with third parties.[186] This results in increased vulnerability of data: greater quantities of it are collected, it can be easily de-anonymized, and it can then be shared and analyzed.[122,181] Importantly, many users are unaware of what has been shared, have little control over what is shared, and have no way to retrieve or change this data.[1,109,195] This data may be available for others for the entirety of one's lifetime.[94]

Then, there is the risk of data inaccuracies and misuse.[62,100] XR, supported by AI, can infer personal and intimate user characteristics and protected traits (e.g., sexual preference, gender identity, religion or belief, national origin, etc.) based on information extracted without the user's knowledge or consent.[111] This type of data analysis is referred to as "biometric psychography", wherein XR is able to gain a "sophisticated, longitudinal understanding" of a person by tracking not only their behaviour but also their mental and affective states (e.g., happiness, sadness, anger, fear, arousal, frustration, etc.) and cognitive processes (e.g., attention, memory encoding and retrieval, decision-making, problem-solving, perception, reasoning).[111,p.11] Authors note that this inference-making capability is not always accurate, but can nevertheless be used to potentially discriminate against the user, or for targeted marketing efforts.[109,115] It can also be used to alter behaviour in a way that benefits a company or brand.[2,p.289]

Self-sovereignty, as discussed by authors, is related to control. "VR," writes Marloth et al.[148] is "understood as artificially created and completely controllable". It is difficult to determine who, exactly, is in control within a virtual environment setting – the user, the developer/designer, or the technology itself. Some authors, like Marloth et al., imply that there is an inherent lack of control in artificially created spaces where the user has fundamental design input.[145] The Metaverse is also discussed in terms of control, where it is pointed out that though users have an expectation of being exposed to other actors (i.e., lack total control), there are nevertheless social and interpersonal expectations within worlds about issues like anonymity, personal reputation, and who can watch and when.[215,p.96]

3.2.2.3 Surveillance

To be surveilled is to be monitored or observed.[231] While some forms of surveillance enhance (e.g., public health surveillance), sometimes to be surveilled serves to reduce autonomy (and other rights).[231] Surveillance is closely related to the topics discussed above – privacy and self-sovereignty. Multiple sources refer to XR as a vehicle for surveillance, across units of analyses, devices, and platforms.[62,66,67,71,108,218] Surveillance is discussed as an inherent aspect/feature of virtual environments/Metaverse.[224,p.5]

AR-related literature discusses issues concerning persistent and pervasive devices and platforms.[122] Pervasive AR is described as "always on" and a "disappearing interface," which makes issues of private use but also workplace use problematic.[122,p.87] Increased workplace surveillance is cited as a risk of XR technology in general, made possible by the unique affordances of immersive wearables such as HMDs. Employers can potentially monitor employees through biometric sensors, and make potentially unsound conclusions about focus and procrastination.[1,p.41] It is not only the workplace that is monitored. Some authors proffered XR as instrumental in enabling government surveillance, often referred to as "Big Brother." They suggest that criminal investigators may use XR to identify individuals at a protest, or may obtain a journalist's 360 video.[221,p.340] In addition to government surveillance, the risk of citizen-driven surveillance —referred to as "Little Brother" or "sousveillance"—is also discussed, both in the real world and in virtual environments or the Metaverse.[103,115,215,221] Wearables, especially AR smart glasses, are considered efficient tools for tracking and spying on persons without their knowledge.[115,p.130]

3.2.2.4 Authenticity

Authenticity concerns what it means to be oneself, to act oneself, or to be "expressive of one's own self-identity".[232,p.1] Authors raise the question of whether an avatar is, in fact, an autonomous agent acting of their own authentic desires, or whether the controlled and constructed nature of virtual environments prevent authenticity.[115,187] Maslen and Salvulescu note:

> immersive technology might render the actions of the virtual agent inauthentic or, at least, not continuous with those of the 'real life' agent. The concern is not that the agent herself becomes inauthentic, but rather that her activities in the virtual environment are not her own thus, the question is not so much whether the use of immersive technologies renders the self inauthentic but, rather, whether one can be authentically oneself in virtual environments. If I visit you as my robot avatar, have you really met me, and are the actions I take mine? (,[187] p.4).

Other sources discuss a reduction in authenticity in terms of a pressure to conform under constant monitorization (authenticity as relational to issues of surveillance and self-sovereignty).[144,181] Conformism in the Metaverse is talked about as a flattening of the individual in favour of a collective or group identity.[224,p.4] Other analyses posit that VR can reinforce certain social interactions in a way that may lead to homogenisation.[1]

3.2.3 Epistemic Risks

Epistemic risks concern how knowledge or beliefs are formed,[233] and in this case, how XR informs the actions, choices and judgements of users, as well as how these choices affect scientific or research practices This theme is divided into: epistemic and scientific uncertainty, algorithmic imperfection, and manipulation.

3.2.3.1 Epistemic uncertainty

Some authors claim that immersive XR is inherently epistemically uncertain.[116] This is because virtual environments are generated, and these generated environments then interact with a user's senses in various ways. Inhabiting a virtual environment, therefore, is inherently risky when it comes to knowing what is real/true. One author notes that the visual experience of a person is generally assumed to correspond with "ground truth" or an objective physical reality. However, XR is inherently unstable, where generated data can be controlled, rearranged and manipulated such that the sensory experiences of users are altered.[116,145,148]

Within XR, the issue of what is true and how it may be known is also one that relates to distinguishing between real and simulation – a problem first discussed under Health and Wellbeing risks. Authors not only consider this as a cognitive and psychological problem, but also a risk relevant to knowledge acquisition, belief, and truth. This is not only an issue for VR, but AR and MR, where illusions generated by a computer may transform into a belief.[122,p.88] Pervasive AR, further, aims to further blur the boundary between the "real" from the "virtual." Authors warn that, as

a result, "perceptual artifacts" may become increasingly capable of shaping individuals' attitudes, beliefs and knowledge.[1,122]

There are also risks related to avatar identity and potential user harms. It can be difficult to determine whether a user's virtual identity coheres with their real-world identity. There is no guarantee that someone online is who they claim to be,[102–104,216] nor can it be guaranteed that a user is interacting with a real individual or a bot.[102,103] This may have several consequences in terms of eroding trust.[102]

3.2.3.2 Scientific Uncertainty

Several authors discuss the relationship between XR and science. These discussions revolve around two main points: authors who question the evidence supporting XR as a therapeutic, educational, or training tool, and authors questioning the epistemic validity of experiments using XR, i.e., that an experiment is actually measuring what it claims to measure.[197,204,205] First, while there is much research taking place on the effects of XR, there is still a lack of knowledge within certain domains and subject areas, particularly regarding the physiological, ethical and social dimensions, as well as the psychological impacts on special populations or vulnerable groups.[24,41,142,201] As such, there is a risk of overstating the possibilities and benefits of XR technologies.[24,188] Regarding scientific validity – specifically how generalisable experimental findings can be – studies may not be adequately accounting for gender differences.[204] Additionally, some authors question how field of view impacts results[197] and whether "virtual" experiences can adequately inform us about "material" (i.e., non-virtual) experiences at all.[1,p.35] Authors also caution that XR could be used with clinical populations without sufficient training or might be applied without the participant fully understanding associated risks.[152] Finally, there is a risk of engendering the participant or patient with a sense of false hope at the possibilities afforded by XR.[142,143,148]

