

SOCIAL GRAMMARS OF VIRTUALITY 2023

Inside a Year of Research: A report on Key
Trends and Findings in Extended Reality
Scholarship

Annenberg Extended Reality Lab
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FROM THE EDITORS

Welcome to the first issue of Social Grammars of Virtuality. This is a new type of digital publication providing a high-level, critical summary of social science extended reality (XR) research. This report is intended as a resource for the global community of researchers and practitioners wishing to better understand the social fabric and communicative dynamics around XR experiences, including virtual, augmented, and mixed reality. In this issue readers can find a systematic mapping of the intellectual, geographic, and funding sources of 1,457 XR peer-reviewed, social science articles published in 2022. This is followed by sections providing a summary of cutting-edge, social science advances in XR theories, methods, technological innovations, and language.

Our deepest gratitude to Dean John L. Jackson, Jr. and our colleagues at the Annenberg School for Communication at the University of Pennsylvania for their support for this project. We also extend thanks to our colleagues and Editorial Board members who have generously shared their time and feedback on early drafts and ideas: Drs. Guobin Yang, Jessa Lingel, John Pavlik, Marcus Carter, Danny Pimentel, Donna Davis, Spencer Striker, Jasmine Erdener, and Christin Scholtz.

INTRODUCTION AND EXECUTIVE SUMMARY

Katerina Girginova, Kyle Cassidy, Maxwell Foxman, Matthew O'Donnell, Katie Rawson

Welcome to the first issue of the Social Grammars of Virtuality. This is a new type of digital publication providing a high-level, critical summary of social science extended reality research. The Social Grammars of Virtuality will be published annually and is a free resource to the global community of researchers and practitioners interested in the field. At present, there is a version of the publication in English and Spanish.

We weighed each word in the title carefully. Social reflects the need to better understand the changing social identities and relationships between individuals, communities, organizations, and extended reality technologies. Grammar highlights the fundamental, and often structured role of communication in facilitating social formations and creating meaning. Finally, virtuality underscores the context within which the social interactions and meaning-making takes place. The synergy between these key terms reflects our desire to promote critical scholarship, which may better harness how new technologies are used to shape a more just and sustainable world.

Augmented, mixed, and virtual reality technologies – collectively known as extended reality or XR – offer an evolving user experience driven by our desire to extend the capacities of the human body and to approach worlds beyond our reach. While virtuality itself is nothing new, advances and corporate marketing in the past decade have brought it to the forefront of popular and academic attention.

For simplicity's sake, we can think of XR technologies on a spectrum of technologically-assisted realities with varying degrees of user interaction. On the one end of the spectrum, augmented reality (AR) technologies enhance our physical surroundings by overlaying graphics and information on top of them. Camera filters on applications like Instagram and Live View on Google Maps are popular examples of AR. On the other end, virtual reality (VR) creates an entirely artificial environment where we are fully visually immersed. VR experiences include gaming where the user puts on a headset to see the application. Lastly, mixed reality (MR) lies in the middle of the spectrum and shares characteristics of both AR and XR. MR overlays graphics on top of a user's physical surroundings and allows for high degrees of user interactivity with the virtual objects, like in medical operation simulations.

XR technologies are becoming increasingly pervasive in our societies. It is estimated that in

2022 there were over 170 million VR users worldwide (almost 70 million were in the US), and there are some 101 million AR users in the US alone[1]. These populations use XR in the contexts of various trainings, health and medicine, and media and entertainment. As the findings of this report also indicate, XR research and development is a national-level priority field of study in many countries. Yet, social sciences-focused research – that is, work that studies society, its interrelationships, and XR use – only presents a fraction (~10%) of this total published output.

We argue that a critical understanding of the social dimensions of XR use is key for creating ethical and effective XR experiences. Questions such as who is using XR tools, why, and to what avail are not secondary to issues of technical development and deployment. In fact, they should be driving it. As communication scholars who also straddle a number of other fields of inquiry, we are particularly interested in critically understanding the ways that we communicate about XR tools and, simultaneously, the ways that these tools and practices allow us to communicate, to form relationships, and to create various social structures.

In turn, this report is one part of a larger project that pursues these aims: the Annenberg Virtual Reality CoLABorative, based at the University of Pennsylvania, which is a lab dedicated to the critical and creative study of XR technologies within society. We hope that this report presents a valuable step toward bringing communication and, broadly speaking, social science voices to the fore of XR conversations in society – and to do so in an accessible way. While social science XR research presented a fraction of the total output of XR research in 2022, this still amounted to almost 1,500 peer-reviewed research papers, a significant amount for even the most avid reader. Thus, The Social Grammars of Virtuality becomes the first publication of its kind to provide a systematic review of the literature through:

- A knowledge mapping review of the intellectual, cognitive, geographic, and organizational structure of XR social science research based on all available, peer-reviewed publications in English in 2022.
- A high-level, critical summary of XR research within social sciences from three core academic journals: *Frontiers in Virtual Reality* and *Virtual Reality and Presence: Virtual*

and Augmented Reality, plus additional sources. (See Methodology section in the Appendix for more details.)

- A discussion of new ideas and approaches to the study of XR.

This report is intended as a tool for researchers and practitioners wishing to better understand the social fabric and communicative dynamics around XR experiences. It contributes to broader, global efforts to develop our collective understanding, vocabulary, and agency to actively intervene within the practical and intellectual developments of XR in society. This report is also intended as a valuable supplement to our cousins in the fields of medical and technical XR research, who have been producing and benefitting from various systematic reviews for years.

Each of the following sections may be read on its own to give a quick, high-level overview of developments in a particular area such as XR theory. The sections may also be read consecutively by the reader wishes to capture the synergy between them. Below, we share five key findings and three recommendations based on our systematic analysis. We look forward to the conversations that will ensue.

KEY FINDINGS

- Globally, many more people in 2022 experienced AR technologies on a daily basis than VR technologies. Yet, VR research dominates the academic literature.
- While different geographical regions exhibit some variation in the research undertaken, in general, XR research significantly lags behind technological developments.
- XR, and specifically, VR research is frequently studied from a cognitive psychology perspective and framed around several key terms: immersion, presence, and embodiment. Yet, these terms are often taken as static concepts rather than as ideas to critically interrogate, which limits the types of new knowledge that can be produced.
- XR media consumption often requires new and higher degrees of physicality from its user than previous media forms. For example, virtual tours require their user to move around a space and virtual sport skills training demands the performance of physical movements. Capturing and describing this type of physicality – a new type of audience experience – requires researchers to develop nuanced approaches and vocabularies.
- Major companies like Meta, the global leader in VR hardware, have significantly impacted the popular creation, consumption, and imagination of XR media (often, by strategically limiting development).

RECOMMENDATIONS FOR XR RESEARCHERS AND PRACTITIONERS

- Be specific in our definitions and intentional in our use of key terms that define XR experiences and research methodologies. For example, measuring how a user feels present in a VR experience first requires a very clear and explicit understanding of what presence is (or is not), and how it is achieved.
- Adopt more user-centric methods of analysis. Specifically, to include deeper, qualitative analyses of XR engagement that consider diverse user experiences (age, gender, demographics).
- Ethically expand our vocabulary of XR media and experiences. At present, research often subscribes to terms popularized by the corporate world, like colonization, new frontiers, and the metaverse. This type of language frequently perpetuates capitalist regimes of surveillance and invisible labor.

AUTHOR BIOGRAPHIES



Katerina Girginova, Editor of the Social Grammars of Virtuality series, is Co-Director of the Annenberg Virtual Reality ColLABorative. She is interested in how global media, audiences, bodies, and events migrate into various virtual realms. Prior to joining the University of Pennsylvania, Katerina worked in a number of media organizations and enjoys combining creative and critical perspectives in media production.

Kyle Cassidy is Co-Director of the Annenberg Virtual Reality ColLABorative and has been writing about technology since the early 1990's. He has authored a number of books about computer science and has been a contributing editor to Videomaker Magazine for two decades. He's won four Keystone Journalism Awards and in 2020 he won the University of Pennsylvania's Model of Excellence award for his work in Virtual Reality.



Maxwell Foxman is an Assistant Professor of media studies and game studies at the University of Oregon's School of Journalism and Communication. His research focuses on the intersection of games and play in non-game contexts, industries, and professions, including immersive media (VR/AR/XR), esports, gamification, and game journalism.

XR KNOWLEDGE MAPPING REVIEW

Katerina Girginova, Matthew O'Donnell

Editors' Note: This essay was amended in January 2025 due an oversight in the initial query criteria. The use of the term "AR" falsely included material from the biomedical sciences that were not about extended reality. See the revised, corrected query in footnote 4.

Knowledge mapping, also known as science mapping, is a process that allows us to visualize and analyze the core features of publications on a specific topic (Chen, 2017[1]). This process reveals a number of important factors about a body of literature, including its intellectual and geographical structure. Knowledge mapping also allows us to ask and answer questions like, who are the key authors within the field of social science[2] XR research? Or where is our knowledge geographically emanating from? Or who is funding this work and how democratized is the knowledge (i.e., what is its open access status)? Examined over time, knowledge mapping may also reveal paradigm shifts within a research field.

Whereas the sections on XR theory, methodology, language, and technologies that follow draw from 344 peer-reviewed articles published within three specific journals dedicated to XR research[3], this section takes a more expansive approach. In order to map out all of the peer-reviewed, social science publications in English during 2022 and to compare them to XR research efforts across disciplines, this section draws from two wider bodies of work:

- 1,457 articles, which make up all of the accessible, peer-reviewed social science publications in English during 2022.
- 8,219 articles, which include the 1,457 articles from social science publications, and all accessible, peer-reviewed articles from other disciplines that have published research in English related to XR in 2022.

For more details about the selection criteria and specific methodology applied for this review please refer to the appendix.[4] The findings from the knowledge mapping review first situate social science XR research contextually and historically, and then delve into questions of authorship, affiliation, and funding.



Matthew O'Donnell teaches applied data science at the University of Pennsylvania's Annenberg School for Communication, with classes focused on data storytelling, automated content analysis, and generative text AI in relation to Communication theory and method. Matt's research uses methods from computational social science, including natural language processing, machine learning and network analysis. He is interested in combining linguistic analyses of media language and persuasive discourse with behavioral, neuroscience, and XR approaches.

Katie Rawson is Director of Library Services and Operations at the University of Pennsylvania's Annenberg School for Communication. She's held positions in digital scholarship, learning innovation, and publishing. She has published on data curation, academic collaboration, computational methods, and food culture. Whether studying data models or short-order cooks, her research focuses on ways of knowing.



Zippia. "25+ Amazing Virtual Reality Statistics [2023]: The Future Of VR + AR" Zippia.com. Feb. 27, 2023, <https://www.zippia.com/advice/virtual-reality-statistics/>

Figure 1 below shows that social sciences made up a relatively small percent (~10%) of the overall pool of 8,219 XR-related articles in 2022. As might be expected, computer science was the output leader followed by engineering and medicine, which together accounted for about 55% of the total publication output. There are several reasons for this imbalance, including the fact that the latter are all applied fields, not only at the forefront of using XR technologies, but also actively developing them.

