The Metaverse: Concepts and Issues for Congress

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The Metaverse: Concepts and Issues for Congress

Congress has long paid attention to technologies for users to access computer-simulated environments and participate in virtual activities on the internet. These technologies include augmented reality, mixed reality, and virtual reality technologies (AR, MR, and VR respectively) that show potential for innovation in a variety of applications such as entertainment, healthcare, engineering, real estate, retail, military, education, and collaborative work. AR, MR, and VR technologies, some enthusiasts argue, may support new ways for users to interact, work, socialize, transact, and access services in an immersive virtual world, which is often referred to as the *metaverse*.

SUMMARY

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Some business and technology leaders assert that the metaverse does not refer to any specific technology or set of technologies, but rather a shift in how users interact with online technologies, services, platforms, and each other. Under this framework, the metaverse represents changes that, if actualized, might eventually transform the architecture (e.g., communications and network infrastructure, hardware and software, and human-computer interfaces) and operation of the internet (e.g., content production and consumption and user interaction with platforms and services). Some proponents assert that the metaverse is inevitable, given the shift to virtual environments sparked by the COVID-19 pandemic and the expansion of online games. Critics maintain that the idea of the metaverse has been over-hyped and its promise and significance exaggerated. They argue that some companies are merely attaching the label to long-existing human-computer interaction technologies and their applications. Other critics have raised concerns about the potential inability of metaverse services to sustain user interest, the lack of sustainable business models, and prevalence of inappropriate and unlawful content.

Metaverse services are likely to feature three key characteristics that differentiate them from two-dimensional (2D) online applications: (1) an immersive, three dimensional (3D) user experience; (2) real-time, persistent network access; and (3) interoperability across networked platforms. The immersive experience provides users with an enhanced feeling of presence and immersion within a virtual 3D world. Users' experience of presence in the metaverse could be further enhanced if the virtual environment is persistent, meaning it does not "disappear" when a user has finished using it. Achieving persistence would require computing and data architectures capable of hosting always-on, interconnected virtual spaces as well as high-bandwidth, low-latency, wireless networks to support user devices and access. Metaverse interoperability would provide users with an immersive and persistent virtual experience and allow them to move seamlessly across multiple networked virtual spaces, access different platforms and services, and interact with other users and objects using the same human-computer interface devices and digital assets (e.g., digital identity, currency, and objects). Critics argue that the data infrastructure needed to support the volume of data that metaverse services and their users would generate and the speed at which that data would need to be transmitted does not yet exist.

Major technologies that could enable metaverse services include extended reality (XR), advanced wireless communications, and blockchain. XR is an umbrella term that represents a range of technologies, such as AR devices that project a digital overlay over physical objects, MR devices that enable users to interact with virtual objects displayed in the real-world environment, and VR devices that work within a computer-generated virtual environment. Brain-computer interface technology may provide a new way for users to interact with the metaverse. Fifth-generation (5G) and next-generation (e.g., 6G) wireless technologies may provide the high-bandwidth and low-latency internet infrastructure required by the metaverse. Blockchain and block-chain enabled digital assets (e.g., non-fungible tokens (NFTs)) may enable commerce and transactions in the metaverse.

Some experts have expressed concerns that the immersive, persistent, and real-time environment and large-scale virtual platforms of the metaverse could reproduce and magnify the issues already surrounding the online platforms, services, and applications, such as content moderation, privacy, competition, and the digital divide. Members of Congress have shown interest in each of these issues in the context of current online platforms and may consider addressing them in the specific context of the metaverse.

This report introduces the concepts associated with potential metaverse services and key enabling technologies, highlights select companies engaged in metaverse development, and concludes with a discussion of selected policy issues for congressional consideration.

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Introduction

Congress has maintained an interest in policy issues related to the internet, particularly universal, reliable, high-speed internet access to support online applications and services. These applications and services have become essential to economic, educational, research, and social activities in the United States.[1] The internet facilitates communications and data flow that support these activities as well as the creation of new digital products and services that "now permeate every aspect of our daily lives."[2] An estimated 91% of the U.S. population[3] and 59% of the world's population used the internet in 2021.[4] Internet users aged 16 to 64 in the United States reportedly spent an estimated average of seven hours per day online to retrieve and generate information, communicate and share information, consume multimedia content, and conduct business transactions.[5] The International Telecommunications Union (ITU) has described the internet as a source of "opportunities for personal fulfilment, professional development, and value creation."[6] Users access the internet through desktop and laptop computers, smartphones, and tablets to use text-and-image-based websites, email services, social networks, and online marketplaces.[7] The internet also enables computer-simulated environments that users can interact with via an interface, often referred to as a virtual world, virtual space, or virtual reality.[8]

There has been sustained congressional interest in technologies for users to access and interact with computer-simulated environments and participate in virtual activities on the internet.[9] These technologies include augmented, mixed, and virtual reality technologies (see the "Extended Reality (XR)" section below) that show potential for innovation in a variety of application areas such as entertainment, healthcare, engineering, real estate, retail, military, education, and

[1] Section 60101(1) of the Infrastructure Investment and Jobs Act (IIJA; P.L. 117-58).

[2] White House, "A Declaration for the Future of the Internet," April 28, 2022, p. 1, at https://www.whitehouse.gov/wp-content/uploads/2022/04/Declaration-for-the-Future-for-the-Internet_Launch-Event-Signing-Version_FINAL.pdf.

[3] International Telecommunication Union (ITU), *Country ICT Data (Latest Available Data): Percentage of Individuals Using the Internet*, ITU Development Sector (ITU-D) ICT Statistics, December 2021, at https://www.itu.int/en/ITU-D/Statistics/Documents/statistics/2021/December/PercentIndividualsUsingInternet.xlsx.

[4] ITU, *Statistics*, ITU-D ICT Statistics, November 2021, at https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx.

[5] Simon Kemp, *Digital 2022: Global Overview Report*, DataReportal, January 26, 2022, at https://datareportal.com/reports/digital-2022-global-overview-report.

[6] ITU, *Measuring Digital Development: Facts and Figures 2021*, ITU-D, 2021, p. 1, at https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2021.pdf.

[7] Michael Martin, *Computer and Internet Use in the United States:2018*, U.S. Census Bureau, American Community Survey Reports, ACS-49, April 2021, at https://www.census.gov/content/dam/Census/library/publications/2021/acs/acs-49.pdf.

[8] Richard A. Bartle, *Designing Virtual Worlds* (San Francisco, CA: New Riders, 2004), p. 2. See also N. Burgess and J.A. King, "Navigation in Virtual Space: Psychological and Neural Aspects," in *International Encyclopedia of the Social & Behavioral Sciences*, ed. Neil J. Smelser and Paul B. Baltes (Pergamon Press, 2001), p. 10417, at https://doi.org/10.1016/B0-08-043076-7/03564-6.

[9] Introduced in 1992, the Information Infrastructure and Technology Act of 1992 (S. 2937 and H.R. 5759, the 102nd Congress) would have directed the National Institutes of Health to develop "applications of high-performance computing and high-speed networking in the health care sector," including "virtual reality technology for simulating operations and other medical procedures." Since then, more than 60 bills have been introduced, containing a reference to the terms "virtual reality," "augmented reality," or "mixed reality." Among these bills, 19 had been introduced in the 117th Congress, as of July 2022.

collaborative work.[10] For example, doctors could be trained in a virtual environment[11] and view patients' biometric information in augmented reality glasses during procedures. Augmented, mixed, and virtual reality technologies, some enthusiasts argue, may support new ways for users to interact, work, socialize, transact, and access services in an immersive virtual world, which has come to be called the *metaverse*.[12]

The founding Members of the Congressional Caucus on Virtual, Augmented, and Mixed Reality Technologies (referred to as the Reality Caucus)[13] have asserted that "[a]s these technologies develop, questions will inevitably rise in privacy, intellectual property, and other areas."[14] Given the importance of the internet to the domestic and global economy and for health, education, work, and social interaction, this report seeks to elaborate key concepts, technologies, and implications of the metaverse to assist Congress in making informed policy decisions.

This report first introduces concepts that many believe will shape the metaverse, focusing on three core aspects—an immersive user experience, persistent network access, and interoperability. The report then describes key technologies supporting the metaverse in three categories—extended reality, fifth-generation (5G) and next-generation wireless communications, and blockchain.[15] Next, the report highlights select companies that currently engage in the development and investment related to the metaverse. The report concludes with a discussion of selected policy issues for congressional consideration, including content moderation, data privacy, market power and competition, and the digital divide.[16]

[10] Heather Bellini, Wei Chen, Masaru Sugiyama, et al., *Virtual & Augmented Reality: The Next Big Computing Platform?* The Goldman Sachs Group, Inc., Equity Research, January 13, 2016, p. 16, at https://www.goldmansachs.com/insights/pages/technology-driving-innovation-folder/virtual-and-augmented-reality/report.pdf.

[11] John Soroushian, Babu Jackson, and Sabine Neschke, *Thinking Ahead About XR: Charting a Course for Virtual, Augmented, and Mixed Reality*, Bipartisan Policy Center, April 2022, p. 10, at https://bipartisanpolicy.org/download/?file=/wp-content/uploads/2022/04/XR-Report_Final-Copy.pdf.

[12] Stefan Brambilla Hall and Cathy Li, *What Is the Metaverse? And Why Should We Care?* World Economic Forum, Global Agenda Articles: The Metaverse, October 29, 2021, at https://www.weforum.org/agenda/2021/10/what-is-the-metaverse-why-care/. See also Paul Daugherty, Marc Carrel-Billiard, and Michael Blitz, *Meet Me in the Metaverse*, Accenture, The Technology Vision 2022 Report, p. 24, 2022, at https://www.accenture.com/_acnmedia/Thought-Leadership-Assets/PDF-5/Accenture-Meet-Me-in-the-Metaverse-Full-Report.pdf.