3.2.3.3 Algorithmic Imperfection

XR technologies are reliant on data to function. Collecting, processing, and transmitting this data is, in turn, dependent on algorithms and other automated systems (e.g., machine learning).[234] Algorithms, however, can be "black boxes" whose inner processes can be unknown even to those developing them, and whose results may be flawed.[111] In XR, where user data may include environmental or biometric information, algorithmic errors can have serious implications: an incorrect inference — for example, falsely identifying a user as having a mental illness — can affect how users are represented, treated, and even how they perceive themselves, thereby impacting personal identity.[111,195]

Authors further question the training datasets for XR technologies and XR learning analytics, as well as the predictive power of such analytics, often trained on male, white, neurotypical and able-bodied engineers.[195] In other words, these algorithms are subject to bias.[111,195]

3.2.3.4 Manipulation

Knowledge manipulation or the manipulation of virtual environments includes the "usual suspects" of internet manipulation: misinformation and disinformation, fake news, deepfakes, filter bubbles, gatekeeping, cyberbalkanization, among others.[92,96,97,181,221,222] What further complicates these manipulatory practices common to all digital platforms, authors claim, is that the immersive XR experiences facilitate these practices more easily and convincingly.[53,96,97,222] Consider a VR deepfake, where persons may "be portrayed as carrying out actions and saying things they did not do. This is already powerful enough in photos and videos, but in XR could be even more dangerous because plausibility includes the automatic attribution of realness to virtual humans".[116,p.7] AI, with its enormous generative potential, when combined with VR and other immersive technologies, significantly increases the risk of malicious content creation and the spread of disinformation.[222]

Immersive virtual environments may use cognitive or psychological manipulation to achieve various objectives.[99,221] Marketing agencies may take advantage of persons by designing virtual environments towards the goal of furthering sales.[122,223] An HMD user can be physically steered into various directions through subtle, imperceptible changes in spatial cues—a technique known as the "human joystick attack"—potentially causing dizziness or confusion.[119,222] The wealth of knowledge available about a user may fuel a nefarious actor's ability to exploit the user, potentially for financial or social gain.[222] Users may be scammed, experience extortion or "sextortion".[92]

Manipulative potential may be scaled up such that there is "risk of harm to our own processes of knowledge creation and reasoning".[97,p.93] For example, pervasive AR, where digital objects become indistinguishable from "real" objects, may be

used to facilitate a false reality. This effect on "objectivity" includes fabricating journalistic or social events. Scaled up, malicious actors may introduce "paranoviruses" as a mode of social control, were networked devices are used to provoke group panic, paranoia, or to facilitate propaganda.[101,p.736]

3.2.4 Normative Risks

To make a "normative" decision is to determine which actions or outcomes are good or permissible and which are bad, or impermissible.[235] In this way, constructing a "norm" means determining rules for behaviour, sometimes based out of convention or etiquette, other times rooting in moral or ethical reasoning. Human rights may be considered a type of explicitly recognized (legally, socially) moral norm.

3.2.4.1 Norm Violations (Moral and Conventional)

Authors generally refer to potential norm violations as arising from or being influenced by virtual environments. Some argue that the immersive and highly realistic experiences of some virtual spaces/worlds may encourage immorality in general, or unethical behaviours, as these environments expose people to what may be considered immoral content. This is, of course, subjective, as perceptions of what is moral vary widely from society to society and even within societies. However, there are some things that may be deemed morally objectionable by a broad segment of society. An example is the simulation of underage sex.[166,196,223] There is also some speculation that certain exposures, for example, violent content, might alter normativity.[114,206]

Further, the felt "realness" of XR experiences may serve to motivate what some call "empathy content":

> VR as an 'empathy machine' puts the device to work as an effective curative to circumvent cruel or indifferent thoughts about already immiserated people and replace them with intense sensory experiences that invoke feelings of presence… 'Seeing as' a refugee… making racial empathy pleasurable puts the under commons to work providing empathy content.[112,p.53]

Nash discusses empathy-oriented content as carrying the risk of "improper distance", where immersive virtual environments or virtual videos facilitate "forms of self-focus and self-projection rather than a more distance position that allows for recognition of distance between self and other…. it presents distant spaces and others in an aesthetic mode, inviting a contemplation of the scene as a tableau vivant or spectacle rather than a painful reality".[220,p.125] In other words, moral engagement with another person becomes centered on how the user feels or experiences the feelings of others—prioritizing the user's emotional response over the reality of the person whose "painful reality" is being portrayed. There is moral power, Nash argues, in VR's ability to *simulate* experience as opposed to merely showcasing events (like traditional television). This runs the risk of no longer recognising the other *as* other, but rather foregrounds the emotional experience of users themselves.

Avatar representations within virtual environments and AR filters may also have an impact on norms. The homogenization of society intra-virtually may influence a loss of diverse, culturally specific norms,[132] as well as may alter norms of beauty.[116] When analysing normativity within virtual environments, Deng and Ruan argue that an avatar is a symbolic representation of a person's past and present selves, in addition to being an "extension" of a user's personal identity—highlighting that personal dignity in virtual environments can indeed be violated.[170,p.338] The avatar, considered by some to be an extension of a person is also referred to as having a prominent "moral" effects on users represented by their avatars.[1,p.49] Other examples of dignity violations, authors argue, are the presence of deepfakes of the dead in virtual environments.[1,104]

Some authors discuss the "moral danger" of XR, suggesting that normative accountability in XR becomes challenging in a virtual environment where consequences for actions may be absent: "if I feel I have nothing to lose, why treat other people with dignity and sensitivity?"[3,p.1542] Virtual Reality Social Networks may facilitate a societal and personal shallowness, wherein information is presented instantly, which according to some, means little time is spent contemplating and "digesting" the presented information.[181,p.19]

Other potential violations occur when inappropriately using devices. Playing AR mobile games like Pokémon GO can risk crossing cultural or ethical boundaries. The game, for example, has been played in churches or at the Holocaust Museum.[166,171]

3.2.4.2 Rights violations

Rights violations, potential and actual, are reported across units of analyses, platforms, and virtual environments. Of note are discriminatory practices in the design or deployment of XR, un-inclusive design and accessibility issues, and the

possibility of XR deepening existing societal inequalities.[142,198,204] Some authors suggest that XR devices are often modelled on the physical attributes of white, able-bodied young men, using them as standards for device design.[195] In addition to the devices themselves, XR platforms and virtual environments are said to be built to reflect the needs, desires, and implicit biases of the same demographic group, thereby negatively impacting the XR experience of other races or genders despite their initial interest in the device and/or platform.[105,118,196]