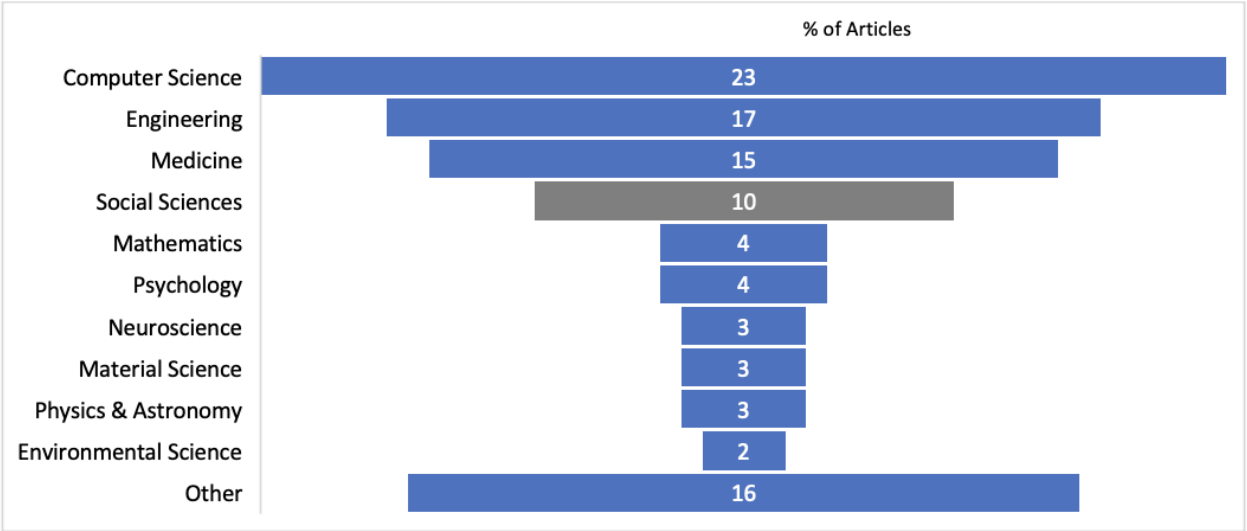


Figure 1: 8,219 XR Research Documents Published in 2022 by Discipline[5]

Nonetheless, there has been an increase in interest in XR in the social sciences, as evidenced by the upsurge in publications within the last decade (See Figure 2). This momentum coincides with what is often called the second wave of XR; that is, the phase during which XR tools became commercially available due to technological advances and lowered costs. Nonetheless, it is worth noting that the majority of the articles in both, the social sciences set, and the overall 2022 XR publication set, set were specifically about VR experiences and technologies

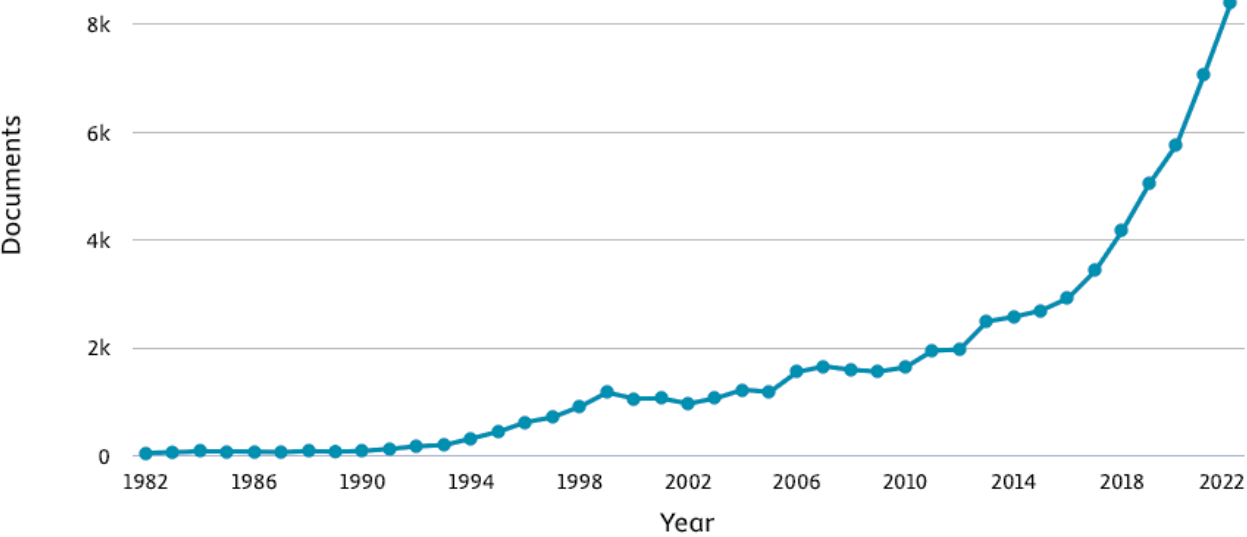


Figure 2: Social Science XR Publications 1982-2022

Notably, a high percent of the 1,457 social sciences articles published in 2022 were from the field of education. Furthermore, four out of the five most prolific authors (Huang, H., Mantri, A., Cheng K-H., and Makransky, G., in order of number of articles published) in the social sciences were writing about education-related topics. Upon closer review, many of these articles were inspired by the recent educational upheavals caused by the COVID-19 pandemic and examine facets of distance learning in an often-implicit precaution to similar events in the future. In fact, many of the educational or professional training advances in XR research are framed as much within the hype of democratized online learning as they are in preparation for further global doomsday mitigation.

GEOGRAPHIES OF KNOWLEDGE PRODUCTION

Out of the 8,219 XR articles published in 2022, China was the leading intellectual source (22%), with the US in second place (20%). Within the scope of social sciences XR articles these two positions were reversed, but the output gap was significantly bigger: China accounted for 13% whereas the US for 22% of publications. Figure 3 below shows the most social science research-prolific countries globally.

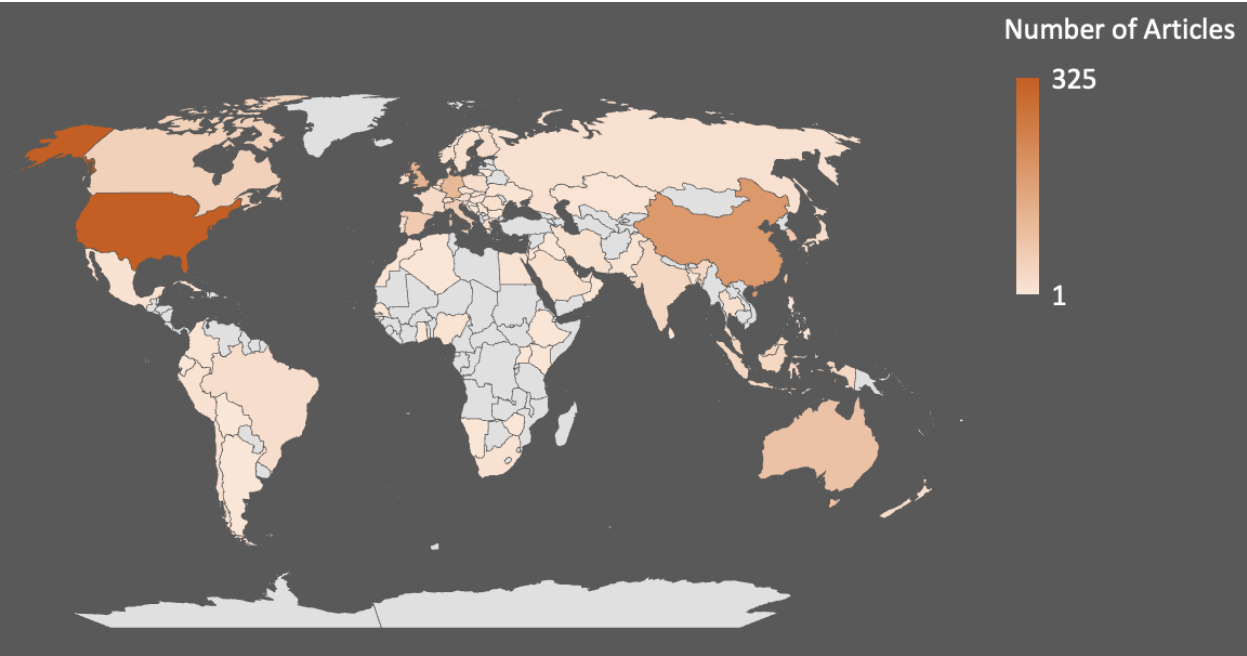


Figure 3: Social Science XR Publications in 2022 by Country

AUTHORS AND AFFILIATIONS

Over 90% of all social science XR articles were co-authored. Further, the most prolific institutions in terms of XR social science output all house multiple XR labs or departments conducting related research. The most prolific institutions were: National Taiwan Normal University, University of Florida, University of Toronto, University of Singapore, Monash University, and National Taiwan University of Science and Technology. This is a promising indication of institutional support for an emergent, global field of research. It is also a reminder of the cross-disciplinary nature of XR research, and the knowledge-production benefits of academic institutions with multiple XR labs or experts from different disciplines. Notably, as the findings suggest, it is still possible for smaller institutions and individual XR researchers to attain similar synergies through external collaborations.

On a broader scale, from the total 8,219 publications across all disciplines in 2022, the top 10 academic affiliations in XR knowledge production were all based in France, China, UK, Canada and Australia. The most prolific affiliation of output is CNRS (Centre National de la Recherche Sceintifique), which is a French state research organization and the largest fundamental science agency in Europe, with a production of just over 1% of all publications. While no single organizational affiliation dominates the research output – the most prolific one accounts for just over 1% of works – the top three organizations are all national-level bodies, which demonstrates the present importance of XR technologies. For comparison, every one of the top ten social-science publishing institutions was university. Similarly, no single institution dominated the social sciences research in 2022, with the top institution, National Taiwan Normal University, accounting for just 1% of the overall publications.

KEYWORDS

The keywords reveal that the overarching themes of education and learning dominated the XR social science agenda in 2022. In addition, COVID-19 and terminology from cognitive psychology suggests two further contexts driving work.

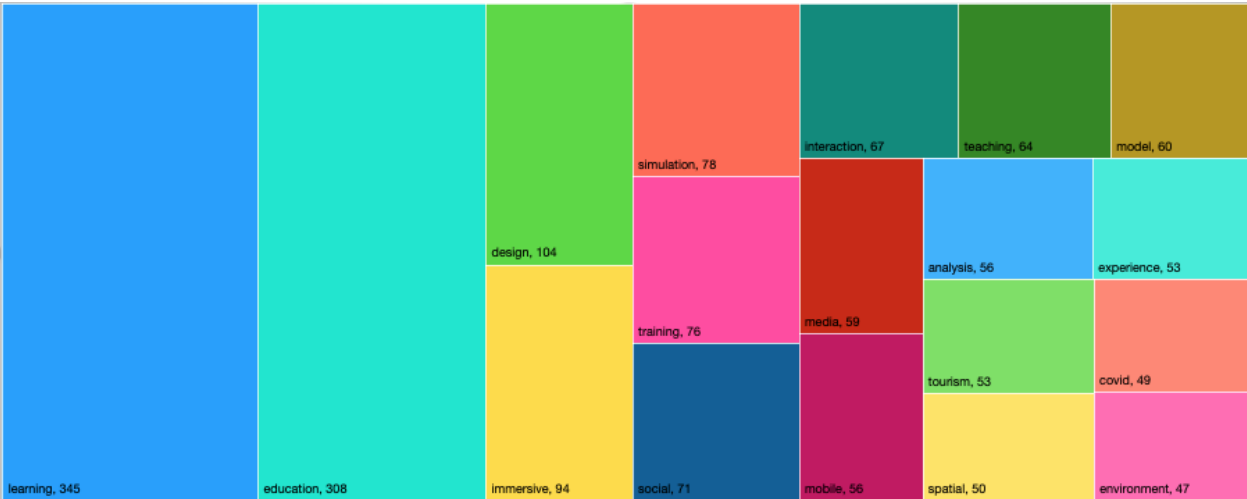


Figure 4: Top 20 Keywords from XR social science articles in 2022[6]

SOURCES

Figure 5 below shows the ten most actively publishing journals for XR social science research in 2022. In addition, the three core journals dedicated to XR research, which are the main subject of analysis of the remainder of the sections of this publication, are listed at the top of Figure 5 in blue.