[13] In May 2017, Representatives Suzan DelBene, Yvette Clarke, Bill Flores, Darrell Issa, and Ted Lieu formed the Congressional Caucus on Virtual, Augmented, and Mixed Reality Technologies for the 115th Congress, also known as the "Reality Caucus." The purpose of the caucus was to promote the advancing technologies of virtual reality, augmented reality, and mixed reality to Members of Congress and their staff.

[14] Reps. DelBene, Clarke, Flores, Issa and Lieu, "Reps. DelBene, Clarke, Flores, Issa and Lieu Form Reality Caucus," press release, May 3, 2017, at https://delbene.house.gov/news/documentsingle.aspx?DocumentID=1953.

[15] For an introduction to the 5G technology, see CRS Report R45485, *Fifth-Generation (5G) Telecommunications Technologies: Issues for Congress*, by Jill C. Gallagher and Michael E. DeVine; for an overview of blockchain applications, see CRS Report R47064, *Blockchain: Novel Provenance Applications*, by Kristen E. Busch.

[16] For general information of content moderation related to social media, see CRS Report R46662, *Social Media: Misinformation and Content Moderation Issues for Congress*, by Jason A. Gallo and Clare Y. Cho; for an introduction to data privacy law, see CRS In Focus IF11207, *Data Protection and Privacy Law: An Introduction*, by Stephen P. Mulligan and Chris D. Linebaugh; for information and analysis of antitrust issues related to large technology companies, see CRS Report R45910, *Antitrust and "Big Tech"*, by Jay B. Sykes. The *digital divide* refers to "the gap between those who have access to broadband internet and those who do not." See CRS In Focus IF12030, *The Broadband Digital Divide: What Comes Next for Congress?*, by Colby Leigh Rachfal.

Key Metaverse Concepts

The concept and idea of a virtual world as we currently understand it can be traced to the 1960s when scholars proposed a kinesthetic human-computer interface with interactive graphics, force-feedback, body movements, and sound.[17] After decades of advances in computing power and networking and communication technologies, some technologists, innovators, entrepreneurs, investors, and journalists believe that the physical world and computer-generated virtual worlds are converging.[18] The term *metaverse* has been in use since at least 1992[19] and currently it generally refers to the concept of an immersive and persistent virtual world where users can communicate and interact with other users and the surrounding environment and engage in social activities, similar to interactions in the physical world.

Some business and technology leaders assert that the metaverse does not refer to any specific technology but rather a shift in how users interact with online technologies, services, platforms, and each other.[20] Under this framework, the metaverse represents changes that, if actualized, might eventually transform the architecture (e.g., communications and network infrastructure, hardware and software, and human-computer interfaces) and operation of the internet (e.g., content production and consumption and user interaction with platforms and services).[21] Others assert that the metaverse is inevitable, given the shift to virtual environments sparked by the COVID-19 pandemic and the expansion of massively multiplayer online (MMO) games such as Fortnite and Roblox.[22] These MMO platforms are sometimes seen as "proto-metaverses," offering some virtual interactive user experiences (e.g., virtual concerts with fewer than 100 participants), but limited by current technology and network capabilities from offering truly immersive and persistent virtual experiences for large numbers (potentially billions) of users simultaneously.[23]

In contrast, many critics assert that the idea of the metaverse has been over-hyped, and its promise and significance to the internet have been exaggerated. They argue that some companies are merely attaching the label "metaverse" to long-existing human-computer interaction

[17] Ivan E. Sutherland, "The Ultimate Display," *Proceedings of IFIP Congress*, vol. 65, no. 2 (1965), pp. 506-508, at http://papers.cumincad.org/data/works/att/c58e.content.pdf. See also Tomasz Mazuryk and Michael Gervautz, *Virtual Reality: History, Applications, Technology and Future*, Institute of Computer Graphics, Vienna University of Technology, Austria, Technology Report TR-186-2-96-06, 1996, at https://www.cg.tuwien.ac.at/research/publications/1996/mazuryk-1996-VRH/TR-186-2-96-06Paper.pdf.

[18] See Kian Bakhtiari, "Welcome to Hyperreality: Where the Physical and Virtual Worlds Converge," *Forbes*, December 30, 2020, at https://www.forbes.com/sites/kianbakhtiari/2021/12/30/welcome-to-hyperreality-where-the-physical-and-virtual-worlds-converge/.

[19] CRS conducted a literature search using the term "metaverse" and did not find any technical research articles in English containing the word before 1992. Many scholars and journalists trace the origin of the term to Neal Stephenson's science fiction novel, *Snow Crash* (New York: Bantam Books, 1992). The metaverse was the author's vision of a wireless internet system with three-dimensional graphics and a virtual reality, which was populated by digital avatars of real people and accessible via terminals on a worldwide fiber-optics network using special goggles.

[20] Eric Ravenscraft, "What Is the Metaverse, Exactly?" *WIRED*, November 25, 2021, at https://www.wired.com/story/what-is-the-metaverse/.

[21] Ibid. See also Paul Daugherty, Marc Carrel-Billiard, and Michael Blitz, *Meet Me in the Metaverse*, Accenture, The Technology Vision 2022 Report, p. 24, 2022, at https://www.accenture.com/_acnmedia/Thought-Leadership-Assets/PDF-5/Accenture-Meet-Me-in-the-Metaverse-Full-Report.pdf.

[22] Alexander Lee, "With the Metaverse Hype Cycle at Full Blast, Experts Take the Long View," *Digiday*, August 4, 2021, at https://digiday.com/marketing/with-the-metaverse-hype-cycle-at-full-blast-experts-take-the-long-view/.

[23] Edd Gent, "What Can the Metaverse Learn from Second Life?" *IEEE Spectrum*, November 29, 2021, at https://spectrum.ieee.org/metaverse-second-life.

technologies and their applications, such as online video games.[24] Some skeptics have raised concerns about the possibility that problems similar to those that some MMO games have faced—inability to sustain user interest, lack of sustainable business models, and the prevalence of inappropriate and unlawful content—might be replicated in the development of the metaverse.[25]

The trajectory of metaverse development is unclear. The myriad devices, platforms, applications, and services that may contribute to it are developed by a heterogeneous set of global actors with different business models, objectives, foci, and priorities.[26] A single metaverse may emerge with collective virtual spaces with shared protocols and standards, like the current internet ecosystem, to support applications and services from different companies and service providers. Some executives of Meta Platforms, Inc. (formerly Facebook, Inc.) have asserted that the metaverse will not be created by one company, but rather by many companies, each contributing various building blocks with a consideration of interoperability with other companies.[27] Alternatively, some experts anticipate "a multiverse of metaverses," each with different focus, business model, and form and currently developed by leading platform players in the sectors including online games, digital commerce, virtual collaboration, and entertainment.[28] In the latter scenario, if the companies that develop metaverse platforms and services opt for proprietary technologies and standards,[29] they may preclude interoperation with the platforms and services of other providers.[30]

This report uses the term "the metaverse" to refer to the general concept and its related technologies but not a specific configuration of devices, platforms, applications, and services. The metaverse is likely to feature three key characteristics that differentiate it from two-dimensional (2D) online applications: (1) an immersive, three dimensional (3D) user experience; (2) real-time, persistent network access; and (3) interoperability across networked platforms. The remainder of this section examines these three concepts.

Immersive User Experience

The concept of an immersive user experience is to provide users with an enhanced, individual feeling of presence and immersion within a virtual 3D world, expanding the human-computer interface beyond a 2D (sometimes referred to as "flat") computer or smartphone screen.[31]

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[24] Harry Robertson, "Wall Street Is Pumped About the Metaverse. But Critics Say It's Massively Overhyped and Will Be a Regulatory Minefield." *Business Insider*, December 25, 2021, at https://markets.businessinsider.com/news/stocks/metaverse-outlook-overhyped-regulations-facebook-meta-virtual-worlds-genz-2021-12.

[25] Leah J. Williams, "The Metaverse Is Not New, and It Won't Change the World," *GamesHub*, November 30, 2021, at https://www.gameshub.com/news/opinions-analysis/metaverse-facebook-gaming-virtual-worlds-8573/.

[26] Paul Daugherty, Marc Carrel-Billiard, and Michael Blitz, *Meet Me in the Metaverse*, Accenture, The Technology Vision 2022 Report, p. 7, 2022, at https://www.accenture.com/_acnmedia/Thought-Leadership-Assets/PDF-5/Accenture-Meet-Me-in-the-Metaverse-Full-Report.pdf.

[27] See Mark Zuckerberg, *Founder's Letter, 2021*, Meta, October 28, 2021, at https://about.fb.com/news/2021/10/founders-letter/. The concept of interoperability is discussed in the sub-section of "Interoperability" in this report.

[28] Michael Gurau, "A Multiverse of Metaverses," *Forbes*, March 22, 2022, at https://www.forbes.com/sites/forbestechcouncil/2022/03/22/a-multiverse-of-metaverses/.

[29] Andrew Morse and Scott Stein, "The Metaverse Is on the Way: Here's What You Need to Know," *CNET*, March 27, 2022, at https://www.cnet.com/tech/services-and-software/the-metaverse-is-on-the-way-heres-what-you-need-to-know/.

[30] Stephen Shankland, "The Metaverse Will Be a Multi-Platform Mess," *CNET*, March 26, 2022, at https://www.cnet.com/tech/computing/features/here-comes-the-multi-metaverse-mess/.