Persons living with disabilities or cognitive impairments may also encounter use limitations, such as some HMDs requiring a non-sitting position, or an overt focus on visual or auditory cues to navigate platforms.[142] Cisgendered women or those with a smaller head size are not accommodated in HMD hardware design, increasing the likelihood of experiencing simulation sickness.[118,204]

Hosfelt et al.[109] and Lee & Hu-An[196] argue that player characters/representations and roles are not adequately represented in XR. Further, avatar representations themselves may be built around gendered or racialised stereotypes and often assume the player or user is a heterosexual male, thus catering to their perceived preferences (e.g., females portrayed as damsels in distress or objectified sexually).[1,196] Thus, there are concerns that platforms and virtual environments, programmed with biased data, will serve to perpetuate real-world inequalities and the marginalisation of certain groups.[105,109] Pokémon GO, for example, appears to be systemically biased toward urban places with few minorities as its geographic mapping of in-game points of interest is predominantly concentrated in these communities.[164]

A final consideration is that not all people can afford XR or have access to it.[114,225] The increasing use of XR in school or work contexts may potentially engender inequalities, where those with digital literacy or economic potential face a competitive advantage, turning XR into a gatekeeping technology, i.e., access to educational or career opportunities may become implicitly or explicitly contingent on XR familiarity or ownership. Gatekeepers — such as employers, educational institutions, or credentialing bodies — may hinder career progress by making XR experience or access a precondition for participation or advancement.[1,p.52]

3.2.5 Structural Risks

This category describes risks to high-level structures: socio-politics, law, and economics/finance. It looks at large-scale arrangements of people, entities or systems, and how they may be affected by XR technologies.

3.2.5.1 Socio-political Risks

This is a combination category addressing risks to political and social systems. One large-scale social harm is the datafication of society, closely related to the algorithmisation of persons.[185,225] To "datafy" is to transform life into digitally analysable units.[195] These phenomena are further facilitated by the large-scale data acquisition capacities of XR, and the nature of virtual environments as surveillable, analysable, and controllable.[195,225]

Critics argue that datafication is inherently limiting, bracketing or setting boundaries on knowledge in a way which affects social relations on both personal level and within large scale systems.[181,194,195] Algorithmisation is, similarly, described as the reductionist application of algorithms to analysing life.[225] Datafication and algorithmisation are considered by some as a form of "data violence" which may harm persons in unintended or unforeseen ways, predicated on implicitly (and sometimes explicitly) flawed data systems and engineering.[195,p.4] These processes, authors claim, are highly beneficial to big tech companies, reinforcing power and influence and producing new forms of surveillance capitalism i.e., a form of capitalism which relies on personal information as value.[196,225] The concentrated power of technology companies may contribute to democratic decay, and also facilitate governance via technocracy.[109,224] It is argued that these technologies are increasingly privatizing social interactions, shifting them to virtual environments and platforms – spaces where "inherently biased viewpoints and ideological framing" are present.[196,p.8]

3.2.5.2 Economic/Financial Risks

This category describes risks which apply to how resources are produced, used and managed. Several authors discuss the potential for XR technologies to increase the cost of living, as well as contribute to processes of gentrification. This is due to XR aiding in the shift of work to digital spaces, which may mean local workforces are no longer relied upon.[1] Additionally, certain XR affordances such as augmented sensing in combination with artificial intelligence have been

shown to diminish the need for human labour, which can further limit opportunities for work.[94] Healthcare, too, may face increasing costs due to the implementation of XR systems in clinical settings.[161,175,192]

Another risk is that the XR market may become monopolized, which not only contributes to consolidating power and political impact, but also limits competition in an open market.[1,p.52] The monopolisation of platforms has effects on competition, and serves to facilitate the "interests of the few".[109,p.1] Virtual environments also present a range of resource management difficulties, particularly concerning virtual assets.[102]

3.2.5.3 Legal Risks

A legal risk is any risk that pertains to the lack of or breaking of existing laws. There are several identified by authors, stemming from actions taking place within virtual environments themselves, but also from using the technology in unlawful ways such as using geolocational data to target someone for a crime, or trespassing for game purposes.[20,166,167,212] Virtual environments are described as "lawless", underscoring that governance (legal but also social) is at its infancy.[217,p.3] Thus, legal responsibility – whether of the developer, designer, or user – for unethical or illegal actions is unclear, and regulation is in its infancy.[1,167] This lawlessness may facilitate fraud and scams, identity theft, pyramid and Ponzi schemes, copyright violations, intellectual property theft, and unregulated banking and gambling.[1,102,217] XR users can potentially experience violations of already existing data protection rules such as the General Data Protection Regulations (GDPR). However, the application of these regulations to XR is not well understood.[116]

3.2.6 Technical safety and security

This category pertains to risks stemming from the technical or digital limits and vulnerabilities of XR. These can be understood as risks inherent to XR's hardware or software – technical systems which can be disrupted or exploited.

3.2.6.1 Security risks

This subcategory identifies issues related to the design, maintenance and management of hardware, software, data, and services provided through XR technologies. These can be targeted attacks upon the system or user, exploits such as malware, as well as issues with negligent or unsatisfactory design.[115,225] These targeted attacks may take on various methods; some may attack infrastructure directly by way of controlling the application or system (sometimes without user knowledge).[49,222] Other attacks may occur by observing user interactions with devices, such as by way of shoulder surfing, or using sensors to deduce password inputs.[109,111] Perhaps most worrisome, some authors purport, is the ease with which wearables such as HMDs can be overtaken and manipulated such that the user is physically manipulated (more below). The human joystick attack has been shown to unwittingly and unknowingly move HMD users from one physical location to another location selected by the manipulator.[126,p.550]

Other technical security risks may be brought about as a function of poor code or design. These can lead to various breaches, data leaks, and difficulty authenticating information.[102,110,122] The complex relationship between intra-devices also means that systems may share security problems between them.[126]

3.2.6.2 Dual Use Risks

According to EU Regulation 2021/821, "dual use" refers to technologies that "meet many civilian needs, but … can also be used for defense, intelligence and law enforcement".[236] However, this review treats dual use more expansively, as authors describe dual use scenarios as any application of XR that, although designed nominally for a person's benefit, may be used to "threaten or harm people, animals or the environment".[237]

Immersive VR, accessible via wearables like HMDs, was often the focus of analysis. Authors describe the potential "double-edged sword" nature of XR technologies, which offer great societal promise by way of their unique immersive capabilities (among other potentialities), yet can simultaneously be used for nefarious purposes.[208,p.21]