Journal Name	Number of Articles
Virtual Reality	211
Frontiers in Virtual Reality	111
Presence: Virtual and Augmented Reality	22
Sustainability Switzerland	93
Education and Information Technologies	39
International Journal of Emerging Technologies in Learning	30
Proceedings of the ACM On Human Computer Interaction	26
International Journal of Human Computer Studies	22
Computers and Education	21
Building and Environment	18
Computer Applications in Engineering Education	18
Education Sciences	17
BMC Medical Education	16

Figure 5: Articles per Journal

FUNDING AND ACCESS

The leading journals by number of XR publications cluster around education, human-computer interaction, and environmental issues. Education is the leading context of social science research; however, sustainability and the environment make a notable appearance in 2022.

Almost half (49% or 725 papers) of the articles designated as XR social science research were backed by some form of funding. The main funding bodies were national-level agencies, such as numerous Ministries of Education and the European Commission. As figure 6 shows, four of the five top funding sources were based in Asia (specifically Taiwan, China, and Korea). This suggests that XR is a national research priority field with numerous practical applications. It is also worth noting that hardware manufacturers like HTC, Meta, and Pico are mostly located within these top three countries.

Funding Agency	Number of Grants
Ministry of Science and Technology, Taiwan	19
National Natural Science Foundation of China, China	16
National Science Foundation, US	14
Japan Society for the Promotion of Science, Japan	9
Ministry of Education; National Research Foundation of Korea, Korea	9
Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research, Germany)	7
Australian Research Council, Australia	6
Ministry of Science and Technology of the People’s Republic of China, China	6
Ministry of Science, ICT and Future Planning; National Research Foundation of Korea, Korea	6
Nederlandse Organisatie voor Wetenschappelijk Onderzoek (Dutch Research Council; the national research council of the Netherlands)	5

Figure 6: Funding Sources of Social Science Research in 2022

While XR education and training-related research was common across all grant-funded work, some country-specific differences in additional priority contexts did emerge. Grant-funded research emanating from China and Taiwan focused on developing manufacturing, building, and tourism-related XR research. Work funded in the US had a mental-health focus, and grants from Taiwan favored work advancing technical developments and ways to stimulate creativity.

Half of the articles were classified as open access, which leaves room for improvement in the democratization of knowledge; specifically, if the work is designated of national-level importance.

1] Chen, C. (2017). Science mapping: a systematic review of the literature. Journal of data and information science, 2(2), 1-40. <https://doi.org/10.1515/jdis-2017-0006>

2] Our working definition of social science research refers to work that explores human society and social relationships. This includes fields such as sociology, psychology, and communication studies amongst others. However, it is worth noting that the exact selection criteria and algorithms the Scopus database used to determine what articles classify as social science are not made explicit and they do certainly affect the data obtained, even if in minimal ways.

3] The 344 articles represent all of the research publications in 2022 from the following three journals, which are specifically dedicated to XR studies: Frontiers in Virtual Reality and Virtual Reality and Presence: Virtual and Augmented Reality.

4] The following string query was updated and used in Scopus on January 23rd, 2025, to obtain the results:

TITLE-ABS-KEY ("XR" OR "VR" OR "mixed reality" OR "virtual reality" OR "extended reality" OR "augmented reality") AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (PUBYEAR , 2022)) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "IMMU") OR EXCLUDE (SUBJAREA , "PHAR") OR EXCLUDE (SUBJAREA , "CHEM"))

5] The category labeled 'Other' consisted of a range of smaller publication fields like Earth Sciences. In addition, some of these categories are not mutually exclusive but Scopus seems to have categorized the articles into disciplines based on the highest relevancy.

6] Keywords are based on the top 20 author-identified keywords across the 1,457 social science articles.

THEORIES IN XR, 2022

Maxwell Foxman

The theoretical thrust of major journals mostly derives from the proliferation of XR technology. Scholars enlisted established psychological theories from the 1960s through the 1990s (e.g., Minsky, 1980) regarding the effects of immersive media on users to support their subject-specific arguments, in part because of their prominence in studies of VR research. Papers in *Presence*, *Virtual Reality*, and *Frontiers of Virtual Reality*—the journals we studied—drew from disciplines like healthcare, industrial design, Human-Computer Interaction (HCI), and Game Studies. The articles centered on testing VR in relation to the aforementioned sectors. For example, several *Frontiers of Virtual Reality* essays explored the technology's ability to foster telepresence to intervene in physical therapy (Elor et al., 2022) or temper body image disorders (Döllinger et al., 2022).[1] Core psychological attributes that distinguish VR were apparent across studies. Writers seemed to draw conceptually on the broader set of theories that frame VR as a complex communications technology made up of innovations in tracking, rendering, and display of digital representations and avatars (e.g., Blascovich & Bailenson, 2012). Some major theoretical strands, to be discussed further and in the annotated bibliography, leaned heavily on the following concepts: presence, a sense of “being there” (Heeter, 1992); embodiment, or the ability to “change one’s character or perspective” (Lachmair et al., 2022); avatars, or a “graphical representation of a user in a virtual world” (Lin & Latoschik, 2022); and cybersickness, or motion sickness caused by virtual environments experienced in Head Mounted Displays or HMDs (Sato et al., 2022). These were sourced to confirm and advance central assumptions about XR. For instance, Mel Slater’s (2009) groundwork on presence was a “hallmark of the VR experience” (Hartmann & Hofer, 2022) that, when combined with other factors, produced a medley of related phenomena, including spatial, tele- and co-presence. In other words, scholars deployed such ideas and terms to develop measures (e.g., Hayes et al., 2022) and protocols (e.g., Ziabari et al., 2022) for their research interests.[2]

Most of *Virtual Reality*’s articles apply cognitive concepts and frameworks from psychology to explain processes of attention, memory, and decision-making. The theories of Reasoned Action (TRA) and Planned Behavior (TPB) were invoked in learning or training using XR. In most cases, the goal was to observe and evaluate interactions between one’s cognitive processes and behaviors in XR environments. There were also variations on TRA and TPB. The Technology Acceptance Model (TAM), augmented by the cognition associated with technology use and the notion of flow (Davis & Csikszentmihalyi, 1977), contributed to

the magnitude of positive feelings, experiences, and creative capacities found in users in a given scenario. In *Frontiers of Virtual Reality*, pieces on HCI referenced Quality of Experience (QoE) that determined the “degree of overall satisfaction or annoyance gained” (Fang et al., 2022) from an application. Fewer journal entries broached theories from the managerial/organizational domain. However, about half of *Virtual Reality*’s articles and even more in *Frontiers of Virtual Reality* and *Presence* lacked explicit references to theories. The annotated bibliography contains examples from these journals that use theory in empirical work, as well as more conceptual pieces.

THEORIES FOR PRESENCE, EMBODIMENT, AVATARS, AND CYBERSICKNESS

Presence was supported by other models, such as co-presence—a sense of togetherness with another (Slater et al., 2022); social presence—or feeling like being with another (Glémarec et al., 2022); and spatial presence—being in a virtual environment (Barreda-Ángeles & Hartmann, 2022). Underlying these were psychological theories involving illusion: Place Illusion Theory asserted the need to believe in depicted VR spaces; and Plausibility Illusion Theory underscored the importance that events in VR feel like they are actually happening (Slater et al., 2022). In *Frontiers*, under the aegis of these theories, researchers tested XR limitations (Latoschik & Wienrich, 2022), designed mindfulness experiences (Kelly et al., 2022), and even delved into issues like how adding sonification might enhance a user's feeling of presence (Bremner et al., 2022). A handful of articles debated these theories. Authors in *Presence* argued against a binary understanding of presence—as in believing we are, or are not, somewhere—because that can make it seem like our mind is monolithic. They advocated instead that more attention should be applied to the user who actively contributes to the overall illusion of the experience (Murphy & Skarbez, 2022)—see the full bibliography in the language section of the digest. Another article suggested that congruence provided more consistent spatial cues in virtual environments than presence (Latoschik & Wienrich, 2022). Hartmann and Hofer (2022), as featured in this annotated bibliography, similarly advocated that presence should always be considered with a general “media awareness” that users take into their XR experiences, rather than assuming they are completely transported to another space.

Integral to user activity are theories of embodiment, which likewise proceeded from psychological activities including cognitive load, plausibility illusion (including body ownership in virtual environments), and their connection to presence. Emerging from 20th-century scholarship on the interaction between vision, touch, and the perception of physical actions (Botvinick & Cohen, 1998), body ownership when tested specifically in avatars found that inhabiting them could lead to “physiological, behavioural, attitudinal, and cognitive changes” (Slater et al., 2022) in users. Studies in 2022 used the same theories to elucidate how changes in representation affected everything from perceptions of body weight (Döllinger et al., 2022; van der Waal et al., 2022) to skin color of virtual hands (Pohl & Mottelson, 2022) and went as far as to gauge police officers’ empathy toward Black suspects (Kishore et al., 2021). Also measured were the limits of body ownership along vectors like splitting bodies in two (Kondo & Sugimoto, 2022) or changing size and scale (Pouke et al., 2022). Studies of cognitive load

found how, in various users—such as medical patients (Chaby et al., 2022)—communicating through embodied virtual agents influenced thinking and helped avoid abrupt demand for attention when measured through an electroencephalogram as part of research into cognitive load and brain activity. This study suggested that different levels of embodiment (from matching gestures to gaze) can have trade-offs in users’ brains (Chang et al., 2022).

With respect to agents, studies of avatars favored ideas of identification, or the “shift in media users’ self-concept to include aspects of an avatar’s characteristics” (Rheu et al., 2022). Identification was often tied to realism, with some papers turning toward the Uncanny Valley theory (Mori et al., 2012), which posits that avatars’ realism quickly slips from pleasant to uncanny, especially in XR (Wolf et al., 2022). Researchers utilized this notion to ascertain the extent of realism needed in virtual agents, suggesting that only certain parameters like facial expression were necessary for identification (Oker, 2022), or even that realism was not necessarily a key factor in avatars’ persuasiveness. The Proteus Effect, in which attitudes and behaviors of users in actual and virtual worlds match their avatars, affirmed claims that completely realistic graphic fidelity might not be necessary (Kyriltsias & Michael-Grigoriou, 2022). In other words, the research indicated an enduring interest in the extent to which realism impacted embodied self-identification, which was fueled by positive results. For instance, one article proposed that altering representation (such as skin color) could change perspectives on social issues, specifically that adjusting a user’s hand color was found to reduce implicit racial bias in white participants (Ambron et al., 2022). The authors proposed that embodiment and affiliated shifts in perception happen within a few seconds and could be an important step in using XR for interventions “to favor inclusion and social integration between different racial groups.”