[31] *Telepresence* or virtual presence is a psychological state or subjective perception in which a user does not notice the role of a technology in the user experience, even though part or all of the experience is generated by the technology. See International Society for Presence Research, *Presence Defined*, at https://ispr.info/about-presence-2/about-

Academic research on virtual presence has shown that the sense of embodiment may contribute to users' positive experience in the virtual environment.[32] Some enthusiasts describe the metaverse as the "embodied internet"—where users are *within* the internet, "not just looking at it."[33]

Persistent Network Access

Users' experience of presence in the metaverse could be further enhanced if the virtual environment is persistent—it does not "disappear" when a user has finished using it (e.g., when the user logs off).[34] A persistent virtual space would continue to exist and evolve even when no users interact with it.[35] Moreover, it is available to users whenever and wherever they want.[36] Achieving persistence would require computing and data architectures capable of hosting always-on, interconnected virtual spaces as well as high-bandwidth,[37] low-latency,[38] wireless networks to support user devices and provide real-time access to the metaverse.[39]

To achieve this requirement, services and platforms in the metaverse would likely require high-performance computing devices.[40] A virtual environment would generate an immense number of textured, high definition 3D objects, as well as their positions, motions, sounds, surroundings, and simulated interactions with other objects and users.[41] The amount of data created and transmitted

presence/. See also Paul Daugherty, Marc Carrel-Billiard, and Michael Blitz, *Meet Me in the Metaverse*, Accenture, The Technology Vision 2022 Report, p. 24, 2022, at https://www.accenture.com/_acnmedia/Thought-Leadership-Assets/PDF-5/Accenture-Meet-Me-in-the-Metaverse-Full-Report.pdf.

[32] See International Society for Presence Research, *About Presence*, at https://ispr.info/about-presence-2/.

[33] Paul Daugherty, Marc Carrel-Billiard, and Michael Blitz, *Meet Me in the Metaverse*, Accenture, The Technology Vision 2022 Report, p. 24, 2022, at https://www.accenture.com/_acnmedia/Thought-Leadership-Assets/PDF-5/Accenture-Meet-Me-in-the-Metaverse-Full-Report.pdf. See also Mark Zuckerberg, *Founder's Letter, 2021*, Meta, October 28, 2021, at https://about.fb.com/news/2021/10/founders-letter/.

[34] Andrew Morse and Scott Stein, "The Metaverse Is on the Way: Here's What You Need to Know," *CNET*, March 27, 2022, at https://www.cnet.com/tech/services-and-software/the-metaverse-is-on-the-way-heres-what-you-need-to-know/. See also Matthew Ball, *The Metaverse: What It Is, Where to Find It, and Who Will Build It*, MatthewBall.vc, The Metaverse Primer, January 13, 2020, at https://www.matthewball.vc/all/themetaverse.

[35] Richard A. Bartle, *Designing Virtual Worlds* (San Francisco, CA: New Riders, 2004), p. 2.

[36] Srushti IMX, "Why Commonness and Interoperability Is Critical in Metaverse," at https://srushtiimx.com/blog/why-commonness-and-interoperability-is-critical-in-metaverse/.

[37] *Bandwidth* is the data transfer capacity of a digital communications network. In general, multimedia data (e.g., graphics, audio, and video) in digital form (i.e., represented by binary codes) consumes more bandwidth than text-based data does during a data communication.

[38] A network *latency* indicates the amount of time it takes a network to transmit a piece of data between two nodes in the network. It could be one-way (i.e., the time from the sender to the receiver) or round-trip (i.e., the time from the sender to the receiver plus the time from the receiver back to the sender). High latencies may affect the quality of some interactive services perceived by users. Latency is one of the key network performance metrics, particularly for real-time internet services such as video chat, video conferencing, and online multiplayer games. FCC, *Eleventh Measuring Broadband America Fixed Broadband Report*, The FCC Office of Engineering and Technology, December 31, 2021, p. 10, at https://data.fcc.gov/download/measuring-broadband-america/2021/2021-Fixed-Measuring-Broadband-America-Report.pdf.

[39] Derek Robertson, "The Arms Race to Build the Metaverse," *Politico*, May 4, 2022, at https://www.politico.com/newsletters/digital-future-daily/2022/05/04/the-arms-race-to-build-the-metaverse-00030029.

[40] Matthew S. Smith, "Is the Metaverse Even Feasible?" *IEEE Spectrum*, March 21, 2022, at https://spectrum.ieee.org/is-the-metaverse-even-feasible.

[41] See examples of Microsoft Flight Simulator and other online games described in Matthew Ball and Jacob Navok, *Networking and the Metaverse*, MatthewBall.vc, The Metaverse Primer, June 29, 2021, at https://www.matthewball.vc/all/networkingmetaverse.

in the metaverse at any time would be likely at the gigabyte (GB) scale.[42] Data volume could increase rapidly during a real-time event (e.g., a live online concert) involving a large number of geographically dispersed participants generating dynamic input (e.g., text and voice comments), actions (e.g., interacting with others), and reactions (e.g., cheering). An Intel executive suggested that the metaverse would require "a 1,000-times increase in computational efficiency from today's state of the art."[43]

The data architecture supporting the metaverse would also need symmetrical network bandwidth—not only a high download speed but also a high upload speed to transfer user-generated rich media data from their devices back to the network.[44] The current speed benchmark for fixed broadband service adopted by the Federal Communications Commission (FCC) is asymmetrical—25 megabits per second (Mbps) for download and 3 Mbps for upload (25/3 Mbps).[45] Most broadband services using coaxial cable or digital subscriber line (DSL) technologies provide greater download speeds than upload speeds, while service providers using the fiber technology claim their network bandwidths are nearly symmetrical.[46]

Moreover, to be truly immersive and persistent, a user's experience of the metaverse should have an imperceptible lag between the user's actions and simulated reactions; for example, some experts suggest a network latency of 20 milliseconds (ms) or less.[47] According to the data collected by the FCC in September and October 2020, latencies of DSL networks ranged from 21 ms to 37 ms; latencies of cable networks were between 12 ms to 26 ms; and latencies were lowest for fiber networks, from 8 ms to 13 ms.[48]

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[42] For comparison, Netflix, an online video streaming platform, estimates that watching high-definition video on its app consumes between 1 and 3 GB of data per hour, per device. See Netflix, "How to Control How Much Data Netflix Uses," at https://help.netflix.com/en/node/87. In an existing example similar to the immersive, virtual environment of the metaverse, Microsoft Flight Simulator, an amateur flight simulation program, creates 2.5 million GB of data rendering 2 trillion trees, 1.5 billion buildings, and roads, mountains, cities, and airports around the world in its simulated environment. See Matthew Ball and Jacob Navok, *Networking and the Metaverse*, MatthewBall.vc, The Metaverse Primer, June 29, 2021, at https://www.matthewball.vc/all/networkingmetaverse.

[43] Raja Koduri, *Powering the Metaverse*, Intel, December 14, 2021, at https://www.intel.com/content/www/us/en/newsroom/opinion/powering-metaverse.html.

[44] Mike Dano, "Why 5G Is Uniquely Ill-Equipped to Support the Metaverse," *Light Reading*, March 1, 2022, at https://www.lightreading.com/the-edge/why-5g-is-uniquely-ill-equipped-to-support-metaverse/a/d-id/775668.

[45] FCC, *Fourteenth Broadband Deployment Report*, FCC 21-18, January 19, 2021, pp. 6-7, at https://docs.fcc.gov/public/attachments/FCC-21-18A1.pdf. In July 2022, FCC Chairwoman Jessica Rosenworcel proposed to increase the national broadband standard to 100 Mbps for download and 20 Mbps for upload. See FCC, "Chairwoman Rosenworcel Proposes to Increase Minimum Broadband Speeds and Set Gigabit Future Goal," press release, July 15, 2022, at https://docs.fcc.gov/public/attachments/DOC-385322A1.pdf.

[46] Jon Brodkin, "100Mbps Uploads and Downloads Should Be US Broadband Standard, Senators Say," *Ars Technica*, March 4, 2021, at https://arstechnica.com/tech-policy/2021/03/100mbps-uploads-and-downloads-should-be-us-broadband-standard-senators-say/.

[47] GSMA Future Networks, *Cloud AR/VR Whitepaper*, Global System for Mobile Communications (GSM) Association, April 26, 2019, at https://www.gsma.com/futurenetworks/wiki/cloud-ar-vr-whitepaper/. See also Matthew S. Smith, "Is the Metaverse Even Feasible?" *IEEE Spectrum*, March 21, 2022, at https://spectrum.ieee.org/is-the-metaverse-even-feasible.

[48] FCC, *Eleventh Measuring Broadband America Fixed Broadband Report*, The FCC Office of Engineering and Technology, December 31, 2021, pp. 17-18, at https://data.fcc.gov/download/measuring-broadband-america/2021/2021-Fixed-Measuring-Broadband-America-Report.pdf.