Attributes of VR include its purported ability to increase empathy, which authors warn could, instead, decrease empathy,[219,p.6] or facilitate other behavioural or emotional changes.[143] These impacts on empathy may be applied to not only the general population but could be applied to military contexts, which may desensitize actors in delicate combat situations to further a nation-state's goals.[1,125,219]

3.3 Further considerations

3.3.1 Special Populations (Vulnerable Groups)

There are some consistencies across categories which should be noted. First, that risks to certain populations or groups are made worse/heightened in some way.[98,99] These populations were generally referred to as having a heightened susceptibility to experiencing harm, the causes of which were multi-factorial (physical, cognitive, social, etc.). In the category of health and well-being, these were often children, the elderly, disabled persons, as well as people with pre-existing conditions.[99,143] Notable risks for children and young people pertain to how reality is experienced and understood, particularly when using HMDs.[99,143] Here, a heightened risk of false memory adoption is noted, concern over whether children can discern properly between physical and digital realities after being immersed, as well as overall impact on cognitive development.[99,143] Further, those with pre-existing cognitive or psychiatric conditions also experience heightened use-risks, such as those with reality-perception disorders or dissociative disorders becoming further destabilised.[150] Autistic users may experience specific psychological and physiological effects.[149] Those with vestibular or oculomotor conditions, or damage to the central nervous system, face a higher risk of cybersickness.[145,146] Older users, too, face injury and usability limitations from deteriorated vision and hearing, as well as unstable gait.[150,151]

3.3.2 Unknowns and long term uses

Common to all categories and across units of devices, platforms and virtual environments were discussions pertaining to what is simply unknown about these technologies. For health and wellbeing, a combination of lacking and potentially problematic research means cognitive, psycho-emotional, socio-relational and physical risks of XR on persons is unknown (with special populations like children also being mentioned).[24,143,144,148,183,221] The infancy of the tech produces unknowns at the level of governance and responsibility, as well as security vulnerabilities which may yet to be discovered (novel ways of attacking XR devices).[110,224] It is also unclear what XR can do to the normative sphere, how it will change moral and social conventions, or to socio-political structures.[122] These unknowns deepen temporally – it is unclear how long-term use will further deepen these risks.[98]

3.4 Mitigation measures

A subsidiary objective of this review was to identify corresponding harm-reducing or risk mitigation strategies proposed in the literature. The coded measures are reported based on our interpretation of the literature and, as much as possible, reported in a general (non-specific) format to facilitate ease of comprehension. The main themes are organised into four domains, namely: society (government and non-governmental), industry (design, development and deployment), research (with XR technologies), and individuals (users and bystanders) (see Table 12).

3.4.1 Society (Government and non-governmental organisations)

At the societal level, several authors emphasised the need for interrogating existing laws to identify how and when these may be applicable to current identifiable legal issues arising with the use of XR technologies.[69,102,139] The recommendations at the societal level include governance measures and a call for more research-knowledge building in relation to implementation and impact of XR technologies. Governance considerations include the examination of existing laws and development of policies to address known crimes related to breach of privacy, property and ownership, and trespassing.[175,176,195,213] There is a general appeal across the literature for the creation of or modernizing of laws and policies to address new and emerging legal challenges such as those that arise with property and commercial transactions in virtual environments.[72,176] Corporate restrictions or limitations are also proposed to prevent data monopoly, emotional analysis, managing virtual content and types of games that may be considered dangerous and inappropriate.[225] Crime management measures include incorporation of digital forensics and cross border information sharing.[213] Rules and guidelines were recommended to address norm (moral and conventional) violations with regards to bias and discrimination as well as respect for cultural diversity, thereby ensuring inclusivity.[86] Codes of conduct and etiquette would be essential for social interactions when using the technology.[69]

Governance measures are particularly emphasized in relation to the Metaverse as it becomes more expansive in various activities including the purchase of property, commercial and other social activities. The risk of new types of crime in the Metaverse beyond the scope of current legislative measures are significant considerations in a comprehensive report issued by the Interpol and the World Economic Forum.[180,213] Finally, building and/or facilitating equitable and safe XR should be prioritised, thereby ensuring ethical and human centered XR technologies.[124] There is an appeal for further longitudinal studies (knowledge building) on the technologies to understand the long-term impact and unknowns.[41] Some authors also propose the use of design fiction— "the creation of tangible representations of imagined technologies

Table 12. **Mitigation measures.**

Domains	Proposed Mitigation measures			
Society *Government & non-governmental organisations*	**Governance**	**Laws, standards, and policies**	**Data protection** • implement existing data standards (user and sharing) • clear and comprehensible privacy agreements • use of explicit consent forms **Modernize laws for virtual environments** • property rights • trespass **Corporate restrictions/limitations** • data monopoly • emotional analysis • type of content & games • tracking and sharing of sensitive data • virtual product placements	
		Crime management	Digital (NFT) forensics, cross border information sharing	
		Rules and guidelines	• address bias and discrimination • respect for cultural norms and inclusivity • Codes of conduct and etiquette	
	Equitable and safe XR	Ensure ethical and human centered XR technology Use design fiction to speculate on future Digital equity and connectivity		
Industry *Design, Development & Deployment*	**Software**	**Structural**	**Privacy & wellbeing**	**Technical security**
		Ethics by design Empower users to define own virtual representation Interoperability Mechanisms for mitigating harassment Valuing and enhancing transparency and accountability	Access restriction Augmented consent protocols Limit audio inputs Minimizing tracking and biometrics Motion cues Protocols for identity protection Permission requests Spatial awareness sensors in headset to prevent collision User controlled profiles Warnings/notification of notification of danger/ tracking Warning lights to signal use of facial recognition to bystander	AI-based security protocol Block chain technology Dynamic security control Encryption Intelligent system design Preventive game design Privacy bubbles Shadow avatars Trustworthy XR architecture
	Hardware	Design lightweight and ergonomic devices for comfortable use with prescription glasses Design adjustable headsets for different head size and inter-pupillary distance		
Research *with XR Technologies*	**Review system**	Apply the equivalence principle (TEP) Dual use awareness Institutional Review Board model in organization Informed consent XR-specific code of ethics		
	Experimental design	Control of simulation environment Inclusion/exclusion criteria • Screening for person with cybersickness, • Contraindications • Vulnerabilities/vulnerable groups		

Table 12. *Continued*

Domains	Proposed Mitigation measures		
		Transparency	
	Safety		Gradual acclimation Minimizing tracking and biometric extraction Offline use of technology during experiments Post experience well-being Use of grab bars Training researchers
Individual *Bystander, User*	**Responsible use of technology**	Balance time virtual with real life Breaks in play User awareness of bystander Risk awareness Ensure that correctable eye and vision problems are corrected	

to provoke discussion about possible futures"[238] --to speculate on possible future consequences and to encourage investment in digital equity and connectivity.[86,222]