Additionally, some work scrutinized representation through the parallel concept of digital twins, or a virtual copy of a product meant to stimulate an actual product fully and accurately as it is especially utilized in industrial design (e.g., Sharma et al., 2022). However, these were treated more atheoretically and usually referenced as proofs of concept for software and protocols (Weistroffer et al., 2022).

Studies aiming to combat cybersickness leaned on several presumptions about motion sickness. These included:

- Sensory Conflict Theory, which states conflicting visual-vestibular and somatosensory signals cause sickness.
- Postural Instability Theory, which contends that unnatural or unexpected motion impacts user stability.
- Eye-Movement Theory, which claims that the sensory and motor signals used to stabilize a virtual image “innervate the vagal nerve” (Adhanom et al., 2022).
- Sensory Mismatch Theory, which examines mismatched senses associated with body movement (Brown et al., 2022).
- Issues of vection, where Expectancy Violation Theory, as well as Sensory Rearrangement Theory, convey similar neural mismatches when it comes to illusions of self-motion (Teixeira et al., 2022).

Therefore, while some of the aforementioned psychological theories tended to concentrate on how we think of ourselves when taking on a virtual body, studies of cybersickness treated negative reactions to virtual environments as symptoms that needed to be solved. Clearly, XR developers and researchers are still struggling with ways to address ongoing problems of properties like gender and age as measured in surveys and experiments (e.g., Bailey et al., 2022; Brown et al., 2022; Hejtmánek et al., 2022; Suwa et al., 2022), and therefore can present very practical barriers to adoption by large segments of the population.

Finally, some work pushed beyond the standard psychological and physiological theories by drawing on frameworks from scholars’ specific fields: investigating the dark side of flow in VR gambling (Oberdörfer et al., 2022); applying Self-Determination Theory to XR experiences (Piumsomboon et al., 2022); Attention Restoration Theory to explore mindfulness (Sadowski & Khoury, 2022), or even narrative story-living—where users participate and feel as if they live within the drama (Vallance & Towndrow, 2022)—and technological affordances (MacCallum, 2022) to influence the design of content. These theories were often used to answer specific questions about issues like gambling or narrative construction rather than making general claims about immersive media. Only a handful of articles focused on developing core psychological concepts around presence, plausibility, and embodiment, some of which can be found below in the affiliated bibliographic entries. Together, our analyzed corpus suggests that in 2022 there was room to amplify and further evaluate theories key to understanding XR. Few authors questioned long-standing assumptions but instead used them as foundations

for empirical work. This position reinforces the psychological benefits of the technology, where presence or embodying avatars in VR may lead to better communication between individuals, while not necessarily questioning the broader culture and context in which these technologies are embedded, which is discussed in the next section.

CRITICAL AND CULTURAL PERSPECTIVES

As XR finds wider audiences, the three journals we analyzed eschewed critiques of race, gender, class, and other cultural conditions. Probes into these aspects can be found in journals not solely dedicated to the medium and are being tackled by groups like the Critical Augmented and Virtual Reality Network (CAVRN).[3] From the political economy perspective, academics situated XR within the broader “platformization of cultural production” (Poell et al., 2021), where platform logic is extended to XR itself. As described in the annotated bibliography below, Egliston and Carter (2022) studied Meta/Oculus’ evolution through their Reality Labs initiative, arguing that a dynamic mode of control happened between the company and third parties ranging from businesses to developers and academics. Meta acquired or brought these actors into their ecosystem through a programmable technical infrastructure and associated policies. Chia’s (2022) work similarly tied the metaverse’s growth to the platform logic of game engines, reminding readers of their broad use beyond gaming and how they lock-in norms from this industry into metaverse production. Harley (2022) critically interpreted the discourses surrounding VR and Oculus, stressing how the technology, despite its many years in the public imagination, is still associated with language of newness; the use of colonialist concepts like pioneering and wild west suggest it provides new terrain to be conquered. The annotated bibliography on language provides a full summary of this article.

Engaging with theories from media psychology, Bengtsson and Van Couvering (2022) used glitches to explore how presence and plausibility can be rethought in relation to theories of gender. Their work is discussed in the annotated bibliography along with Raz (2022) who rigorously approached XR’s potential as an “empathy machine,” although notably in the three journals which made up the bulk of our focus, this particular topic appeared less than it might have in previous years (e.g., Oker, 2022; Pratviel et al., 2022; Zhang et al., 2022).

Numerous theoretical positions, however, remain unchallenged. The cultural experience of both producers and consumers of XR in their adoption, use, and negotiation of the technology is especially understudied, particularly when compared to the taken-for-granted concepts of presence, embodiment, avatars, and cybersickness. Somewhat ironically, even as XR’s sway extends into new terrains, fields, and professions, the very people championing and making use of it are still inadequately represented compared to those propounding theoretical assumptions about VR as a tool for media psychology.

ANNOTATED BIBLIOGRAPHY

Kaimara, P., Oikonomou, A., & Deliyannis, I. (2022). Could virtual reality applications pose real risks to children and adolescents? A systematic review of ethical issues and concerns. Virtual Reality, 26(2), 697-735.

The authors systematically review 85 articles to identify and classify three of VR’s primary harmful effects on children and adolescents. The categories include damaging physical, cognitive, and psychological byproducts that frequently result from overuse. Notably, children do not have a decently developed capacity to distinguish between make-believe and reality. Thus, the authors recommend adults help younger participants disconnect from VR experiences. Furthermore, as more modern developmental theories strive to take a life-long approach to learning, the authors encourage future researchers to consider physical, cognitive, and psychological factors of XR use. Of the articles surveyed, only one adopted this integral strategy.

Chia, A. (2022). The metaverse, but not the way you think: game engines and automation beyond game development. Critical Studies in Media Communication, 39(3), 191-200.

Chia applies the frame of platform studies to critique modern conceptions of the metaverse and claims the importance of game engines and similar software in understanding XR. The close connection between the way games are made and the metaverse renders content and people within gaming’s cultural norms. By using the same tools as game developers, the logics of these platform tools (Foxman, 2019) are locked into assumptions about what content is best for the metaverse. The work aligns VR studies with material conditions of production, along with general issues surrounding media archeology, and critical and cultural concerns to include the broader contexts in which XR technology is being adopted by the general public.

Bengtsson, L., R. & Van Couvering, E. (2022). Stretching immersion in virtual reality: How glitches reveal aspects of presence, interactivity and plausibility. Convergence. <https://doi.org/10.1177/13548565221129530>

While much of XR literature focuses on the fidelity of immersive experiences, Bengtsson and Van Couvering introduce specific glitches into an experiment to better discern gender inequalities. These consisted of scenarios like meetings where the user is acknowledged but then is glitched by not being able to do anything other than observe the other participants as the scene unfolds. The authors find that such glitches, particularly when based on gender, affect different users’ experiences, leading to more critical reflection. The result is a study that adds cultural complexity to core theories surrounding the interactivity and plausibility of

XR media, forming a robust framework to account for issues of immersion.

Raz, G. (2022). *Rage against the empathy machine revisited: The ethics of empathy-related affordances of virtual reality*. *Convergence*, 28(5), 1457–1475. <https://doi.org/10.1177/13548565221086406>

While many have argued about the controversial definition of VR as an empathy machine (e.g., Foxman et al., 2021), Raz specifically looks at the ethics of embodiment. To better assess the relationship between empathy and inhabiting an “other,” they draw on psychophysiological evidence and theory to explain how users can be manipulated into novel modes of perceptual and conceptual transformation. This viewpoint not only brings ethical considerations to core VR concepts, but also addresses the other through the technology. Ultimately, the author successfully acknowledges that VR itself may afford complicated and even problematic means of creating a kind of “placeholder” embodiment that is devoid of “biography and independent personality.”

Egliston, B., & Carter, M. (2022). *‘The metaverse and how we’ll build it’: The political economy of Meta’s Reality Labs*. *New Media & Society*. <https://doi.org/10.1177/14614448221119785>

Egliston and Carter examine the expansion of Meta’s XR industry. Their historiographical study of Meta’s Reality Lab initiative finds that the company deployed a number of economic, policy, and data forms of capture to expand the notion of XR as a programmable platform. Relying heavily on a theoretical stance informed by the political economy of platforms and infrastructures, they address issues of production via software development kits and other material norms for producers. Their approach reveals a dynamic and complicated relationship between Meta’s top-down regulations and the influence of other actors like academics.

Norton, W. J., Sauer, J., & Gerhard, D. (2022). *A quantifiable framework for describing immersion*. *Presence*, 29, 191–200.

This article explores a key concept of XR technology, namely immersion. The authors put forth an abstract model, building on Slater’s (2009) theory, that sets quantifiable units for studying levels of immersion. By instituting an immersed sensory spectrum and field metrics, the authors are able to establish a practical scale that is rich with implications for future work. In particular, Norton, Sauer, and Gerhard suggest a measurable gulf between rational and theoretical sensibility. Thus, their research further explains how users of current

XR devices may have different immersive experiences because not all hardware immerses equally and can also differ based on personal factors and senses.

Hartmann, T., & Hofer, M. (2022). *I Know It Is Not Real (And That Matters) Media Awareness vs. Presence in a Parallel Processing Account of the VR Experience*. *Frontiers in Virtual Reality*, 3. <https://doi.org/10.3389/frvir.2022.694048>

In this theoretical paper, Hartmann and Hofer tackle the core concept of presence and the plausibility illusion to argue for a new means to apprehend the psychological experience of XR devices. Rather than feeling an acute sense of presence, they contend that VR is more of a dualistic experience. They consequently advocate for media awareness, enabling users to be more conscious basically or dynamically of the artifice of virtual environments. As a parallel to the notion of presence, the work suggests an increasingly comprehensive theory of psychological experiences with the technology where both components shape the overall user experience.

Slater, M., Banakou, D., Beacco, A., Gallego, J., Macia-Varela, F., & Oliva, R. (2022). *A Separate Reality: An Update on Place Illusion and Plausibility in Virtual Reality*. *Frontiers in Virtual Reality* (3). <https://doi.org/10.3389/frvir.2022.914392>

Slater and colleagues return to core theories regarding XR technology that the scholar pioneered throughout the 2000s. This piece tackles presence and its relationship to the plausibility illusion. Reviewing different methods of measuring presence, this work adds important dimensions to the theories behind the concept. For instance, the authors not only argue that the plausibility illusion is a complex factor that requires both psychophysical and qualitative methods to better understand XR’s efficacy but also advocate that participants are always, to some degree, aware of their place in virtual environments.

Aeschbach, L. F., Opwis, K., & Brühlmann, F. (2022). *Breaking immersion: A theoretical framework of alienated play to facilitate critical reflection on interactive media*. *Frontiers in Virtual Reality*, 3. <https://doi.org/10.3389/frvir.2022.846490>

The authors draw on key theories of play to better analyze immersion. They propose a new theoretical basis of immersion which they define as “alienated play,” where pleasure in interactive media is drawn partly from observing oneself playing. Referencing long-standing video game conceits, such as the procedural rhetoric embedded in game mechanics

(Bogost, 2010), they put forward divergent theories of approaching XR, specifically those that allow for more critical reflection of users' positions in virtual environments which will assist designers in evaluating the role of immersion in their practice.