As of August 2022, the FCC has not published reports measuring mobile broadband in the United States. According to Ookla, a network testing and analysis company that operates the Speedtest program, the median mobile download speed in the United States in July 2022 was 60 Mpbs, the upload speed was 8 Mbps, and latency was 34 ms. See Speedtest.net, "United States Median Speeds July 2022," at https://www.speedtest.net/global-index/united-

Interoperability

Interoperability—the ability to deliver an immersive and persistent virtual experience seamlessly across multiple networked platforms or interconnected virtual spaces—is a key concept for proponents of a unified metaverse. Interoperability would allow users to move between virtual spaces and access different platforms and services using the same devices and digital assets (e.g., digital identity, currency, and objects).[49] Common technical standards and protocols would be necessary to enable interoperability and portability of data and content between platforms and services.[50] Some experts argue that mass adoption and success of the metaverse will require it to be built on open standards and globally accepted protocols.[51] This approach could potentially lead to a unified user experience in an interconnected metaverse system.[52] Some technical standards groups are working on projects for "open metaverse interoperability."[53]

Technologies Supporting the Metaverse

While many aspects of the metaverse are emerging, technologies that support an immersive user experience and other potential metaverse functions exist and are evolving. This section surveys some of major technologies that could serve as building blocks for the metaverse, including extended reality, advanced wireless communications, and blockchain.

Extended Reality (XR)

An immersive user experience, as discussed in the previous section, depends on a host of human-computer interface technologies, known by the umbrella term *extended reality* (XR). XR—the extension of the reality perceived by users—refers to any technology that can alter the reality by adding digital elements to the user's environment.[54] Some experts compare the early adoption of

states#mobile.

[49] For example, with interoperability, the digital currency a user owns in one virtual space could be recognized, accepted, and used in another space. See Rabindra Ratan and Yiming Lei, *What Is the Metaverse? 2 Media and Information Experts Explain*, The Conversation, October 29, 2021, at https://theconversation.com/what-is-the-metaverse-2-media-and-information-experts-explain-165731. See also Will Oremus, "In 2021, Tech Talked Up 'The Metaverse.' One Problem: It Doesn't Exist," *Washington Post*, December 30, 2021, at https://www.washingtonpost.com/technology/2021/12/30/metaverse-definition-facebook-horizon-worlds/; Akash Takyar, *Interoperability and the Future of the Metaverse*, LeewayHertz, at https://www.leewayhertz.com/metaverse-interoperability/; and Srushti IMX, "Why Commonness and Interoperability Is Critical in Metaverse," at https://srushtiimx.com/blog/why-commonness-and-interoperability-is-critical-in-metaverse/.

[50] See Merav Ozair, "Interoperability: Unleashing the True Benefits of Web3 and the Metaverse," *Nasdaq*, May 2, 2022, at https://www.nasdaq.com/articles/interoperability%3A-unleashing-the-true-benefits-of-web3-and-the-metaverse.

[51] Matthew Ball, *The Metaverse: What It Is, Where to Find It, and Who Will Build It*, MatthewBall.vc, The Metaverse Primer, January 13, 2020, at https://www.matthewball.vc/all/themetaverse. See also Yiming Lei and Rabindra Ratan, *What Is the Metaverse? 2 Experts Explain*, World Economic Forum, Global Agenda Articles: Fourth Industrial Revolution, August 17, 2021, at https://www.weforum.org/agenda/2021/08/metaverse-media-information-experts/.

[52] Andrew Morse and Scott Stein, "The Metaverse Is on the Way: Here's What You Need to Know," *CNET*, March 27, 2022, at https://www.cnet.com/tech/services-and-software/the-metaverse-is-on-the-way-heres-what-you-need-to-know/.

[53] See W3C, "Metaverse Interoperability Community Group," at https://www.w3.org/community/metaverse-interop/. See also W3C, "Immersive Web Community Group," at https://www.w3.org/community/immersive-web/.

[54] Laia Tremosa, *Beyond AR vs. VR: What Is the Difference Between AR vs. MR vs. VR vs. XR?* Interaction Design Foundation, February 2022, at https://www.interaction-design.org/literature/article/beyond-ar-vs-vr-what-is-the-difference-between-ar-vs-mr-vs-vr-vs-xr.

XR wearable devices to the introduction of personal computers and smartphones, asserting that XR technologies may become "the next major computing platform," providing entry points and means to experience the metaverse.[55] XR includes technologies on a spectrum from devices that project a digital overlay over physical objects (augmented reality, AR); devices that enable users to interact with virtual objects displayed in the real-world environment (mixed reality, MR); to devices that work only with a computer-generated virtual environment (virtual reality, VR).[56] AR and MR can use holographic projection technology to render 3D images and superimpose them on the user's view of the physical world.[57] VR requires more computing power than augmented reality and mixed reality (both discussed below) to render a real-time, high-definition, 3D virtual world and process virtual objects and activities in it.[58]

Augmented Reality (AR)

Within the category of XR, AR provides an enhanced version, not a replacement, of a user's perception of physical reality. AR technologies enable the overlay of computer-generated content (e.g., digital information, images, or sounds) onto physical world objects in real time.[59] The level of augmentation can vary from a simple information display to the addition of virtual objects.[60] To access AR functions, users use smartphones or tablets with cameras, wearable see-through AR glasses, or heads-up displays (HUDs).[61] AR technologies often display contextual information based on the real-world environment (see **Figure 1**).

[55] Stefan B. Hall and Moritz Baier-Lentz, *3 Technologies That Will Shape the Future of the Metaverse—And the Human Experience*, World Economic Forum, February 7, 2022, at https://www.weforum.org/agenda/2022/02/future-of-the-metaverse-vr-ar-and-brain-computer/. See also Stefan Brambilla Hall and Cathy Li, *What Is the Metaverse? And Why Should We Care?* World Economic Forum, Global Agenda Articles: The Metaverse, October 29, 2021, at https://www.weforum.org/agenda/2021/10/what-is-the-metaverse-why-care/.

[56] Mark McGill, *Extended Reality (XR) and the Erosion of Anonymity and Privacy*, Institute of Electrical and Electronics Engineers (IEEE), The IEEE Global Initiative on Ethics of Extended Reality (XR) Report, November 2021, p. 6, at https://standards.ieee.org/wp-content/uploads/import/governance/iccom/extended-reality-anonymity-privacy.pdf. See also Vasco Pereira, Teresa Matos, Rui Rodrigues, Rui Nóbrega and Joao Jacob, "Extended Reality Framework for Remote Collaborative Interactions in Virtual Environments," *2019 International Conference on Graphics and Interaction (ICGI)*, Faro, Portugal, November 2019, p. 17, at https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8955025&tag=1.

[57] Daniel Ackerman, "Using Artificial Intelligence to Generate 3D Holograms in Real-Time," *MIT News*, March 10, 2021, at https://news.mit.edu/2021/3d-holograms-vr-0310.

[58] Arm Blueprint Staff, *xR, AR, VR, MR: What's the Difference in Reality?* Arm, April 1, 2022, at https://www.arm.com/blogs/blueprint/xr-ar-vr-mr-difference.

[59] Oliver Bowling, "The Metaverse: Who Really Wins?" *Oxford Business Review*, December 9, 2021, at https://oxfordbusinessreview.org/the-metaverse-who-really-wins/.

[60] Fredrik Alriksson, Du Ho Kang, Chris Phillips, et al., "XR and 5G: Extended Reality at Scale with Time-Critical Communication," *Ericsson Technology Review*, no. 8, August 24, 2021, p. 2, at https://www.ericsson.com/4a492d/assets/local/reports-papers/ericsson-technology-review/docs/2021/xr-and-5g-extended-reality-at-scale-with-time-critical-communication.pdf.

[61] HUD is an information system that "projects information onto a usually transparent surface that sits directly in a user's line of vision." Merriam-Webster.com Dictionary, "Heads-up Display," *Merriam-Webster*, at https://www.merriam-webster.com/dictionary/heads-up%20displays. HUD technology has been used in aircraft and automobiles to display navigation information directly on the windshield within an operator's field of view.

Figure 1. Example of Using AR Technology in Navigation

Source: Miroslav Lysyuk, *World-Scale AR Navigation with ODG Wearables*, Mapbox, January 19, 2018, at https://blog.mapbox.com/world-scale-ar-navigation-with-odg-wearables-b344d0b17afc (with permission from the author and Mapbox.com).

Notes: This image viewed in an AR wearable display integrates maps, location, and turn-by-turn directions with the physical world around the user.

Some smartphone users have experienced basic forms of AR in mobile games and apps, such as Pokémon Go and apps that enable shoppers to visualize furniture in their homes before making a purchase decision.[62] While AR provides users with a composite view of digital elements and physical-world elements, the technology generally does not involve interaction with digital elements.[63] The physical environment acts as a background for the AR-generated view.[64]

Mixed Reality (MR)

In addition to allowing the projection of digital elements onto the physical environment (as in AR), MR allows the user to interact with both digital and physical elements.[65] This blending of virtual objects with real environments creates a new, hybrid environment in which digital and physical elements co-exist and react to each other, to an extent, in real time.[66] Some experts assert

[62] Fredrik Alriksson, Du Ho Kang, Chris Phillips, et al., "XR and 5G: Extended Reality at Scale with Time-Critical Communication," *Ericsson Technology Review*, no. 8, August 24, 2021, p. 2, at https://www.ericsson.com/4a492d/assets/local/reports-papers/ericsson-technology-review/docs/2021/xr-and-5g-extended-reality-at-scale-with-time-critical-communication.pdf.

[63] Laia Tremosa, *Beyond AR vs. VR: What Is the Difference Between AR vs. MR vs. VR vs. XR?* Interaction Design Foundation, February 2022, at https://www.interaction-design.org/literature/article/beyond-ar-vs-vr-what-is-the-difference-between-ar-vs-mr-vs-vr-vs-xr.

[64] Henrique Centieiro, "The Roles of VR, AR, and MR on the Metaverse," *DataDrivenInvestor*, January 7, 2022, at https://medium.datadriveninvestor.com/the-roles-of-vr-ar-and-mr-on-the-metaverse-593569cfb686.