3.4.2 Industry

The industry mitigation measures were focused on improvements with software and hardware. Software recommendations were extensive and highly technical. To simplify the reporting, measures were organised as structural, privacy and well-being, and technical security. Structural software considerations include intelligent systems designs as well as ethics by design, including users in the design process, empowering users to define their virtual representations.[24,43,75,197] There is a need for implementing mechanisms in virtual environments for mitigating harassment and promoting a culture that values transparency and accountability.[173,211,213] Interoperability is an important and necessary structural measure.[102] Measures to protect privacy and well-being include minimizing tracking and collection of biometric information, enabling protocols for identity protection, permission requests, and augmented security protocols.[102,109,170] To minimize or mitigate against collisions and dangerous situations, some authors recommended spatial awareness sensors and warning message.[161,211] Warning lights may also be placed on output devices, such as AR glasses for example, to signal use of facial recognition to bystanders.[69] Hardware design was also highlighted as a key consideration for industry. The authors asserted that developers should also consider designing lightweight and ergonomic headsets that are adjustable to facilitate different head size and inter-pupillary distance as well as ensure comfortable use with prescription glasses.[43,124] Technical security measures include the use of AI-based or dynamic security control.[173] Some authors emphasised encryption and preventive game design. Within the virtual environments such as the Metaverse, privacy enhancing technologies, block chain technology, shadow avatars and privacy bubbles were presented as plausible measures of protection.[211,213]

3.4.3 Research with XR technologies

Proposed measures within the research domain include (a) adopting a review system tailored to the unique challenges of conducting research with XR technologies, (b) designing experiments with inclusion/exclusion screening for persons likely to experience cybersickness or may have contraindications or vulnerabilities, and finally (c) safety measures to facilitate gradual acclimation to the technology, ensuring researchers are adequately trained on how to use the technology, assessment of post-experience well-being for research participants.[149,203] Privacy measures include use of the technology offline during experiments and minimising tracking or data and biometric extraction.[109,139,170] Safe physical environments to prevent both foreseeable and unintended harm to the participants could include a practical measure such as grab bars that would prevent users (especially the elderly) from falling when feeling disoriented.[203] The adoption of an Institutional Review Board (IRB) model within organisations where there is awareness of the possibility of dual use of

XR for unintended purposes, ensuring informed consent by users, and development of XR specific code of ethics.[125,211] Some authors argued for the application of the equivalence principle when assessing the ethics of a virtual experience when conducting research. They posit that "if it would be wrong to subject a person to an experience then it would wrong to a virtually real analogue of that experience".[206,p.260]

3.4.4 Individuals

Individual mitigation measures aim to empower and protect users and bystanders. The main recommendations centred on the responsible use of XR technology. Maslen and Savulescu contend:

> …moral responsibility is a function of the intentions and foresight the agent had with respect to the harm risked or caused, and the avoidability of that harm, together with whatever duties of care exist… Such principles would extend to telepresence. Whether a manufacturer is liable for some portion of the harm, or whether responsibility attaches fully to the agent who assumed the risks associated with using the technology, will in large part depend on the respective duties of care in the situation, the user's expectations relating to the functioning of the technology, any abnormal use of the technology, and the degree of foreseeability of the harm.[187]

Users are encouraged to balance virtual time with real life and take breaks in play and going into nature.[161] Risks awareness is important for both users and bystanders.[72,86,113]

4. Discussion

The review gives a mapping of risks and harms of XR technologies across various use cases. Following a scoping method in conjunction with a qualitative descriptive content analysis, we identified risks and harms spanning across six major categories of risk: health and well-being, autonomy, epistemic and scientific, normative, structural, and technical safety and security. The following discussion will contextualise some of the charted items and findings (including the risk typology), point to potential knowledge gaps, and offer some reflections on the scoping review process.

4.1 Summary of results

First, the increase in XR publications over the last few years, the geographical distributions of said publications and how the distribution relates to knowledge-building and mitigation strategy are discussed. Then, the significance of the emergent risk typology will be addressed alongside a comparison of similar typologies.

The increasing number of publications on XR risks and harms over the last decade reflects the change in academic and societal interest in these issues. This might feed strategic efforts towards redress, and hopefully, more knowledge will bring about change. It is uncertain, however, what that change will look like or whose voices will be heard in this changemaking. The review's majority of sources originate from economically advantaged countries, and therefore contains an underrepresentation of views from regions/countries that are economically disadvantaged (e.g., countries categorized as low- and middle-income from Africa, Asia, Latin America, and the Caribbean). How this underrepresentation may affect or steer the global discussions on how risks and harms are to be considered and mitigated is unclear.

Most of the sources were from the USA (46%), a country with advanced XR infrastructure accompanied by a robust startup ecosystem, accounting for 37% of global XR revenue share.[239] China and Japan are also projected to be key builders and investors in XR,[235] but only 6% of the sources were from China. There were no sources form Japan. Having no contributed works, however, does not mean that scholarship and knowledge building on XR risk is not available. Sources may have been published in non-English languages. Thus, there may be discussions taking place that account for risks and harms to which non-native speakers are not privy.

This review includes a comprehensive mapping of risks and harms related to XR technologies, with over 200 codes mapped. The listing of this large number of actual/potential harms in a reportable format may be overwhelming for the reader, but it is also a starting point for further research on risks and harms. The listed risks/harms are not connected to particular use cases, output devices or platforms. Connection can be made, however, through cautious inference, as 70% of the use cases were for general application, healthcare, and entertainment (gaming) as well as the main types of output devices being VR and AR.

Although use cases such as education, research, governance, commerce, and industry were not significant in number of publications reviewed, the relevance of risks within these areas of application is of importance as these areas are projected to grow, especially for industry training.[240] Social and entertainment applications of XR were amongst the most frequent use cases reviewed. With the increasing convergence of social networks and XR – Meta's Horizon, for example – it is

expected that novel risks and harms will emerge.[241] Military applications were notably absent from our findings. Given the sensitive and security risks associated with use of XR in military settings, this absence is explainable.

The mapping is not only comprehensive in terms of breadth of risks/harms, but also covers risks/harms across domains and units of analyses (explicitly including virtual environments and the Metaverse). As far as can be found, only Cyber-XR offers a risk typology which includes all units of analysis (VR, MR, AR, but not virtual environments) and covers all domains (i.e., for general use).[18] There are several areas of alignment between their typology and this one. This alignment is encouraging, as it reinforces our findings and subsequent categorisation of risk themes. For example: Cyber-XR has five risk categories: human, financial, legal, information, and societal.[18,p.56–57] They do not, however, explicitly identify epistemic risks as a major concern. Instead, they grouped what herein is outlined as structural, normative, and epistemic under societal and legal risks, identifying issues such as disinformation, deep fakes and other epistemic risks as "manipulated social discourse".[18,p.56] Notably, Cyber-XR classify "lack of ground truth" and "inability to establish truth" under societal and legal risks, respectively.[18,p.57]

While these things may indeed produce legal and social problems, they point to an inherent issue with XR: XR makes it more difficult to distinguish between digital information and non-digital information. Thus, the epistemic risk category is important to bring forward as an independent/unique conceptual category. It is critical that the knowledge ascertained and interpreted from XR technologies are assessed in their own right – especially given the nature of immersive virtual environments as changeable and experientially convincing, and the increasing integration of AI. Further, epistemic and scientific uncertainty is highly relevant to those conducting research with or on XR technologies.