Barreda-Ángeles, M., & Hartmann, T. (2022). Hooked on the metaverse? Exploring the prevalence of addiction to virtual reality applications. Frontiers in Virtual Reality, 3. <https://doi.org/10.3389/frvir.2022.1031697>

In this original research, Barreda-Ángeles and Hartmann confront an age-old question in media and communication studies: the addictive quality of VR. They find, through surveying 754 VR users on issues of addiction, somewhat unsurprisingly, that immersive applications are not more addictive than other technologies. However, by connecting research to key theories surrounding flow, presence, and embodiment, they are able to disentangle some leading indicators for addiction for the small subset of those who may be susceptible. Specifically, time spent in VR, and the associated sense of embodiment may be two predictors.

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Barreda-Ángeles, M., & Hartmann, T. (2022). Hooked on the metaverse? Exploring the prevalence of addiction to virtual reality applications. *Frontiers in Virtual Reality, 3*. <https://doi.org/10.3389/frvir.2022.1031697>

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1. To elucidate how theories were used in articles from these journals, one of us actively read each article and then compared notes/summaries to draw conclusions about the prominence of certain theories, and more importantly how they were employed.
2. These are not the only major areas of theoretical interest in VR/XR research which have long included other topics like artificiality, interaction, simulation, and networked communication, among other subjects. For more on these traditional areas, see Heim, 1993.
3. <https://cavrn.org/>

XR METHODS AND METHODOLOGIES

Katie Rawson

This analysis considers two things: 1. What research methods are currently used in three major journals dedicated to extended reality or XR (Virtual, Frontiers in Virtual Reality, Presence: Virtual and Augmented Reality), and 2. from a communication perspective, what do the ways of knowing used in these studies suggest about the field? In particular, two elements seem central to methods in XR: how we treat the body as a space for evidence and, in that vein, how we approach subjective and objective modes of evidence.

Much of the research published in the journals surveyed is experimental. Authors conducted human subjects research, which used physical measures (like heart rate and an electroencephalographic, or EEG, test to monitor reactions in the brain), subjective standardized questionnaires (like the Motion Sickness Questionnaire), or measured actions (walking, pegboard tests, performance in a test). Other conducted technical experiments that compared the performance of systems (e.g., An, 2022; Genova 2022).

MEASURING THE BODY

Given the level of physicality that is key to experiences in XR – a physical embodiment that often surpasses previous media – it is not surprising that many of the studies focus on measuring the human body. These studies employ two approaches to making knowledge from people’s bodies: observing and combining observing with asking.

In the first kind of study, people are monitored. Studies track eye, body, or face motion; people’s position in space; or their distance from objects and encounters with them. Most of this work is aimed at either improving the mechanics of XR (e.g., W. Kim 2022, H. Liu 2022) or learning how people respond in XR (e.g., Pastel 2022, Goncalves 2022).

Second, in the combined methods approaches, researchers monitor participants’ brains and hearts to interpret how they respond to XR in combination with responses to surveys and other subjective instruments (e.g., Z. Chang 2022, Krokos 2022, Lemmens 2022, Ventura 2022). For example, Lemmens et al. (2022) combined four subjective measures, surveying attitudes and feelings, with objective measures like heartrate. One study explores the possibility of supplanting a frequently-used subjective measure for cybersickness with an EEG measurement (Krokos & Varshney, 2022). Noting the methodological challenges of either interrupting a subject or asking them to recall their experience, this study argues for using an EEG measurement for real-time feedback about cybersickness in subjects. EEGs have been effectively used in previous motion sickness studies, and this study shows promise for this method.

In these studies, the body becomes homogenized by design. Despite the fact that different people are being recorded, the studies are based on the idea of a shared set of bodily responses.

USER EXPERIENCE

Another significant proportion of articles are observational studies, including quasi-experimental work and user studies. The most notable trend here is the role of UX (the abbreviation for user experience from the field of design). In the XR literature broadly, there is a split between researchers conducting and describing their work as research studies and those describing their work as user studies (e.g., Pan, Alves, Jin, Risso, 2022). In part, this reflects the prominent role of design and development in the field – often the research write-up is describing a technological or platform advance. User testing is a sound approach to establishing the achievement and value of technical innovation.

However, UX and research studies have different underlying assumptions about value. Research studies are designed around knowing through verifiable practices, whether those are controlled experiments or discipline-constrained observation. UX, on the other hand, prizes individual experiences and preferences over disciplinary knowledge derived from shared methods. Users’ desires and behaviors determine the success of a user study – and the outcome, in this case, is usually to shape a technology toward users. In a field that is technologically fertile, it makes sense that we would see a balance of standard academic knowledge creation and user-focused UX studies. For social science researchers, this raises questions about how they approach a UX forward technology as they assess its social significance and, at the same time, might offer insights in methods for using XR for teaching, treatment, and research. We may also see a shift in the UX-framed studies that adopts other research methods, including mixed methods that combine scaled (e.g., surveys) or measured (e.g., EEG) responses with in-depth ethnographic observation.

We can see the ways that UX approaches are part of the XR research even in publications that are framed as more traditional scholarship. The social science research on XR often concerns effectiveness. Most of the literature measures XR techniques for effective learning (e.g., Hammar Wijkmark, Jeong, Papagiannakis) or therapy (see literature review from Weibe 2022), but there are also publications on communication and pleasure-based experience like tourism, art, and relaxation (e.g., Hall, Crolla). For many of those studies, the methods are a tried-and-true mixture of pre- and post-tests alongside questionnaires analyzed in forms that are similar to the study of other practices, treatments, or interventions.

OTHER METHODS

Researchers are also beginning to use VR as a tool in their methods. Unlike the efficacy experiments that have VR as their subject, these are studies that use virtual environments to explore the answers to social science questions. For example, Line Tremblay, Brahim Chebbi, and Stéphane Bouchard's research on body image uses VR and haptics, but its question is fundamentally about body image and anti-fat attitudes. It uses the affordances of VR to assess and validate theories in a controlled experiment. While much of the VR literature grapples with how to understand and create presence, this work takes the affordances of presence in order to study people in bodies.

Lastly, the articles from 2022 include a series of reviews (e.g., Atsikpasi, Hoffman, Lin, Sadowski) and literature-based theoretical models (e.g., Huang, Stohman), which speaks to the build-up of a critical mass of XR literature in a field where development is moving quickly and, at the same time, the structures of assessment and understanding are being built and debated.

It should be noted that there is a dearth of anthropological and in general qualitative methods. While there are a few ethnographic approaches to VR published in 2022 (Blackman 2022, Pike 2022), the use of participant observation, in-depth interviews, longitudinal studies, and other methods that involve human interaction and observation over extended periods of time (rather than the duration of the test or through a survey) are lacking. These are methods that seem like they could provide us with better ways of understanding and informing extended reality, given that it is a medium, as the documentary film *We Met in Virtual Reality* suggests, that people inhabit.

As we consider methods in XR, the content as much as the method of these works suggest that continuing to explore the body. What it means to be in a body and to use the information people get from their bodies, including for communication purposes (i.e., how we signal to each other, how we interpret signals, how we interact) are key topics for consideration. XR literature started in the fields of engineering and computer science and has been adopted in medicine and tech business but is still in the periphery of the social sciences. The methods in many of these publications reflect this, skewing toward the scientific and technical, controlled, or quasi-experiments, and not deep in qualitative or critical work. The range of methodologies to build knowledge may be expanded by continued broader engagement

with XR, whether that is through using VR to test premises or figuring out how to better design and understand experiences and measures of realities.

ANNOTATED ENTRIES

Kroma, A., Grinyer, K., Scavarelli, A., Samimi, E., Kyian, S., & Teather, R. J. (2022). *The reality of remote extended reality research: Practical case studies and taxonomy*. *Frontiers in Computer Science*, 4. <https://www.frontiersin.org/articles/10.3389/fcomp.2022.954038>

Kroma et al. promote conducting more remote studies in XR and elevating best practices and standards in this form of research. Acknowledging that much XR research requires the stringent controls or the access to very specialized equipment of a lab, they describe the possibilities for research beyond those constraints. The pandemic brought with it the challenge and opportunity of doing participant-based research studies without being physically co-present. How can one do XR studies with participants in their own homes rather than in the room with the researcher? Building on principles and practices of other remote human-computer interaction and social science research, they describe six studies and classifications meant to provide a categorical guide for thinking through remote research design in XR. Their system includes five main elements: study, participants, apparatus, researcher, and data collection. Equally significant, they raise a series of issues – things that were repeated but solvable challenges in their case studies, like platform security, study protocol issues, recruitment and motivation, monitoring errors, and equipment delivery – and then research design guidelines to solve some of these issues, including workflow visuals for participants, bullet-proof and bug-free hardware and software, and research participant communities that provide social rewards (in addition to traditional incentives). Further, they argue that because remote study design makes it so that participants don't have to come to a fixed place (e.g., don't have to travel to a university lab) at a fixed time (e.g., sitting in a room from 3 to 5 p.m. on a Thursday), it becomes feasible for more a diverse population to join studies and for studies to be sustained over longer periods of time, which improves the research in the field.

Huang, J., & Jung, Y. (2022). *Perceived authenticity of virtual characters makes the difference*. *Frontiers in Virtual Reality*, 3. <https://www.frontiersin.org/articles/10.3389/frvir.2022.1033709> Aburumman, N., Gillies, M., Ward, J. A., & Hamilton, A. F. de C. (2022). *Nonverbal communication in virtual reality: Nodding as a social signal in virtual interactions*. *International Journal of Human-Computer Studies*, 164, 102819. <https://doi.org/10.1016/j.ijhcs.2022.102819>

In XR literature, scholars often examine the same concept in methodologically divergent

ways. Consider the approach of Junru Huang and Younbo Jung in "Perceived Authenticity of Virtual Characters Makes the Difference" (2022), as opposed to Nadine Aburumman et al in "Nonverbal communication in virtual reality: Nodding as a social signal in virtual interactions" (2022). Huang and Younbo use extant literature and argument-based methods of developing theoretical models to propose how people judge the authenticity of virtual characters. In a series of definitional and deductive steps they establish that these virtual entities are social actors defined by both their moment-to-moment agency and their representation. Their authenticity – defined by trustworthiness, originality, and spontaneity – is created through interactions. Drawing the distinction between realism and authenticity, they note that machine-identified virtual characters can be perceived as more authentic in certain contexts because authenticity is about investment and belief in the interaction that allows for imagination or alternative ways of being real (not unlike people's relationship to fictional characters in books and movies). One of the key factors they identify in their models is the interplay of stated representation and expectations of behavior in interaction (so a character that says it is a machine and then behaves in social interaction like a machine can be more authentic than a virtual character that is hyper-real or humanlike in presentation but fails to act in a natural human way). Most of their model is based on definitional and logical assertion based in years of literature on authenticity and virtual characters with the extension of their model about communicative interactions and authenticity.

Aburumman et. al. on the other hand take up a parallel communication question: verisimilitude and the expectations surrounding social signal, in this case nonverbal communication, but employ a small study, comprising 21 participants. This study used a series of tasks and questionnaires to better understand how people respond to head-nodding, eye-blinking, and facial expressions. They learn that having virtual agents engage in nonverbal communication builds trust – aligning with the theories that Huang and Jung present as well as previous studies on nonverbal communication in VR (which are legion). Neither article developed a novel methodology; however, they illustrate two key paths researchers are taking in creating knowledge in XR – the proliferation of often small, task-based studies (which is the most common approach in the literature we examined) and theoretical studies invested in framing the literature and adding to the models these studies test.