[65] Laia Tremosa, *Beyond AR vs. VR: What Is the Difference Between AR vs. MR vs. VR vs. XR?* Interaction Design Foundation, February 2022, at https://www.interaction-design.org/literature/article/beyond-ar-vs-vr-what-is-the-difference-between-ar-vs-mr-vs-vr-vs-xr.

[66] Tiago Andrade and Daniel Bastos, "Extended Reality in IoT Scenarios: Concepts, Applications and Future Trends," *2019 5th Experiment International Conference*, Funchal, Portugal, June 2019, at https://ieeexplore.ieee.org/document/

that in such a hybrid environment users can experience natural and intuitive 3D human-computer interactions.[67] For example, a user can interact with a digital object in the physical world as if it were physically present there (see **Figure 2**).[68]

Figure 2. Example of User-object Interaction in an MR Environment

Source: Carols Fy, *File: Entrenamiento-industrial-Fyware.jpg*, Wikimedia Commons, October 11, 2017, at https://commons.wikimedia.org/wiki/File:Entrenamiento-industrial-Fyware.jpg (used under the Creative Commons Attribution-Share Alike 4.0 International license, at https://creativecommons.org/licenses/by-sa/4.0/deed.en).

Note: This image illustrates a scenario where a user via a pair of MR glasses can see and interact with virtual objects in a physical environment; in this example, for training purposes.

MR requires advanced input technologies that can capture a user's body positions (e.g., head, hand, and finger movements), objects, surfaces, distances, locations, boundaries, and ambient lights and sounds.[69] Through spatial perception technologies, MR can provide users with a more natural, dynamic visualization of a digital object than a fixed-distance 2D display does.[70] For example, as a user moves away from a physical table on which a digital vase is placed, the vase displayed in the user's MR device would get smaller with increasing physical distance between the user and the table.[71]

8876559.

[67] Microsoft, *What Is Mixed Reality?* Mixed Reality: Discover Series, April 28, 2022, at https://docs.microsoft.com/en-us/windows/mixed-reality/discover/mixed-reality.

[68] Ibid.

[69] Ibid.

[70] Yashar Nezami, *What Is the Metaverse and Why Does It Need 5G to Succeed? The Metaverse 5G Relationship Explained*, Ericsson Group, April 21, 2022, at https://www.ericsson.com/en/blog/2022/4/why-metaverse-needs-5g.

[71] Ibid. Spatial perception technologies can also be used in AR.

Virtual Reality (VR)

VR technologies create an immersive, 3D, computer-generated, artificial environment, which replicates either the physical world or an imaginary world (see **Figure 3**).[72] VR replaces the user's physical reality with a simulated one with realistic sounds, images, and other sensations. Unlike AR and MR, VR does not incorporate the user's actual physical surroundings.[73]

Figure 3. Example of Using VR Technology in Scientific Investigation

Source: The National Aeronautics and Space Administration (NASA), *Experiments: Technology Development and Demonstration: Pilote*, at https://www.nasa.gov/mission_pages/station/research/experiments/explorer/Investigation.html?#id=8347.

Notes: NASA's Pilote program studies remote operation of robotic arms and space vehicles. The image shows a NASA astronaut participating in the investigation, wearing a VR headset, using hand-held controllers, and interacting with a computer-generated robotic arm.

A user can see and interact with a VR environment from a first-person perspective or through a digital avatar—a digital representation of the human user, which facilitates interactions with other users, virtual objects, or the surrounding environment.[74] Users can access VR environments using hardware such as headsets, hand-held controllers, gloves, body sensors, and motion detectors[75] and via software such as computer games, applications, and operating systems. Advances in

[72] Oliver Bowling, "The Metaverse: Who Really Wins?" *Oxford Business Review*, December 9, 2021, at https://oxfordbusinessreview.org/the-metaverse-who-really-wins/. See also Henrique Centieiro, "The Roles of VR, AR, and MR on the Metaverse," *DataDrivenInvestor*, January 7, 2022, at https://medium.datadriveninvestor.com/the-roles-of-vr-ar-and-mr-on-the-metaverse-593569cfb686.

[73] Henrique Centieiro, "The Roles of VR, AR, and MR on the Metaverse," *DataDrivenInvestor*, January 7, 2022, at https://medium.datadriveninvestor.com/the-roles-of-vr-ar-and-mr-on-the-metaverse-593569cfb686.

[74] Kristine L. Nowak and Jesse Fox, "Avatars and Computer-Mediated Communication: A Review of the Definitions, Uses, and Effects of Digital Representations," *Review of Communication Research*, vol. 6, 2018, p. 34, at https://doi.org/10.12840/issn.2255-4165.2018.06.01.015.

[75] Henrique Centieiro, "The Roles of VR, AR, and MR on the Metaverse," *DataDrivenInvestor*, January 7, 2022, at https://medium.datadriveninvestor.com/the-roles-of-vr-ar-and-mr-on-the-metaverse-593569cfb686.

haptic wearable technologies[76] have enabled users to embody their avatars (i.e., make the avatar move and react in response to the user's own movements) and use hand-tracking controllers to interact with virtual objects by making real-world gestures.[77]

VR currently faces some technical challenges. Current graphic rendering is not truly photorealistic, so the user experience, while immersive, may not feel completely natural.[78] Moreover, some users experience motion sickness after prolonged wearing of a VR headset. Sensations can include "general discomfort, apathy, drowsiness, headache, disorientation, or fatigue."[79] To mitigate these sensations, some experts suggest that VR needs improved technologies that provide users with graphical displays with fast screen refreshing rates and natural depth and light perception, spatialized audio, and interfaces using natural gestures and movements.[80]

Brain-Computer Interface (BCI)

BCI technology, based on research at the intersection of neuroscience and computing, aims to replace traditional screens and input devices on computers and mobile devices with direct connections to the user's brain, by picking up and relaying the brain's internal electrical activity either through implantable sensors or by capturing electroencephalographic (EEG) activity at the scalp through non-invasive wearable devices.[81] With BCI, a user's interaction with a computing device does not depend on the user's peripheral nerves and muscles.[82] Rather, a BCI device captures a user's neural signals and translates the user's mental intent directly into action. For example, the user might control and move a drone just by thinking of directional commands.[83]

BCI technology may provide a better cognitive user interface in the metaverse than existing AR/MR/VR devices do,[84] by enabling users to control digital avatars, objects, and interactions with brain signals.[85] A core element of BCI is an algorithm that converts electrophysiological

[76] Haptic technologies enable HCI through touch and external forces. "Unlike traditional interfaces such as displays and sound devices, haptic devices render mechanical signals (i.e., external force) that stimulate human touch and kinesthetic channels." Carlos Bermejo and Pan Hui, "A Survey on Haptic Technologies for Mobile Augmented Reality," *ACM Computing Surveys*, vol. 54, no. 9 (December 2021), pp. 1-35, at https://doi.org/10.1145/3465396.

[77] Kyle Orland, "So What Is 'The Metaverse,' Exactly?" *Ars Technica*, November 7, 2021, at https://arstechnica.com/gaming/2021/11/everyone-pitching-the-metaverse-has-a-different-idea-of-what-it-is/.

[78] Louis Rosenberg, "There Are Two Kinds of Metaverse. Only One Will Inherit the Earth," *Big Think*, January 11, 2022, at https://bigthink.com/the-future/metaverse-augmented-virtual-reality/.

[79] Tiago Andrade and Daniel Bastos, "Extended Reality in IoT Scenarios: Concepts, Applications and Future Trends," *2019 5th Experiment International Conference*, Funchal, Portugal, June 2019, at https://ieeexplore.ieee.org/document/8876559.

[80] Ibid.

[81] See Antonio Regalado, "Elon Musk's Neuralink Is Neuroscience Theater," *MIT Technology Review*, August 30, 2020, at https://www.technologyreview.com/2020/08/30/1007786/elon-musks-neuralink-demo-update-neuroscience-theater/. See also Alexandre Gonfalonieri, "What Brain-Computer Interfaces Could Mean for the Future of Work," *Harvard Business Review*, October 6, 2020, at https://hbr.org/2020/10/what-brain-computer-interfaces-could-mean-for-the-future-of-work.

[82] Jonathan R. Wolpaw (Guest Editor), et al., "Brain-Computer Interface Technology: A Review of the First International Meeting," *IEEE Transactions On Rehabilitation Engineering*, vol. 8, no. 2 (June 2000), p. 164.

[83] Marissa Norris, *Brain-Computer Interfaces Are Coming. Will We Be Ready?* RAND Corporation, August 27, 2020, at https://www.rand.org/blog/articles/2020/08/brain-computer-interfaces-are-coming-will-we-be-ready.html.

[84] See Amir R. Asadi, "BCI for Metaverse," *Association for Computing Machinery (ACM)*, March 24, 2022, at https://metaverse.acm.org/bci-for-interaction-with-metaverse/.

[85] Niel Patel, "Which Technologies Is Used to Make a Metaverse? Metaverse Development Technologies,"

input from the user into commands that control devices.[86] Recently, such algorithms have used machine learning and other artificial intelligence (AI) techniques to improve its processing efficiency, potentially leading to conversions fast enough for real-time interaction.[87]

Fifth-Generation (5G) and Next-Generation Wireless Networks

As discussed previously in "Persistent Network Access," the metaverse would require a high-bandwidth, low-latency, and reliable internet infrastructure to deliver an immersive, persistent, and interoperable virtual experience. The real-time and portable access to the virtual world via mobile devices would also require advanced wireless communications technologies. Fourth-generation (4G) wireless telecommunications technologies do not support the bandwidth, latency, and reliability required by the metaverse.[88] 5G[89] and next-generation (e.g., 6G) wireless telecommunications technologies may be able to support data-intensive metaverse applications.