The risk typology also distinguishes social risks from socio-political risks, signifying a separation of scale – social risks operating on a micro, inter-personal level whilst socio-political risks operate at a macro level. This separation is important to future scholarship which take on micro, meso, and macro-level analyses. Finally, normative risks were separated from risks to autonomy, while acknowledging the overlap between the two as fundamentally rights-based issues. The reason being that the abundance of literature pertaining to issues of self-sovereignty, surveillance, and privacy, especially, and as such these risks could be considered within a self-contained theme: autonomy.

4.1.1 The development of XR risk-strategies: potential motivators

The uptick in discussions and subsequent publications on XR technologies and its risks may be a function of the relatively increasing affordability and public visibility due to expanding range of applications. The early 2010s saw computer storage advancements, faster processing, powerful graphics chips, improved form factor and the release of the Oculus Rift in 2012.[242,243] Oculus was soon acquired by Meta (then Facebook), "leading to a significant increase in the popularity of VR devices for home use".[242,p.2] Facebook's 2021 rebrand into Meta Platforms also signifies that large technology companies are serious about XR – Meta's own branding echoing the "metaverse". As of 2024, Meta owns nearly three quarters (74%) of the global XR market share.[244]

Technology companies' efforts towards designing and developing XR devices and platforms can have significant effects and influence on research and public discourse. This is especially salient given the relatively "high degree" of independence under which the XR industry operates.[245] For example, there was an increase in AR-related literature, which coincided with the release of Pokémon GO in 2016; with usership at the time in the tens of millions.[246] Thus, the role of technology companies in *mitigating* risks should not be underestimated. Whether the motivation to make critical design and governance changes comes from within company bounds, or whether it requires extra-regulatory power remains to be seen.

It is important to consider that regulatory bodies and civil society groups (NGOs or advocacy groups) are critical to the governance of XR risks as they, too, alongside industry, are stakeholders – and that strategic efforts are indeed being made. Several included publications within this review propose regulatory strategies: The World Economic Forum, Interpol, and IEEE, for example.[102,105,111,142,180,184,213] Co-governance practices, where strategies for redress are collectively established between industry, civil society and governments, are growing increasingly popular.[245] The XRSI (Extended Reality Safety Initiative), an organisation which provides research and standards have advised both industry and governments, for example.[247]

The way technology changes over time also affects how conceptualisation of XR is popularized and communicated, which, in part, may explain the shift in meaning from "virtual reality" as desktop experiences to wearable displays with immersive affordances. "The immersive experience is what most people think of when it comes to VR and is one of the most marketable aspects of VR technology".[242,p.19] It would seem VR's affordances as a technology which can

convincingly transport a person into a new space and have them feel as if they were there, embodied and present, is of interest to scholars and others in various domains. Indeed, VR comprised 43% whereas AR comprised 15% of sources within this review.

AR, whose goal is not to completely immerse but rather to augment or overlay digital information, may seem like less of a risk. However, the potential for AR as a "pervasive" technology, facilitated through the ubiquity of cellphones and mobile platforms, should not be underestimated.[122,248] As Girginova et al point out: "Globally, many more people in 2022 experienced AR technologies on a daily basis than VR technologies. Yet, VR research dominates academic literature".[249] Additionally, scholars predict an uptake of wearable AR which allows for an integration of everyday activity with digital information through optical displays; this "always-on" state means that the volume of user data tracked, stored, and interpreted will increase.[122,p.85] The network sharing capacities of these platforms makes it easier to create large scale 3D spatial maps – potentially against people's knowledge or will.[122,p.85] The wearability of XR and its ability to be integrated more seamlessly into everyday life – the latter being something immersive VR, by nature, cannot do – may bring about epistemic, structural, autonomy-related risks yet to be identified (among others). Therefore, more research within this AR-specific domain is required.

Wearability and everyday integration are important to consider in relation to MR as well, which was the least discussed unit of analysis, comprising 3% of sources. It may be that the relative newness of MR, or its conceptual ambiguity and practical similarities to AR which subsumes discussions about MR under AR.[250] With the 2024 introduction of HMD products like the Apple Vision Pro – marketed as a "spatial computing device" that "just about everyone calls" a mixed reality headset – an increase in company interest in MR/AR technologies is likely, as well as more public consumption.[251,252]

A final thing to consider is that though units of analysis have changed in meaning and expanded over the years in terms of capabilities or affordances, risks identified in earlier sources are still reflected in recent literature.[104,105] At least two decades have passed and problems persist, and become amplified, in immersive XR: harassment (notably of women and minorities), privacy violations, for example, among others. Is this a function of lack of effort, inadequate or insufficient mitigation techniques, or is it simply 'the nature of the beast', an inherent feature of a technology which is controlled by someone else.

4.1.2 Identified areas for further exploration

4.1.2.1 The need for more varied and interdisciplinary research

There are several research opportunities to consider which have already been mentioned including: 1) more attention to "pervasive" AR/MR technologies and 2) the relative similarities and continuation of risks identified more than twenty years ago into present day. In addition to these, more research into the mental, social and physical well-being of persons using these technologies needs to be conducted related to *special populations* and *long term-use* effects. Whilst this review has an extensive overview of potential effects on well-being, multiple sources identified a lack of understanding how XR effects well-being over long periods of time, as well as how it effects minority or vulnerable groups such as those with autism or mental health conditions.[134,149]

Finally, while this review showcases a range of risks – from "concrete" risks to more "abstract" such as normative risks – the majority of literature pertained to more concrete risks. This observation is reflected in the extensive review by Girginova et al.[249], which reveals the underrepresentation of non-STEM research within the XR space. Thus, the humanistic or non-STEM dimensions of XR, they argue, are important to understand if an ethical product is to be made.[249]

4.1.2.2 Ramifications of AI/XR intersection

Attention should be paid to risks related to AI/XR. Though we did not explicitly code AI-related risks, anticipating that XR will increasingly rely on AI, some authors highlighted risks related to generating virtual worlds and the analysis and interpretation of large swaths of extracted information. Hirzle et al.,[253] reports in their scoping review of XR and AI literature that AI can create XR worlds by "creating a realistic replication of the real world, modifying the real world, or generating a synthetic world".[253] They also note that AI may be used to understand and support interactions with users, facilitate interactions with intelligent virtual agents, and enable user authentication and identification.[253] Noting that the AI/XR intersection comes with not only the usual AI-related issues (bias, transparency, etc.) but unique challenges, reviewers posit that AI/XR combinations being used in simulations will augment many of the potential harms discussed

earlier. AI/XR may contribute not only to epistemic and scientific uncertainty risks, but could be used to manipulate behaviour, cognition, emotions, etc. Computer vision and generative AI can facilitate real time surveillance and interactions that are tailored to specific users/bystanders. Reviewers therefore posit that all risk categories are of relevance for deeper reflection in relation to AI/XR intersecting and call for more discussion and research on the ethical and societal impacts of AI/XR combinations.