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THE LANGUAGE OF XR

Katerina Girginova

This section examines the language researchers use to communicate about extended reality (XR) media[1]. This was prompted, in part, by a perceived regurgitation of key terms used to describe XR media interactions. Perhaps, this is due to a limitation of available concepts, which may be self-imposed, to describe our complex interactions with this emergent media form. Interactions, which arguably demand more physicality and a higher level of sensorial engagement from the audience than any previous media form. In equal part, this section comes about via a desire to critically push back against some of the terminology being popularized by corporations. Encouragingly, this desire was echoed in some of the publications examined. In turn, a survey of the articles within the three selected journals (Virtual Reality, Frontiers in Virtual Reality, Presence: Virtual and Augmented Reality) plus, the addition of relevant literature on the language of XR reveals three major themes:

- A call for a clarification and de-colonization (an ethical expansion) of terminology used to communicate our XR experiences,
- An augmentation of our understanding of texts and of the work of their creators,
- A focus on comprehending and communicating embodiment (that is, a person's physical experience of their given surroundings and interactions).

Notably, the majority of the articles within the three journals do not focus on issues related to how XR is communicated. They do, however, define the particular technologies and experiences analyzed in their research (augmented, mixed, or virtual reality) through their affordances (the capacities an environment provides its user: see Gibson 1977) and by using largely consistent keywords like presence, immersion, embodiment, and interactivity.

On the one hand, this linguistic consistency in definitions is both practical and useful. It allows for the creation of a body of literature around a particular topic and technology. On the other hand, it is also problematic, because what is actually meant by descriptive terms like presence, or interactivity is rarely clarified. Hence, the first theme emerges around an absence of clarity in the articles, which may lead to false presumptions, measurements, and a further entrenchment of biases. For example, it is not difficult to imagine that defining presence as the illusion of a non-mediated experience versus the willful creation of belief, would color our research focus and subsequent findings in a particular way. The former suggests that VR technology must more or less disappear in order to feel a sense of presence, whereas

the latter makes no such assumptions, leaving room for more complex interpretations between the user and their technology. Authors Murphy and Skarbez (2022) home in on this definitional gap and offer clarification by unpacking this definitive term of virtuality via the question: what do we mean when we say "presence"? - see bibliographic entry below.

Other authors note that the language of platforms, including XR platforms, is largely driven by corporations (Andrejevic, 2022; Harley, 2022). Subsequently, XR technologies and applications get cloaked in a branding rhetoric of newness, which at once obscures their histories and the labor that goes into producing and sustaining them. The need to clarify our terminology and to acknowledge its roots leads to calls for a decolonization of ideologies and the grasp of the corporations often underpinning them. Specifically, authors highlight the problematic connections between virtual reality, the conquering of new frontiers, and public surveillance.

A second theme emerges around an expansion of our understanding of what we consider to be a text and the ways in which its audiences interact with it (D'Armenio, 2022; Mills, Scholes, & Brown, 2022). For example, as moving around an XR environment becomes fundamental to our experience of it, we need to consider how a user's movement becomes a part of reading and writing an XR media text. As such, the perennial questions of media and communication studies surrounding the production and reception of meaning are reinvigorated in the context of XR.

The last theme, embodiment, is another one of the keywords used to describe XR experiences and technologies. Research shows that all human cognition and creativity is fundamentally embedded within the body and within sensorimotor processes (Gibbs, 2005). Therefore, the unique capacity for increasingly embodied experiences in XR opens up the need for a vocabulary to explain these types of interactions between texts and users. D'Armenio (2022) and Bollmer and Suddarth (2022) offer some novel terms and approaches to help us build this communicative understanding. (See annotated entries below.)

In summary, there is a call for a clarification of terminology – for instance, going one additional step of analysis beyond defining virtual reality as immersive – and for an ethical expansion of language used to communicate our XR experiences, particularly by paying attention to

CALLS FOR CLARIFICATION

users' textual embodiment as a process of meaning making. The annotated entries below expand upon each of these themes and offer some of the necessary new vocabulary to take us forward on these paths.

Murphy, D., & Skarbez, R. (2022). What Do We Mean When We Say "Presence"? *PRESENCE: Virtual and Augmented Reality*, 29, 1-43. https://doi.org/10.1162/pres_a_00360

This article, aptly published in a journal named Presence, builds on a survey that catalogues meanings and intellectual roots of the term presence (Skarbez, Brooks & Whitton, 2017). The authors examine additional literature about the term and apply philosophical and psychological lenses to unpack its most common meanings. Three common descriptions emerge: "Presence as (or as following from) "the assumption of disbelief," presence as the "illusion of nonmediation," and presence as "(the feeling of) being there," (pg. 171). The authors analyze the implicit assumptions behind each of these constructions of presence, paying particular attention to how they each connect to attention. In turn, Murphy and Skarbez identify the understandings of presence that seem the most fruitful (and those that do not), highlighting that the notion of presence is further complicated by the idea that "presence has aspects that cannot be probed or shaped by the will and, separately, aspects that can," (pg. 172).

The authors urge those investigating presence in future studies to be specific about the (sub)definitions and assumptions of presence they subscribe to, especially those using instrument(s) to measure presence. Simultaneously, a poignant footnote cautions against the too abundant splintering of the term, which may be equally confusing. In this provocatively oscillating style, the authors raise several additional ideas. For instance, they probe whether the role of the VR user ought to be framed in a positive and agentic light, via her effortfully achieved creation of belief, as opposed to her suspension of disbelief. This points to the call for a clarification of whether the XR experiences we study function via perceptual means only or, via cognitive effort, too. It also raises questions about how we understand audiences in the context of XR.

Murphy and Skarbez also highlight the oppositional experiences of VR users who cannot stop themselves from having physical reactions (like sweaty palms) to certain experiences, like being positioned atop a thin wooden plank as it is suspended high in mid-air above a city, despite their active knowledge that what they are experiencing is not real. At the same time, they note that our very knowledge of the fact that we are using a VR system, no matter how advanced, is enough to pollute our experience, belief, and presence in it. It is here that the authors question the binary conception of presence. It either exists or it doesn't. They

instead advocate for a more nuanced position of thresholds, which must be met in order for presence to occur. What these thresholds look like and for whom is now the challenge of future research to discover.

Harley, D. (2022). *"This would be sweet in VR": On the discursive newness of virtual reality*. *New Media & Society*. <https://doi.org/10.1177/14614448221084655>

This article identifies and analyzes the discursive frames surrounding corporate claims about the newness of VR. The analyses reveal several stages in one's experience with VR, framing the initial contact as pivotal – "all it takes to believe in VR is to put on a headset," (pg. 5) – and the ultimate goal as the conquering of new frontiers.

The author notes that the language of frontiers, pioneers, and colonization, as well as references to VR as a digital wild West, were previously identified by scholars writing about the earlier wave of VR in the late 20th century (Chesher, 1994), and by those working on broader, critical discourses on technology and labor (Nakamura, 2020). Thus, we see a recycling of corporate language in today's new wave of VR, which come to shape much of popular discourses on the topic.

Harley identifies another inspiration for the language, corporate ideologies, and VR workplace cultures pointing to two books: *Snow Crash* and *Ready Player One*. The former novel specifically is often credited with creating the term metaverse, although it more accurately popularized it. For Luckey (Founder of Oculus VR, which was bought by Meta in 2014 and is the world's leader in wearable VR gear) and Abrash (Previously CTO at Oculus, now Chief Scientist at Meta's Reality labs), these books were important communicative tools that shape their own conceptualizations of VR. This remediation and recycling of rhetoric between novels, technologies, corporate environments, and virtual reality experiences is clearly powerful but, as Harley warns, often problematic. Harley references Nakamura (2020) in the context of our current corporate branding of VR: newness, often "comes at the cost of racialized and gendered labor, problematic representations, unequal access, and a "toxic" embodiment of another person's experiences under the guise of empathy and connection," (pg. 3).

Andrejevic, M. (2022). *Meta-Surveillance in the Digital Enclosure*. *Surveillance & Society*, 20(4), 390-396. <https://doi.org/10.24908/ss.v20i4.16008>

This article gives the example of a personalized display board at an airport, aptly named a parallel reality technology by its production company, to reflect upon the increasing recession of the social, a term the author develops to describe the offloading and obfuscation of social relations to automated systems of augmented and virtual reality. Using a combination of recognition technologies, this display board can show the flight details of up to 100 passengers simultaneously thus, customizing our individual experiences of shared spaces.

The term recession of the social is inspired by Haskell's (1977) account of the rise of professional science in the 1800s. Recession, thus, describes not the quantity of communication – this has significantly increased through the use of virtual technologies – but the "capture (and alienation) of the pattern of our communicative social fabric [...] the commercially driven masking and misrecognition of irreducible forms of interdependence," (pg. 393). Of course, Andrejevic reminds us that in contemporary societies interactive digital environments also serve as capital surveillance systems and, when filtered through these analytical lenses, our vision of sociality becomes increasingly fragmented and incapacitated.

RETHINKING TEXTS, AUTHORS, AND THE BODY IN XR MEDIA

D'Armenio, E. (2022). *Beyond interactivity and immersion. A kinetic reconceptualization for virtual reality and video games. New Techno Humanities. 2*(22), 121-129. <https://doi.org/10.1016/j.techum.2022.04.003>

This article refutes the notion that virtual reality media claim a supreme capacity to induce immersion and interaction over other media. Instead, it artfully argues that the fundamental quality of virtual reality experiences is movement both, in the ways that viewers access virtual worlds by moving throughout them, and via the meaning-making that occurs through those movements. The author then proposes and illustrates the concept of a kinetic syntax – a grammar for capturing and analyzing the meaning of movement in VR.

The article notes that analytical attempts to analyze how XR experiences build meaning are still limited and labels like interactive or immersive start from the assumption of a direct correlation between increased sensory involvement and viewer engagement (Catricalà and Eugeni, 2020). Yet, the connection between the two is not a given.

Instead, the author posits that “Interactive media need to be conceived of as movement-images, meaning systems that obey a deep fusion of two syntaxes: the visual syntax, which has already been studied in semiotics and visual studies, and which pertains to the qualities of still images, and a syntax never addressed before, that is, a kinetic syntax which articulates the qualities of the movement itself,” (pg. 2).

In turn, the author proposes that such interactive experiences be understood as movement-images, a reversed and expanded formulation from Deleuze's image-mouvement (1986).

To illustrate how a kinetic syntax might be applied, D'Armenio gives the poignant example of the old puzzle game Tetris. Tetris requires active and skilled movement a player, and which can be seen as a precursor to modern-day virtual reality gaming experiences. D'Armenio argues that the game's increasing speed of vertically falling figures must be matched by increasingly fast and frantic movements of the player, who tries to turn the figures horizontally and to arrange them in order. Ultimately, the author argues that despite being an abstract video game, Tetris can be 'read' to have a universal semantic component: the human struggle against chaos, which is enacted through movement-images.

Bollmer, G., & Suddarth, A. (2022). *Embodied parallelism and immersion in virtual reality gaming. Convergence, 28*(2),

579-594. <https://doi.org/10.1177/13548565211070691>

This article examines how virtual reality and particularly, virtual gaming, produces a sense of immersion through embodied parallelism, a term the authors develop to describe “a technical mediation in which the embodied gestures and movements of a player must correspond to what is represented within a game or simulation, a correspondence which relies on, but exceeds the visual and requires strange requirements for both player (in terms of their gestures and movements) and game (in terms of including particular limits that police the movements of the player's body),” (pg. 581).