5G

5G represents the next iteration of wireless communications technologies that were designed to improve 4G mobile networks.[90] Some experts assert that the high-speed data transmission in 5G networks will enable data-intensive XR applications.[91] In particular, a high-bandwidth 5G network could shift some intensive XR processing and functionality (e.g., graphical rendering) from users' local devices to high-performance servers at the edge of the 5G network[92]—a strategy called edge computing.[93] The 5G network could then deliver data from the edge server back to the user's mobile XR device with low latency.[94] 5G networks may also facilitate latency-sensitive applications such as on-device head tracking, controller tracking, hand tracking, and motion tracking and thus improve the user experience with lightweight and cost-efficient XR devices.[95]

MakeAnAppLike, December 26, 2021, at https://makeanapplike.com/top-metaverse-development-technologies/.

[86] Jonathan R. Wolpaw (Guest Editor), et al., "Brain-Computer Interface Technology: A Review of the First International Meeting," *IEEE Transactions On Rehabilitation Engineering*, vol. 8, no. 2 (June 2000), p. 164.

[87] See Sissi Cao, "Snap's Latest Acquisition Is a Bet on a Metaverse Controlled by Thoughts," *Observer*, March 24, 2022, at https://observer.com/2022/03/snap-acquire-nextmind-brain-computer-interface-metaverse/.

[88] AT&T, "AT&T 5G Powers Proof-of-Concept Harry Potter Virtual Reality Experience," press release, July 14, 2021, at https://about.att.com/newsroom/2021/5g_harry_potter.html.

[89] For more information of the 5G technology, see CRS Report R45485, *Fifth-Generation (5G) Telecommunications Technologies: Issues for Congress*, by Jill C. Gallagher and Michael E. DeVine.

[90] Ibid.

[91] Fredrik Alriksson, Du Ho Kang, Chris Phillips, et al., "XR and 5G: Extended Reality at Scale with Time-Critical Communication," *Ericsson Technology Review*, no. 8, August 24, 2021, p. 2, at https://www.ericsson.com/4a492d/assets/local/reports-papers/ericsson-technology-review/docs/2021/xr-and-5g-extended-reality-at-scale-with-time-critical-communication.pdf.

[92] Balaji Ethirajulu, *How 5G and Edge Computing Can Enhance Virtual Reality*, Ericsson Group, April 8, 2020, at https://www.ericsson.com/en/blog/2020/4/how-5g-and-edge-computing-can-enhance-virtual-reality.

[93] *Edge computing* is a geographically distributed computing concept that enables application services to be processed and hosted on cloud servers close to end users (i.e., "at the edge of a network"). See Suresh Chitturi, "Enabling Edge Computing Applications in 3GPP," *3GPP (The 3rd Generation Partnership Project) HIGHLIGHTS*, Issue 01, September 2020, at https://www.3gpp.org/news-events/2152-edge_sa6.

[94] Balaji Ethirajulu, *How 5G and Edge Computing Can Enhance Virtual Reality*, Ericsson Group, April 8, 2020, at https://www.ericsson.com/en/blog/2020/4/how-5g-and-edge-computing-can-enhance-virtual-reality.

[95] Fredrik Alriksson, Du Ho Kang, Chris Phillips, et al., "XR and 5G: Extended Reality at Scale with Time-Critical Communication," *Ericsson Technology Review*, no. 8, August 24, 2021, p. 3, at https://www.ericsson.com/4a492d/assets/local/reports-papers/ericsson-technology-review/docs/2021/xr-and-5g-extended-reality-at-scale-with-time-

According to the International Telecommunication Union (ITU), one version of 5G technology can yield peak data rates up to 140 gigabits per second (Gbps) in the download link and 65 Gbps in the upload link.[96] According to 3GPP, a global consortium of national and regional telecommunications standards organizations,[97] a 5G system qualifying its wireless service requirements to support AR/VR applications could achieve an end-to-end latency in the range of 5-10 milliseconds while maintaining high-definition graphical resolution and user-experienced data rate of 10 Gpbs for both download and upload links,[98] and network reliability of data delivery of at least 99.9%.[99]

6G

6G represents the next generation of wireless communications technologies projected to follow and improve 5G data networks. 6G is in the early stage of research and development. Institutions in the United States, China, India, Japan, South Korea, and countries in the European Union have launched 6G research initiatives. Various telecommunications providers, equipment makers, and industry consortia are developing 6G technologies. 6G is expected to achieve a download speed of one terabit per second (1 Tbps; 1 Tb is equal to 1,000 Gb), 10-100 times faster than 5G;[100] latency in the range of 10-100 microseconds (1 microsecond is equal to 1/1000 millisecond), 50-1,000 times less than 5G;[101] and network reliability of 99.999%, versus 5G's 99.9%.[102]

Blockchain

Blockchain[103] is a technology that permanently records information (e.g., commercial transactions) in an interconnected database called a ledger.[104] Blockchain ledgers rely on a distributed-network proof system to prevent falsification or double spending.[105] All participating

critical-communication.pdf.

[96] ITU-R (Radiocommunication Sector of ITU), *Detailed Specifications of the Terrestrial Radio Interfaces of International Mobile Telecommunications-2020 (IMT-2020)*, ITU, Recommendation ITU-R M.2150-1, February 2022, p. 24, at https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2150-1-202202-I!!PDF-E.pdf.

[97] The seven organizations, as 3GPP's Organizational Partners, are from China, Europe, India, Japan (two organizations), South Korea, and the United States. They transpose the technical specifications developed by 3GPP into technical standards. See 3GPP, "Partners," at https://www.3gpp.org/about-3gpp/partners.

[98] 3GPP, *Service Requirements for the 5G System*, 3GPP TS 22.261, version 17.10.0, Release 17, March 2022, p. 58.

[99] *Reliability* is the percentage of data packets successfully delivered to a given device within the time constraint required by the targeted service out of all the packets transmitted. See ibid., pp. 11, 58.

[100] Aarno Pärssinen, Mohamed-Slim Alouini, Markus Berg, et al., *White Paper on RF Enabling 6G—Opportunities and Challenges from Technology to Spectrum*, University of Oulu, 6G Research Visions, No. 13, April 12, 2021, p. 7, at http://jultika.oulu.fi/files/isbn9789526228419.pdf.

[101] Rajesh Gupta, Dakshita Reebadiya, and Sudeep Tanwar, "6G-Enabled Edge Intelligence for Ultra-Reliable Low Latency Applications: Vision and Mission," *Computer Standards & Interfaces*, vol. 77, August 2021, at https://doi.org/10.1016/j.csi.2021.103521.

[102] Zoran Bojkovic, Dragorad Milovanovic, Tulsi P. Fowdur, et al., "6G Ultra-Low Latency Communication in Future Mobile XR Applications," *6th International Symposium on Signal Processing and Intelligent Recognition Systems*, Chennai, India, October 14-17, 2020, pp. 302-312, at https://link.springer.com/chapter/10.1007/978-981-16-0425-6_22.

[103] For more information about blockchain applications, see CRS Report R47064, *Blockchain: Novel Provenance Applications*, by Kristen E. Busch.

[104] Rabindra Ratan and Dar Meshi, *Why You Can't Have the Metaverse Without a Blockchain*, World Economic Forum, January 20, 2022, at https://www.weforum.org/agenda/2022/01/metaverse-crypto-blockchain-virtual-world.

[105] Joshua A.T. Fairfield, "Bitproperty," *Southern California Law Review*, vol. 88, 2015, p. 820, at https://southerncalifornialawreview.com/wp-content/uploads/2018/01/88_805.pdf.

nodes (i.e., computing devices) in a blockchain network share, maintain, and verify transactional data published to the network, making records tamper-resistant.[106] In order to add a block of new data to the blockchain, participating nodes must reach a consensus to validate the legitimacy of the block following the rules of the blockchain.[107] This consensus-driven recording system is cryptographically secured and difficult to defraud.[108]

Some metaverse enthusiasts argue that the success of the metaverse depends on developing a virtual economy with profitable businesses, capital mobility, and strong consumer spending,[109] enabling companies and individuals to build, trade, and invest in virtual products, goods, and services.[110] These activities would require a viable financial infrastructure to support commercial transactions parallel to, or extending, those occurring in the physical world. Some metaverse proponents are optimistic that blockchain-based digital currencies (i.e., cryptocurrency) and financial services could provide the underlying transaction system for the virtual world.

Blockchain-based cryptocurrencies could serve as a payment method in metaverse transactions.[111] Proponents argue that blockchain use in the metaverse could facilitate fast, secure, trusted, and transparent online transactions without a centralized oversight body.[112] Moreover, those who advocate for a decentralized metaverse (i.e., one not owned and controlled by a handful of companies) argue that blockchain could also serve as the technological backbone to build decentralized and distributed applications, services, platforms, and communities in the metaverse.[113]

Other experts believe that the metaverse could exist without blockchain technology.[114] Users can complete transactions of digital assets using traditional electronic payment systems.[115] Leading platform players could agree on open and common standards to enable interoperability of digital assets in the metaverse without blockchain.[116] Prices of blockchain-based cryptocurrencies

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[106] CRS Report R47064, *Blockchain: Novel Provenance Applications*, by Kristen E. Busch.

[107] Ibid.

[108] Ibid. See also Rabindra Ratan and Dar Meshi, *Why You Can't Have the Metaverse Without a Blockchain*, World Economic Forum, January 20, 2022, at https://www.weforum.org/agenda/2022/01/metaverse-crypto-blockchain-virtual-world.