4.1.2.3 Environmental risks, impact and opportunities

In addition to sources detailing AI/XR, attention should be paid to the unique environmental risks associated with XR. Some purport that XR reduces the need to travel for work or leisure, in addition to minimising office-space use which lowers an individual's carbon footprint.[254] XR may also promote immersive strategies for building relationships with nature through storytelling, thereby communicating environmental issues in potentially novel ways.[255] However, only one source within this review identified XR's potential *negative* effects on the environment. Adomaitis et al.[90] point out that the production and maintenance of XR infrastructure necessitates large amounts of material resources and energy. Additionally, they note, "information is physical".[90,p.50] Thus, it is not only the production of hardware as such, but the large energy-consumptive *data* stores and cloud services required by XR which have environmental costs - this includes the data stores necessary to maintaining Metaverse infrastructure. Considering these things, it is surprising that such a low number of references to environmental risks are reported.

It can be assumed that XR's likely integration of AI will serve to further problematize its impacts on the environment by creating additional energy needs. Nascent environmental impacts of generative AI include "expanding demand for computing power, larger carbon footprints, shifts in patterns of electricity demand, and an accelerated depletion of natural resources".[256,p.1]; see also[257] Additionally, energy intensive practices are expected to increase with demand for high resolution images and video.[258] It is also unclear how increasing consumption will further drive electronic waste.[258]

4.2 Limitations and challenges with scoping review process

There are several potential limitations. Indeed, undertaking a review of 195 sources from a range of disciplinary domains and methodologies did not come without challenges. First, registering a scoping review protocol would have been preferred, as it reinforces the values of open science and transparency, as well as potentially yielding valuable community inputs. Though a protocol was made, time constraints directed team efforts towards proceeding with the review.

Secondly, though reviewers believe to have a robust selection of sources, and an effective search strategy, valuable inputs may have been missed by constraining grey literature sources. The popularity of immersive technologies as a topic of speculation assumes a vast number of newspaper articles or popular magazine references – untenable to include for a small research team. The database search ending in January 2023 also may mean the most recent discussions on risks and harms were not included. A preliminary database search using the same search strategy was re-conducted February 2025 yielding 1666 records after de-duplication. This shows a significant growth in potentially relevant articles after the original search period ending in 2023. Though, the addition of resources from citation chaining as well as manually inputted articles between 2023–2024 have indeed brought in relevant and timely literature.

An additional limitation stems from having one reviewer reading texts in-full instead of the recommended two.[24] However, pilot articles were read together, and from there clear criteria was established by consensus. Reviewers additionally met regularly to discuss discrepancies, uncertainties, and when data items were unclear.

Finally, there may be some limitations to the typology itself. Coding was indeed a challenge, both from the perspective of interpreting what sources considered a "risk" or "harm", but also what type of XR or experience they applied to. This means the risks and harms which apply to, for example, a VR desktop platform might not apply to immersive devices or vice versa. It would benefit scholarship to map risks and harms according to conceptual specificity.

Additionally, multiple risks/harms cut across several thematic categories, even if they might not be categorised as such. There are also sub-categories within our typology with great conceptual overlap, such as cognitive risks and psycho-emotional risks. There are some practical reasons for this separation, as combining sub-categories would have made for a lengthy category. Further (non-descriptive) critical analysis should be done on the inter-sections of risks and harm.

5. Conclusion

EXtended Reality technologies are no stranger to evolution, from early panoramic paintings aiming to "immerse" viewers into a scene, to science fiction conceptualisations of the "ultimate display", to modern day headsets rendering believable sensations of joy and awe.[259] It is clear that the landscape of technological possibilities is burgeoning – and with all these

opportunities come many unknowns, including risks and harms. The typology offered by this article renders these risks more clearly, giving scholars, policy-makers, designers and developers a starting point for approaching mitigative strategies from multiple levels: individual, industrial and societal. The article does this across the full spectrum of XRTs devices, as well as domains (i.e. entertainment, etc.). There are several research communities and governance initiatives which will benefit from this work. One such is the Horizon Europe project, XR4Human, whose future ethics and interoperability guidance documents – including a Code of Conduct for the Human-Centered and Ethical Development of Immersive Technologies – are reliant on a complete understanding of risks and harms.

The number of publications on the ethical issues of eXtended reality technologies are rapidly increasing and evolving in number, scope, and context. The focus on VR technologies within identified scholarship, while important, reveals potential gaps addressing the issues posed by AR (and MR), especially as these latter technologies are more ubiquitous and wearable. The review also found that some risks identified decades prior have persisted into present day, indicating a need to better understand why these risks have not been adequately addressed. Additional research opportunities highlighted include the environmental impacts of XRTs, and the changing nature of XR as it increasingly intersects with artificial intelligence.

To reiterate, this typology consists of risks to health and wellbeing (cognitive, psycho-emotional, socio-relational, physical), to autonomy (privacy, self-sovereignty, surveillance, authenticity), epistemic and scientific risks (epistemic uncertainty, scientific uncertainty, algorithmic imperfection, manipulation), normative risks (norm and rights violations), structural (socio-political, economic/financial, legal), and technical safety and security risks (security, dual use). The novelty of this typology is not only its expansive coverage, but its explicit detailing of more abstract risks as warranting independent categorisation, such as epistemic risks. Given the changeable and convincing nature of virtual environments, knowledge formation and the assessment of XR impacts on it are all the more critical.

Ethics and consent

Ethical approval and consent were not required.

Declaration of AI usage

Microsoft Copilot was employed strictly as a grammar tool.

Data availability

Data related to this project is available following an Open Data policy, under CC-BY 4.0 licensures. Scoping Review PRIMSA Checklist for Mapping Risks and Harms of eXtended Reality (XR) technologies" available via ZENODO. https://doi.org/10.5281/zenodo.19663830, license CC-4.0 International.[261] Data charts as defined in section 2.5.1 "Data Charting" are additionally available via ZENODO, https://doi.org/10.5281/zenodo.19663743, license CC-4.0 International.[262]

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This manuscript presents an ambitious scoping review aimed at mapping risks and harms associated with extended reality technologies. The review addresses a timely and relevant topic and provides a useful contribution to the field. However, I believe that some aspects could be further clarified and developed to improve the methodological rigor, conceptual clarity, and overall strength of the manuscript.