This analytical term refuses the assumption that immersion disembodies the user in some way. Instead, immersion is “premised on an explicit engagement with – and not exclusion of – both the physicality of the body and the physicality of the medium, if in deeply contradictory ways,” (pg. 582). Embodied parallelism thus, emerges as a practical technique and analytical term for negotiating between the various material contradictions of one's body and technical apparatus in a VR experience.

Bollmer and Suddarth exemplify embodied parallelism with virtual reality games arguing that becoming good at these games requires the player to discipline her body. They argue that in this context, immersion depends on one's willingness to submit to a dual dynamic; on the one hand, the specific technical demands of a VR medium and on the other, one's capacity to deliberately ignore the materiality of the mediation they are experiencing.

Throughout the article the authors draw fruitful analogies to various historical media and arts, positing that the entire history of both can be viewed either as an attempt to use various technological innovations to create a sense of immersion or, to rebel against immersivity, by creating a reflexive and critical distance from mass culture. Bollmer and Suddarth specifically draw on Wagner's concept of Gesamtkunstwerk (total work of art), which combined poetry, music, dance, and architecture to create an overwhelming experience for his opera audiences. Notably, as part of this illusion, the orchestra and other elements of the production were hidden from sight. Similarly, VR positions the key ingredients of immersion, the body and technology, just out of view in order to be experienced 'correctly' in the game.

Nonetheless, the authors acknowledge that VR gaming and the constant desire to achieve

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a perfect, unmediated experience seem to be largely pursuits of a predominantly male, core audience. Since questions of embodiment are, tangled inseparably from psychology and physiology, it would be important for future research to explore how other populations like women or the elderly experience these sensations, too.

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ADVANCES IN XR TECHNOLOGY

Matthew O'Donnell

This section reviews advances in extended reality (XR) technologies and applications in 2022. To do so, it analyzes the abstracts from the 2022 articles published in *Frontiers in Virtual Reality*, *Virtual Reality*, and *Presence: Virtual and Augmented Reality* to identify key terms, topics, and technologies. Findings are organized into three sections: research themes, which delve into how XR technologies are used in research, hardware, and software. The main themes from the corpus of journal abstracts are identified via topic modeling (Blei et al., 2003) and qualitative analysis. For more information on methodology, please refer to the appendix. The themes below are presented in order of frequency of occurrence in the articles.

Mills, K. A., Scholes, L., & Brown, A. (2022). Virtual Reality and Embodiment in Multimodal Meaning Making. *Written Communication*, 39(3), 335–369. <https://doi.org/10.1177/07410883221083517>

Murphy, D., & Skarbez, R. (2022). What Do We Mean When We Say “Presence”? *PRESENCE: Virtual and Augmented Reality*, 29, 1-43. https://doi.org/10.1162/pres_a_00360

Nakamura, L. (2020). Feeling good about feeling bad: Virtuous virtual reality and the automation of racial empathy. *Journal of Visual Culture*, 19(1), 47-64. <https://doi.org/10.1177/1470412920906259>

1. It is worth noting that the majority of the articles were specifically about VR technologies.

THEMES

Theme 1: Experience and perception in immersive environments

Almost half (48%) of the articles analyzed have content focusing on the development and testing of immersive and interactive environments in virtual reality (VR) and augmented reality (AR). Associated terms include experience, perception, interaction, environment, avatar, immersive, mobile, feedback, and application. Studies measure the effectiveness of various immersive features in mapping (Cheng et al., 2022), exhibitions (Rau et al., 2022), and navigation tasks (Stefanucci et al., 2022). A number of papers focus on the experimental description and validation of visual (Wu et al., 2022), extremity (Kruijff et al., 2022) and object (He et al., 2022) perception, as well comparison of data collected from paired real-world and VR experiments (Cowlyn & Dalton, 2019; Sinclair et al., 2022) and testing definitions of immersion (Norton et al., 2022). This theme has the strongest association with hardware terms such as Oculus, Rift, HMD(Head Mounted Display), headset and controller.

Theme 2 - Education, learning and clinical simulation

The remaining quarter of the articles represent this theme and focus on the use of VR and XR approaches in educational settings and for training through simulation. Associated terms include education, student, training, simulation, medicine, experiment, and participant. Example approaches are the application of XR to medical training (Désiron et al., 2022; Rother & Spiliopoulou, 2022; Zikas et al., 2022) and trauma simulation settings without the need for an instructor (Lombardo et al., 2022). Educational settings include communication (Carnell et al., 2022), journalism (Li & Lee, 2022), law enforcement (Kent & Hughes, 2022; Kishore et al., 2021), emergency services (Hammar Wijkmark et al., 2019), and heavy industry (Obukhov et al., 2022). In addition, this theme incorporated a group of experimental studies focused on measuring core cognitive and emotional responses to VR in the spheres of memory (Cadet et al., 2022), valence and arousal (Krogmeier et al., 2022), and addiction (Oberdörfer et al., 2022).

Theme 3 - Therapeutic use

Associated terms include treatment, group, intervention, anxiety, exposure, fear, pain, patient, and therapy. Articles grouped in this theme have a central focus on the therapeutic use of XR technology. Target groups include veterans (Appel et al., 2022), pain sufferers, specifically pediatric burn victims (Smith et al., 2022), children undergoing medical procedures (Yilmaz & Canbulat Sahiner, 2022), older adults with back pain (Stamm et al., 2022), those with

adjustment disorders (Quero et al., 2022; Rachyla et al., 2022), cognitive decline (Cuesta et al., 2022), and PTSD (Roy et al., 2022).

Theme 4 - Consumer adoption and use in rehabilitation and social research

Associated terms in this theme include social, cybersickness, rehabilitation, stroke, extremity, kinematic, intervention, consumer, and patient. Papers include the examination of psychological factors in consumer adoption of XR technology (Chassin & Ingensand, 2022; Cummings et al., 2022; Fong et al., 2022), testing the embodied nature of cognition (Oker, 2022), stroke rehabilitation contexts (Amini Gougeh & Falk, 2022; Augenstein et al., 2022), facilitation of personal narratives (Vallance & Towndrow, 2022), and measurement of approach/avoidance in social anxiety disorder (Kiser et al., 2022).

Theme 5 - Assessing physiological responses and attitudes

Associated terms in this theme include auditory, visual, scene, vision, attitude, and bias. The foci of articles in this group covers the measurement of attitudes in an immersive environment using an Oculus Rift headset and controllers (Gu et al., 2022), sensorimotor adaptation using an HTC Vive controller (Wähnert & Gerhards, 2022), spatial audio response using an Oculus headset (Kim et al., 2022), and hand representation in VR using Oculus hand controllers (Pohl & Mottelson, 2022).

Theme 6 - Miscellaneous

While at first glance it may not appear so, this was the least distinct of the theme groups. It included terms like cultural, heritage, sport, game, result, outcome, and correct. A number of articles in this group serve to give corrections or retractions of previously published findings (Chiarovano et al., 2022; Harborth & Kümpers, 2022; Smith et al., 2022) and the misuse of existing measurement devices, such as the Simulator Sickness Questionnaire (SSQ) (Brown et al., 2022). Only a handful of articles are strongly associated with this theme.

HARDWARE

Many of the articles in the corpus make use of marketplace/commercially available hardware devices originally developed for game and entertainment applications (although this is not always clear or mentioned in the abstract). These include head mounted display (HMD) units such as Oculus Rift, Microsoft Hololens, and HTC Vive. Many of the studies did not use the latest available technologies nor arguably more physically immersive ones like XR treadmills. In turn, technical advances in XR social science research are less evident in new hardware and more evident in new applications of existing XR hardware and software beyond the original scope of the devices.

Methodological and evaluative studies focused on the comparison of different systems (De Paolis & De Luca, 2022). Other studies have sought to validate the accuracy and sufficiency of these hardware devices for clinical and other precision tasks (Benmahdjoub et al., 2022; Dong et al., 2022; Kelly et al., 2022; Moinnereau et al., 2022; Rojo et al., 2022; Sansone et al., 2022), and their constraints and limitations (Brunzini et al., 2022; Lamb et al., 2022). There is also some work to modify or augment these commercial hardware systems by, for example, changing the tracking system in an HMD (Monica & Aleotti, 2022; Stellmacher et al., 2022). While HMDs are unsurprisingly a primary focus, work is underway to test, augment, and develop controllers (e.g., Vive handheld controller, the MYO armband). Other papers describe the specification, prototyping, and development of new platforms, such as the Triggermuscle 'Haptic VR Controller' (Stellmacher et al., 2022), a 'haptic feedback stylus' (Kudry & Cohen, 2022), and a 'foot sole stimulation' (Kruijff et al., 2022). A handful of papers, particularly those focused on AR, discuss smartphone-based platforms that do not require extensive HMD hardware (De Paolis & De Luca, 2022; De Witte et al., 2022; Zhang & Kajimoto, 2022).

There is also some discussion and attention concerning the challenges of the multiplicity and changing of standards in hardware and software (Weber et al., 2022). While this is common during the early days of technological innovation and adoption, future work and industry developments are needed for a more consistent and universal set of features made available across hardware platforms.

SOFTWARE

As with hardware, many of the studies in the corpus make use of established XR software platforms with foundations in the game industry. Game engines such as Unreal Engine 4, Wwise 3D (Firat et al., 2022; Hejtmánek et al., 2022), and Unity (Augenstein et al., 2022; Gnacek et al., 2022; Oliva et al., 2022; Zhou et al., 2022), that are also used for 3D graphic applications, are specifically designed for extensibility. Many of the aforementioned papers are presenting new libraries, or extensions built on top of these specific engines. While both Unity 3D and Unreal engines have available free versions, they are not open-source software, and because of their commercial use by game developers have subscription and royalty-based licenses. However, plugins and extensions built on top of them can be released with open source (e.g., EmteqVR SDK). This is discussed in Gnacek et al., (2022), via the rehabilitation platform described in Augenstein et al., (2022) or via free for non-commercial use licenses (e.g., QuickVR) in Oliva et al., (2022). Some of broadly used toolkits such as Microsoft's Mixed Reality Toolkit and plugins for SteamVR also carry open-source licenses (although SteamVR itself has free personal usage and commercial licenses).

A handful of articles present new software development either for general XR application (but focused on a specific dimension like 3D scene reconstruction (Dietz & Grubert, 2022)), for a specific application (e.g., medical education (Timonen et al., 2022), or military use for interaction battlefield visualization (Boyce et al., 2022)). Dengel et al. provides a review of authoring toolkits for application in education (Dengel et al., 2022). Real-time full-body motion capture (MoCap) is an essential tool to enable the system simulation and user experience of immersive natural physical and social interaction. Zeng and colleagues (2022) describe the development of PE-DLS, a novel method to perform MoCap and implement it using an HTC Vive headset and five Vive trackers (Zeng et al., 2022). Most of the software development described is targeted to traditional PC and gaming hardware, but a couple of articles in the corpus highlight software for mobile platforms, like a tabled based model generation system (Arnaud et al., 2022).

Lastly, a couple of articles create software development paradigms or approaches designed to make the creation of XR environments more accessible. For example, ARNugget is a pattern-based authoring concept (Rau et al., 2022), as are the VR nuggets which are part of the VR Forge software (Horst et al., 2022). It is worth mentioning the appearance of some initial signs toward the adoption of artificial intelligence for the generation of environments

and as a complementary software development approach (VanHorn & Çobanoğlu, 2022).