[109] Matthew Ball, *Payments, Payment Rails, and Blockchains, and the Metaverse*, MatthewBall.vc, The Metaverse Primer, June 29, 2021, at https://www.matthewball.vc/all/metaversepayments.

[110] Stefan Brambilla Hall and Cathy Li, *What Is the Metaverse? And Why Should We Care?* World Economic Forum, Global Agenda Articles: The Metaverse, October 29, 2021, at https://www.weforum.org/agenda/2021/10/what-is-the-metaverse-why-care/.

[111] See Edd Gent, "What Can the Metaverse Learn from Second Life?" *IEEE Spectrum*, November 29, 2021, at https://spectrum.ieee.org/metaverse-second-life.

[112] Alexander Lee, "WTF Is the Metaverse?" *DIGIDAY*, July 26, 2021, at https://digiday.com/marketing/wtf-is-the-metaverse/. See also Niel Patel, "Which Technologies Is Used to Make a Metaverse? Metaverse Development Technologies," *MakeAnAppLike*, December 26, 2021, at https://makeanapplike.com/top-metaverse-development-technologies/.

[113] Adi Robertson and Jay Peters, "What Is the Metaverse, and Do I Have to Care?" *The Verge*, October 4, 2021, at https://www.theverge.com/22701104/metaverse-explained-fortnite-roblox-facebook-horizon. See also Jake Frankenfield, "Decentralized Applications (dApps)," *Investopedia*, November 16, 2021, at https://www.investopedia.com/terms/d/decentralized-applications-dapps.asp.

[114] Andrew Singer, "Does the Metaverse Need Blockchain to Ensure Widespread Adoption?" *Cointelegraph*, July 4, 2022, at https://cointelegraph.com/news/does-the-metaverse-need-blockchain-to-ensure-widespread-adoption.

[115] Ibid.

[116] Derek Robertson, "Does the Metaverse Need Crypto?" *POLITICO*, April 27, 2022, at https://www.politico.com/newsletters/digital-future-daily/2022/04/27/does-the-metaverse-need-crypto-00028273.

fluctuate and may create value volatility and market uncertainty.[117] Blockchain may also pose regulatory challenges due to potential anonymized criminal transactions and financial fraud.[118]

Non-Fungible Tokens (NFTs)

A non-fungible token is a unique digital identifier recorded in a blockchain with its associated metadata.[119] When attached to a particular asset (e.g., a piece of digital artwork or a musical recording), the NFT can be used to verify the authenticity and provenance of the underlying asset, certify its ownership, or represent a right to use, copy, or display the asset.[120] NFTs and the assets they represent can be traded online and could potentially support commercial transactions of virtual goods and identity management (of digital avatars, for example) in the metaverse.[121]

Select Companies Developing Metaverse Technologies and Services

A number of large technology companies (known collectively as "big tech") have invested heavily in the metaverse, developing and acquiring technologies[122] and seeking to obtain a first-mover advantage.[123] This section highlights select companies in the United States, which currently engage in the development and investment related to the metaverse.

Second Life, released in 2003, is arguably the first example of a large-scale 3D virtual world to be implemented and commercialized.[124] It created an online multiplayer, role-playing, multimedia, 3D platform for users, through their avatars, to explore virtual spaces, play games, make and meet friends, join social events, create and trade virtual goods and services, take online classes, participate in meetings, and have "a second life" in the virtual world.[125]

An event that increased public awareness of the metaverse concept was Facebook Inc.'s corporate name change in late 2021 to Meta Platforms, Inc. (Meta) and the company's shift in emphasis to

[117] Ibid.

[118] Ibid.

[119] CRS Report R47189, *Non-Fungible Tokens (NFTs)*, by Kristen E. Busch. Metadata is the data that provides information about other data. For example, a digital document may include metadata that describes the size, type, and author of the file and when it was created and modified.

[120] Sam Dean, "$69 Million for Digital Art? The NFT Craze Explained," *Los Angeles Times*, March 11, 2021, at https://www.latimes.com/business/technology/story/2021-03-11/nft-explainer-crypto-trading-collectible.

[121] Stefan Brambilla Hall and Cathy Li, *What Is the Metaverse? And Why Should We Care?* World Economic Forum, Global Agenda Articles: The Metaverse, October 29, 2021, at https://www.weforum.org/agenda/2021/10/what-is-the-metaverse-why-care/.

[122] Matt O'Brien and Kelvin Chan, "Explainer: What Is the Metaverse and How Will It Work?" *ABC News*, October 28, 2021, at https://abcnews.go.com/Business/wireStory/explainer-metaverse-work-80842516. See also Cecilia D'Anastasio, "The Metaverse Is Simply Big Tech, but Bigger," *Wired*, November 4, 2021, at https://www.wired.com/story/big-tech-metaverse-internet-consolidation-business/.

[123] *First-mover advantage* is the idea that by being the first to enter a new market, a business gains a competitive advantage over its actual and potential rivals leading to higher revenues and profits over time. See Fernando F. Suarez and Gianvito Lanzolla, "The Half-Truth of First-Mover Advantage," *Harvard Business Review*, April 2005, at https://hbr.org/2005/04/the-half-truth-of-first-mover-advantage.

[124] Joe Tidy, "Zuckerberg's Metaverse: Lessons from Second Life," *BBC*, November 5, 2021, at https://www.bbc.com/news/technology-59180273. See also Edd Gent, "What Can the Metaverse Learn from Second Life?" *IEEE Spectrum*, November 29, 2021, at https://spectrum.ieee.org/metaverse-second-life.

[125] See demonstrations of Second Life at https://secondlife.com/.

building the metaverse.[126] In addition to its family of social media apps, Meta now focuses on AR/VR-related consumer hardware, software, and content to develop immersive social technologies and computing platforms.[127] The company had invested in the development of AR/VR technologies before its name change; for example, acquiring Oculus VR, Inc. for $2 billion in 2014.[128] Meta is developing VR services, such as Horizon Worlds, a platform on which users can create their own virtual home and office spaces and interact with other users.[129]

Microsoft Corporation has described immersive and interactive virtual game spaces as building blocks for the metaverse and a key component in the development of its metaverse platforms.[130] The company asserts the metaverse could also be a place where people work and meet.[131] It is developing Mesh, a collaboration and communication platform, on which users could use 3D avatars to participate in virtual meetings while wearing MR goggles.[132]

Alphabet Inc. has invested in AR technologies (e.g., Google Glass) and plans to integrate them into Google's internet-based navigation, online collaboration, and video content services.[133] Google refers to its vision of the metaverse—which combines its expertise in search engine algorithms, AI, and AR—as "ambient computing." Google describes the user experience in ambient computing as "being within the computer rather than accessing the computer ... being always online rather than always having access to an online world."[134]

Other companies are developing metaverse-related hardware, software, services, and platforms as well. For example

- Apple Inc. is reportedly investing in the development of both hardware and software for AR applications.[135]
- Roblox Corporation is reportedly expanding its virtual world platform by allowing users not only to play millions of games created by independent developers but also to shop for virtual items using its own virtual currency,

[126] See U.S. Securities and Exchange Commission, *Meta Platforms, Inc., Form 8-K (filed October 28, 2021)*, p. 2, at https://d18rn0p25nwr6d.cloudfront.net/CIK-0001326801/e1b7c43d-175d-4702-a6bb-b42fbbb8cdd0.pdf.

[127] Ibid.

[128] Meta, "Facebook to Acquire Oculus," press release, March 25, 2014, at https://about.fb.com/news/2014/03/facebook-to-acquire-oculus/.

[129] Mark Rabkin, "Connect 2021 Recap: Horizon Home, the Future of Work, Presence Platform, and More," Meta Oculus Blog, October 28, 2021, at https://www.oculus.com/blog/connect-2021-recap-horizon-home-the-future-of-work-presence-platform-and-more/. See also Alex Heath, "Meta Opens Up Access to Its VR Social Platform Horizon Worlds," *The Verge*, December 9, 2021, at https://www.theverge.com/2021/12/9/22825139/meta-horizon-worlds-access-open-metaverse.

[130] Microsoft, "Microsoft to Acquire Activision Blizzard to Bring the Joy and Community of Gaming to Everyone, Across Every Device," press release, January 18, 2022, at https://news.microsoft.com/2022/01/18/microsoft-to-acquire-activision-blizzard-to-bring-the-joy-and-community-of-gaming-to-everyone-across-every-device/.

[131] Mark Sullivan, "Microsoft's Metaverse Vision Is Becoming Clear—And Makes Sense," *Fast Company*, January 27, 2022, at https://www.fastcompany.com/90716389/microsoft-activision-metaverse.

[132] Brett Iversen, Satya Nadella, and Amy Hood, *Microsoft FY22 Second Quarter Earnings Conference Call*, Microsoft, January 25, 2022, at https://www.microsoft.com/en-us/investor/events/fy-2022/earnings-fy-2022-q2.aspx.

[133] Alphabet, "Alphabet Q4 2021 Earnings Call," February 1, 2022, at https://abc.xyz/investor/static/pdf/2021_Q4_Earnings_Transcript.pdf. Google is a subsidiary of Alphabet, which focuses on the company's internet-based products and services.

[134] Brian X. Chen, "What's All the Hype About the Metaverse?" *New York Times*, January 18, 2022, at https://www.nytimes.com/2022/01/18/technology/personaltech/metaverse-gaming-definition.html.

[135] Parkev Tatevosian, "Apple CEO Sees Big Potential in the Metaverse," *The Motley Fool*, February 2, 2022, at https://www.fool.com/investing/2022/02/02/apple-ceo-tim-cook-metaverse-interested/.