Major points

Introduction

1. The Introduction provides a useful overview of XR technologies, although some aspects could be further clarified to strengthen the conceptual framing of the review. In particular, several related terms, including XRTs, immersive technologies, VR, AR, MR, virtual environments, immersion, and presence, are introduced in relatively rapid succession. A more integrated presentation could help.
   - For example, the statement that eXtended reality technologies are “also called immersive technologies” could be further supported or clarified, as these terms may not always be fully interchangeable. Similarly, a more precise distinction between immersion, as a technological characteristic, and presence, as the subjective experience of being within the mediated environment, could improve conceptual clarity. The current description seems to partially overlap these two levels.
   - More generally, some broad claims in this section could benefit from additional references or slightly more cautious wording.
1. **Section 1.1.2, pp. 3-4**. The distinction between *risk* and *harm* becomes clearer later in the manuscript, particularly in the Methods, but it could be presented more explicitly at the beginning. At present, the section introduces relatively broad definitions and refers to different disciplinary perspectives (e.g., harm has been extensively debated in philosophical, sociological, and jurisprudential literature without immediately clarifying how the authors operationalize these concepts within the present review). It would therefore be useful to provide a clearer initial definition of what the authors mean by *risk* and *harm* in this specific

context, and to indicate more explicitly the domains considered (e.g., physical, cognitive, psycho-emotional, socio-relational, etc.).

2. **Section 1.1.4.** I think it would be helpful to briefly clarify the main ethical issues identified in the previous mapping of ethics guidelines for XR technologies, since the authors state that the present review builds on those findings. A short overview of these issues, and of how they informed the current mapping of risks and harms, could help make the connection between the two works clearer.
3. **Introduction / section 2.1.** I think the references to WP2, and its internal project structure could be simplified. While the connection with the XR4Human project is relevant, the manuscript may benefit from focusing more directly on the scientific and theoretical contribution of the review rather than on project-specific organizational details. If WP2 members had a substantive methodological role in the review, this could instead be described more directly in terms of their contribution.
4. **p. 3.** I think the references to the specific structure and activities of Work Package 2 could be simplified. The connection with the XR4Human project is certainly relevant, but it may be sufficient to explain that the review provides theoretical and scientific support to the broader project, without detailing the internal organization of the Work Package. This could help keep the Introduction more focused on the scientific rationale of the paper. Similarly (p. 5), the reference to "members of WP2" acting as experts could be reconsidered.
5. **p. 3.** I was not entirely clear about the statement that *"while the project focuses primarily on European contexts, the findings presented here also have global relevance."* Why should the European focus of the project limit, or conversely support, the global relevance of the review? Is this statement referring to the findings themselves, their potential impact, or the intended application of the framework? I think this point could be clarified further.

Methods

1. Section 2.3, Information sources and search strategy, pp. 5-6. I think the choice of using only Scopus and IEEE Xplore could be further justified. The authors state that these databases provide broad multidisciplinary and technical coverage; however, given that the review considers physical, psychological, social, ethical, legal, and other types of risks, it would be helpful to clarify why these two databases were considered sufficient for the scope of the review and whether other relevant databases were considered. This could also be briefly acknowledged in the Limitations section.
2. Inclusion and exclusion criteria, pp. 6-7. I was not entirely clear about the reference to "2000–2024 (manual input)" in Table 3. Since the manuscript later states that some 2023 and 2024 publications were manually added, I wondered whether this date range was intended to refer specifically to these more recent sources. If not, this could be clarified. More generally, it would be helpful to explain what is meant by "manual input": how these additional publications were identified, why they were considered for inclusion, and whether any specific procedure or criteria guided their selection.
3. p 7. I think this section would benefit from slightly greater methodological precision and more consistent terminology throughout. For example, expressions such as *"This review was a 'first pass'* are relatively informal and could be replaced with more specific terms such as *"initial title-and-abstract screening."* Similarly, formulations such as *"excluded for not meeting eligibility criteria"* could be made more informative by specifying, where possible, the main reasons for exclusion. More generally, I would suggest revising the Methods section with particular attention to methodological terminology and reporting precision, as this would further strengthen the rigor and reproducibility of the review.
4. pp. 8-9. Since the included sources also comprise reviews alongside primary studies, I think it

would be helpful to clarify how potential overlap in the underlying evidence was handled. For example, was any procedure used to account for cases in which the same primary study was included directly in the review and also discussed within an included review article?
5. pp. 8-9. I think the development of the six themes and 19 sub-themes could be explained more transparently. The general inductive process is described, but it is not entirely clear how the initial codes were progressively grouped into these specific categories. A clearer explanation of the criteria used to create, separate, or merge themes and sub-themes would strengthen the methodological transparency of the proposed typology.

Findings

Section 3.2, pp. 13-25. I found the presentation of the risk typology very rich, but at times difficult to follow because a large number of conceptually different elements are presented together. Some concepts are defined when introduced, while many others appear mainly as codes in the tables without further clarification. As the Findings progress, the connection with the initial theoretical framing and review objectives also becomes less immediate. I think the Findings could benefit from clearer conceptual organization and more consistent definitions, particularly to clarify the different levels of analysis represented within each category and the rationale for grouping such heterogeneous risks together.

Minor points
- p. 3. In the sentence *"IEEE defined harm as 'any unwanted occurrence which ends in some sort of "value damage or loss" to a person'"*, there is an inconsistency in the quotation marks.
- p. 7. The expression *"This review was a 'first pass'"* seems somewhat informal and potentially ambiguous in the context of a scoping review. I suggest using a more specific methodological term, such as *"initial title-and-abstract screening"*.
- section 2.4, figure 1 and findings, pp. 7-8 and 13. I noticed some numerical inconsistencies in the reporting of the study selection process. The text and the Figure 1 caption report a final sample of 195 publications, whereas the PRISMA diagram reports 193. These numbers should be checked and reported consistently across the text and the PRISMA diagram.
- p. 5. I think the rationale for not conducting a critical appraisal could be clarified, particularly the statement that it "could introduce bias."
- p. 7. The authors state that publications before 2000 were excluded because they were considered "likely to be outdated." I think this cut-off could be further justified, particularly given the historical development of virtual environments and related technologies.

Conclusions
Overall, this manuscript addresses a relevant and timely topic and provides a rich mapping of risks and harms associated with XR technologies. I think the paper is already based on a valuable amount of work, but some aspects could be further clarified and conceptually organized to strengthen its methodological rigor and overall coherence. In particular, clearer definitions, greater transparency in some methodological choices, and a more structured presentation of the findings would help readers better understand how the proposed typology was developed and how it responds to the original review objectives. The Discussion could then be revised accordingly, following the clearer organization and conceptualization developed in the Findings.

Are the rationale for, and objectives of, the Systematic Review clearly stated?

Partly

Are sufficient details of the methods and analysis provided to allow replication by others?
Partly

Is the statistical analysis and its interpretation appropriate?
Partly

Are the conclusions drawn adequately supported by the results presented in the review?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Psychology (experimental) and virtual, immersive and non-immersive technologies

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.