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COMMERCIAL INNOVATION 2022: A YEAR IN REVIEW

Kyle Cassidy

Since the adoption of extended reality (XR) technologies is dependent upon innovations that seep their way into the mass market, this section provides some insights on key commercial developments in 2022. The main source of data for this section is not a systematic review of academic literature but popular literature and press releases instead.

IT'S ALL META

It seems that virtual reality (VR) has been stuck on the event horizon of becoming mainstream for half a decade; always visible, always about to, but never quite living up to its hype (see also article by Harley, 2022[1], which discusses this dynamic in more detail). The following section looks at the ways in which commercial interests have strategically contributed to stimulating and, simultaneously stymying innovation in the VR field. Particularly, this section highlights the disproportionate impact of Meta (formerly known as Facebook) on the development of VR.

Mass market hype has been linked mostly to Meta, the largest global hardware provider of VR wearables. Meta has approached VR in a headlong rush, while simultaneously and strategically dragging its feet. With Meta's multibillion dollar investment in VR more people than ever have heard of the collection of apps and experiences they are calling the metaverse and have started to use virtual reality tools. Yet, at the same time, Meta has stalled technical advancements, and purchased and then stymied competitors.

A lot of this has to do with the decision to step back from content run on a powerful gaming computer and displayed on a headset (PCVR) in exchange for wireless, self-powered headsets with a fraction of the computing power (Standalone Virtual Reality or SVR). This has limited a lot of the popular VR products to a lower resolution, cartoon-like experience. For example, ToastVR's Richie's Plank Experience, which asks users to face their fear and walk out on a wooden plank atop a skyscraper, is still one of the most popular VR demos although the software was released in 2016 and hasn't been updated since.

Meta also has had some difficulties in wrangling VR into its strategic vision. Since it acquired VR frontrunner Oculus in 2014 after their release of a Kickstarter backed CV1 (Consumer Version 1), they have released the Oculus Rift (CV2) in 2016, and then the Oculus Go in 2018 to try to win over Samsung Gear's mobile VR market. However, Meta's stand-alone headsets the Go, Quest, Quest 2, and even the new 2022 Quest Pro still lack the processing power or storage space to run powerful, graphically aweing PCVR apps like Google Earth VR, or any number of so-called AAA games. This is despite the Quest Pro's \$1,500 price tag being not significantly more than an entry level Gaming PC plus VR headset.

BUSINESS USE

The Quest Pro itself is a sideways upgrade to the Quest 2, with significantly better lenses and a PR campaign aimed at business-use rather than gaming (despite not shipping with any business software). In fact, a February 2023 search of the Oculus store for business delivers only seven apps, which include a multiplayer PokerStars VR app and a BBQ cooking game. Similarly, Meta’s announcement that you can now view three virtual computer screens at once in your VR headset enticed few people to spend their day wearing a Quest Pro rather than on their laptop. While Meta has had some success in bringing computing into VR (as in Horizon Workrooms, where users can see their computer screens and keyboards), it’s still not as user-friendly an experience as simply taking off your headset off to type.

In short, Meta is trying to find a solid business usage for its VR platform but still lacks a killer business app that will transform the way we work, just as the release of VisiCalc on the APPLE changed our view of the personal computer from a gaming platform to an essential business tool and spawned copycats Lotus 1-2-3 and Excel.



Meta, Photo illustration from Meta of a user using three monitors in a Quest Pro.

SOCIAL USE

Meta is making a significant bet on the future of VR being in multi-user, social experiences. Indeed, apart from the money Meta brings to the table 2.85 billion active monthly users who are already interacting with each other on Facebook.



Meta, Horizon Worlds promotional image from Facebook, 2020.

However, due to the processing limitations, Meta’s own interactive VR social platform, Horizon Worlds, is a cartoon world full of legless avatars bopping around like a child’s toybox of Fisher Price people[2]. All while competitor VR Chat has had full-body VR-integrated avatars walking, dancing, and getting married in VR Chat for years. VR Chat was also used to deliver one of the first university lectures in VR at the University of British Columbia in 2014.

In short, due to Meta’s dominating role and rhetoric in the VR market, many of our consumer experiences are directly linked to their strategic vision. Of course, this also impacts the course of XR social sciences research through the hardware and software we use, as well as through the subsequent virtual experiences we do (or do not) have access to studying. Thus, it is unsurprising that a number of studies in 2022 have critically examined Meta’s

role in the XR ecosphere. At the time of this writing, we are still waiting to see what Apple is going to enter into the XR market. Thus, for better or worse, Meta has left a meta mark on our current visions of XR.

MACHINE LEARNING AND NERF

It is worth adding a note on two other exciting technologies in the mass-market in 2022: machine learning and Neural Radiance Field (NeRF). The more controversial technological advancement of the two was the advent of publicly available Artificial Intelligence (AI), more accurately described as machine learning. OpenAI's art generator Dall-E, and text-based AI ChatGPT burst into the public consciousness in late 2022 by writing essays, creating illustrations, and causing a panic amongst educators who suddenly had little idea how to handle learners who were generating their assignments via AI. ChatGPT was released in November of 2022 and within about a month it was listed as co-author of several academic papers (see for example: ChatGPT & Zhavoronkov, 2022; O'Connor & ChatGPT, 2023). In turn, major journals Science and Nature quickly updated their editorial policies to forbid AI's Large Language Models from being listed as authors, citing a lack of accountability.

The inevitable integration of AI into VR will have profound effects like more realistic and unscripted interactions with non-human avatars. Furthermore, AI paired with VR has the potential to create VR experiences with less development costs, provided the processing power exists to run them.

Another recent breakthrough with incredible potential is the development of the Neural Radiance Field (NeRF), which uses a combination of video or photographs and AI to capture radiance (light) from every possible point in an area to create a virtual photorealistic scene for a phone, computer, or head mounted display. There are vast implications for this development since a few well-placed cameras could allow a scene to be rendered, streamed in relatively low resolution, and then interpolated by the end user, allowing for fully navigable VR experiences of live events, as well as the easy mapping of spaces. Google has mapped most of America with low-flying airplanes whose side-scanned views are able to interpolate 3D buildings and objects from video. The potential for NeRF technologies to become significantly more robust and accessible to the mass consumer may be very close. It's easy to look ahead to being able to move about in a concert venue or tour a real-time view of a tourist attraction in excruciating detail.

In short, both machine learning and NeRF provide some fascinating opportunities for researchers and one can imagine, simultaneously pose equally interesting questions about the nature of knowledge and research ethics.

1. Harley, D. (2022). "This would be sweet in VR": On the discursive newness of virtual reality. *New Media & Society*. <https://doi.org/10.1177/14614448221084655>
2. Late in 2022 Meta revealed that Horizon worlds avatars will now have a full body, but they will still resemble cartoon-like figures more than fully human ones. There is some interesting debate around the reasoning for this, as research on the 'uncanny valley' of technology has shown that people tend to respond uncomfortably to avatars who look too human, if they can still detect that they are not real.

APPENDIX: METHODOLOGY

This report’s goal is to create a systematic review of the key components of social science XR research in 2022, including theory, method, language, and technology. We define social science XR research as a body of literature dedicated to the study of society and human relationships as they are formed by, and formative of XR technologies. In order to create this systematic analysis, we used academic databases Scopus, EBSCOhost, and Web of Science to identify core journals dedicated to XR research within the realm of the social sciences. This excluded journals which were too broad in scope, like media studies journals, or those that were too technical and did not have a social science focus, like engineering-based journals. In turn, we managed to identify three, peer-reviewed journals in English, which had published regularly throughout 2022: Frontiers in Virtual Reality and Virtual Reality and Presence: Virtual and Augmented Reality. For more information about these journals see Table 1 below.

Table 1: Journal Selection

Name	Year Established	Publication Frequency	Number of Papers in 2022	Publisher	Impact Factor	Website
Virtual Reality	1995	4 per year	111	Springer	4.7	https://www.springer.com/journal/10055
Frontiers in Virtual Reality	2020	Ongoing	211	Frontiers	N/A	https://www.frontiersin.org/journals/virtual-reality
Presence: Virtual and Augmented Reality	1992	Typically 4 per year (2 in 2022)	22	MIT	1.75	https://direct.mit.edu/pvar

Each of the five sections of the report was handled by one or two Section Editors (authors). With the exception of the Knowledge Mapping Review and XR Commercial Innovation sections, each of the other sections followed these parameters:

Each Section Editor drew from the corpus of all 344 available research publications from the three core journals from 2022 (this excluded any pieces like book reviews, editorials, and corrections). The Section Editors then supplemented this pool of literature with additional database searches for other, relevant, peer-reviewed articles in English during 2022, which

were not published within the three core journals. This additional step was deemed necessary by the Section Editors in order to capture as systematic a picture of each of the components (theory, method, language, and technology) as possible. Each Section Editor then read through the corpus of core articles and additional literature to manually identify themes and patterns as related to their specific component of analysis.

It is worth noting that the XR Technology section applied a unique methodology for its thematic analysis. It applied a combination of topic modeling (Blei et al., 2003) and qualitative analysis to the abstracts of the journal articles to identify relevant themes. Specifically, a topic model using Latent Dirichlet Function allocation (LDA) was used to identify six groupings based on the distribution and co-occurrence of the nouns and adjectives in the abstracts. This produced a stable model with reasonable separation between the identified topics. The top 50 terms were examined for each topic/theme and the top 15 abstracts that ranked highest for each topic were examined, too. Each theme has been labeled based on this qualitative coding and they are subsequently presented in order of the proportion of abstracts for which a theme is dominant. The theme numbers are those assigned by the model and included for ease of reference.

KNOWLEDGE MAPPING REVIEW

The goal of this section was to give a broad overview of XR social sciences research in 2022. Thus, the search parameters had to expand beyond the three core journals and their 344 articles. To obtain a fuller picture of the peer-reviewed articles published 2022, seven keywords were identified: XR, VR, AR, mixed reality, virtual reality, extended reality, and augmented reality. The same search for these keywords within the article title, abstract, and keywords was triangulated across the three databases of EBSCOhost, Scopus, and Web of Science. This yielded similar results in terms of number of publications, but Scopus was selected as the database to use due to its ability to select ‘social sciences’ as a category filter. In turn, the following string query was applied to yield the full population of XR-themed, social science, peer-reviewed articles published in 2022:

TITLE-ABS-KEY ("XR" OR "VR" OR "AR" OR "mixed reality" OR "extended reality" OR "augmented reality" OR "mixed reality") AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (PUBYEAR , 2022)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English"))

This query yielded 1,457 articles on January 9, 2023. A similar query, minus the ‘social science’ filter, was conducted to yield the full population of peer-reviewed, English language XR publications in 2022. This was used for comparative purposes. The second query yielded 15,738 articles on January 9, 2023.

XR COMMERCIAL INNOVATION

Lastly, unlike the other sections, which based their analysis upon the 344 core articles from the three core journals plus the addition of any relevant literature, the main source of data for this section instead comprises popular literature and press releases. Since many commercial innovations take a while to seep their way into research, this approach was deemed necessary in order to be able to comment upon the nature of the commercial XR market and its relationship to our current state of research.

1. 2022 still presented an unusual year for publishers dealing with the disruptions of COVID-19. Some journals did not publish any issues and this particular journal published a reduced schedule, some of which contained papers that were originally ready for publication in the previous years.