Robux. The platform also allows users to perform collaborative work and business communications.[136] To some game players, Roblox may be the nearest and most expansive vision of the metaverse.[137]

- Epic Games, Inc. (the developer of the online game *Fortnite*) has received investment from companies such as Sony to develop metaverse-type services and applications.[138]

The investment in, and development of, metaverse technologies and applications by technology firms may raise policy questions around content moderation, privacy, and competition.[139]

Policy Issues for Congressional Consideration

Some experts have expressed concerns that the immersive, persistent, and real-time environment and large-scale virtual platforms of the metaverse could reproduce and magnify the issues already surrounding current online platforms, services, and applications, such as content moderation, privacy, competition, and the digital divide.[140] Members of Congress have shown interest in each of these issues in the context of current online platforms and may consider addressing them in the specific context of the metaverse.

Content Moderation[141]

Some Members of Congress have introduced bills that seek to address issues surrounding content moderation on social media platforms.[142] Some experts assert that content moderation may be much more complicated in the metaverse than social media.[143] Social media companies have pitched the metaverse as a virtual space for immersive social communications, interactions, and

[136] John Herrman and Kellen Browning, "Are We in the Metaverse Yet?" *New York Times*, October 29, 2021, at https://www.nytimes.com/2021/07/10/style/metaverse-virtual-worlds.html.

[137] Ibid.

[138] Eric Ravenscraft, "What Is the Metaverse, Exactly?" *WIRED*, November 25, 2021, at https://www.wired.com/story/what-is-the-metaverse/. See also Epic Games, "Announcing a $1 Billion Funding Round to Support Epic's Long-Term Vision for the Metaverse," press release, April 13, 2021, at https://www.epicgames.com/site/en-US/news/announcing-a-1-billion-funding-round-to-support-epics-long-term-vision-for-the-metaverse.

[139] See Tom Wheeler, *The Metachallenges of the Metaverse*, The Brookings Institution, September 30, 2021, at https://www.brookings.edu/blog/techtank/2021/09/30/the-metachallenges-of-the-metaverse/. See also Cecilia D'Anastasio, "The Metaverse Is Simply Big Tech, but Bigger," *Wired*, November 4, 2021, at https://www.wired.com/story/big-tech-metaverse-internet-consolidation-business/.

[140] See, for example, Quinta Jurecic and Alan Z. Rozenshtein, "Mark Zuckerberg's Metaverse Unlocks a New World of Content Moderation Chaos," *Lawfare*, November 3, 2021, at https://www.lawfareblog.com/mark-zuckerbergs-metaverse-unlocks-new-world-content-moderation-chaos. See also Bradley Tusk, "Regulating the Metaverse(s)," January 31, 2022, at https://mirror.xyz/0x81dB200eD62Ce664B911C211b55F836a208Df868/n-8osyXEl8Dzv_qnrBR1ICdxF55zdIMLP6OI3yU9igY.

[141] For general information of content moderation related to social media, see CRS Report R46662, *Social Media: Misinformation and Content Moderation Issues for Congress*, by Jason A. Gallo and Clare Y. Cho.

[142] The 117th Congress has introduced more than a dozen of bills related to content moderation, which include, for example, the Digital Platform Commission Act of 2022 (S. 4201) and the 21st Century FREE Speech Act (H.R. 7613).

[143] Aaron Mak, "I Was a Bouncer in the Metaverse," *Slate*, May 9, 2022, at https://slate.com/technology/2022/05/metaverse-content-moderation-virtual-reality-bouncers.html. See also Leda Alvim, "How the Metaverse Could Impact the World and the Future of Technology," *ABC News*, January 28, 2022, at https://abcnews.go.com/Technology/metaverse-impact-world-future-technology/story?id=82519587.

engagement.[144] Some analysts argue that bullying and harassment could be exacerbated by the immersive nature of VR.[145] As metaverse users would have virtual bodies and voices, content moderation would likely need to address text, speech, and behavior.[146]

Some analysts also believe that conducting effective moderation on all types of communication and interaction—chat, voice, gestures, and user-generated content—among a massive number of users in real time would require significant effort and may not be feasible.[147] The chief technology officer of Meta has reportedly acknowledged that moderating how users speak and behave in Meta's virtual worlds "at any meaningful scale is practically impossible."[148] In 2021, Second Life founder Philip Rosedale stated, "[w]e don't have identity systems yet that would enable strong governance."[149] Some experts doubt that social media and content providers would be able to moderate a metaverse environment that is enormously more complex and dynamic given the challenges they are facing in moderating their existing services and platforms.[150] Some have expressed concerns that metaverse platforms might end up being uncontrollable or operators might implement strict screening, monitoring, and surveillance processes that restrict a great deal of behavior.[151]

Data Privacy[152]

Data privacy is an issue of concern for many Members of Congress.[153] Some experts assert that personal information is the "seminal asset" in the digital economy and the opportunity to collect and monetize personal data acquired from metaverse users would be immense.[154] Additionally, some commentators have expressed concern that the metaverse might give operators and service providers an expanded set of data sources to track and mine, including body movements, facial expressions, and biometric data.[155] A VR device could generate data that reveals a user's

[144] Bradley Tusk, "Regulating the Metaverse(s)," January 31, 2022, at https://mirror.xyz/0x81dB200eD62Ce664B911C211b55F836a208Df868/n-8osyXEl8Dzv_qnrBR1ICdxF55zdIMLP6OI3yU9igY.

[145] Hannah Murphy, "How Will Facebook Keep Its Metaverse Safe for Users?" *Financial Times*, November 12, 2021, at https://www.ft.com/content/d72145b7-5e44-446a-819c-51d67c5471cf.

[146] Paul Daugherty, Marc Carrel-Billiard, and Michael Blitz, *Meet Me in the Metaverse*, Accenture, The Technology Vision 2022 Report, p. 35, 2022, at https://www.accenture.com/_acnmedia/Thought-Leadership-Assets/PDF-5/Accenture-Meet-Me-in-the-Metaverse-Full-Report.pdf.

[147] Utopia Analytics, "What to Do About Moderation in Meta's Metaverse?" March 16, 2022, at https://utopiaanalytics.com/what-to-do-about-content-moderation-in-metas-metaverse/. See also Hannah Murphy, "How Will Facebook Keep Its Metaverse Safe for Users?" *Financial Times*, November 12, 2021, at https://www.ft.com/content/d72145b7-5e44-446a-819c-51d67c5471cf.

[148] Hannah Murphy, "How Will Facebook Keep Its Metaverse Safe for Users?" *Financial Times*, November 12, 2021, at https://www.ft.com/content/d72145b7-5e44-446a-819c-51d67c5471cf.

[149] Andrew R. Chow, "6 Lessons on the Future of the Metaverse from the Creator of Second Life," *Time*, November 26, 2021, at https://time.com/6123333/metaverse-second-life-lessons/.

[150] Hannah Murphy, "How Will Facebook Keep Its Metaverse Safe for Users?" *Financial Times*, November 12, 2021, at https://www.ft.com/content/d72145b7-5e44-446a-819c-51d67c5471cf.

[151] Leda Alvim, "How the Metaverse Could Impact the World and the Future of Technology," *ABC News*, January 28, 2022, at https://abcnews.go.com/Technology/metaverse-impact-world-future-technology/story?id=82519587.

[152] For general information of data privacy law, see CRS In Focus IF11207, *Data Protection and Privacy Law: An Introduction*, by Stephen P. Mulligan and Chris D. Linebaugh.

[153] The 117th Congress has introduced dozens of bills related to data privacy right and protection, which include, for example, the Consumer Online Privacy Rights Act (S. 3195) and the DATA Privacy Act (H.R. 5807).

[154] Tom Wheeler, *The Metachallenges of the Metaverse*, The Brookings Institution, September 30, 2021, at https://www.brookings.edu/blog/techtank/2021/09/30/the-metachallenges-of-the-metaverse/.

[155] Shirin Ghaffary, "Why You Should Care About Facebook's Big Push into the Metaverse," *Vox*, November 24,

emotions, abilities, and desires.[156] According to a report issued by the Institute of Electrical and Electronics Engineers (IEEE), XR headsets and their peripherals could enable the capture of a wide range of user data, as shown in **Table 1**.

Table 1. Examples of User Data Captured by XR Devices

Data Type	Detailed Data
Movements and physical actions	Optical and inertial tracking of head/body/limb movements, electromyography neuromotor input (e.g., by haptic gloves), sensing of facial expressions, auditory sensing of speech and non-speech activity, etc.
Neural activity	EEG for brain-computer interfaces
Context	Location tracking, Simultaneous Localization and Mapping (SLAM), and machine-learning-driven analysis of optical data
Physiology	Eye/gaze tracking, heart rate variability sensing, and other biometrics

Source: Mark McGill, *Extended Reality (XR) and the Erosion of Anonymity and Privacy*, IEEE, The IEEE Global Initiative on Ethics of Extended Reality (XR) Report, November 2021, p. 7, at https://standards.ieee.org/wp-content/uploads/import/governance/iccom/extended-reality-anonymity-privacy.pdf.

The IEEE report maintains that the pervasive capture of sensitive physical and behavioral data is both unique to XR relative to other consumer technologies and fundamentally necessary to its core functionality.[157] This set of sensed user data could be used with machine learning algorithms and AI techniques for estimation, inference, and prediction of users' identity, behavior, activity, and emotional state.[158] Additionally, some experts point out that interoperability, a core aspect of the metaverse, is fundamentally about data sharing and has inherent privacy risks.[159]

Some observers speculate that metaverse technology companies may seek to use personal data acquired in the metaverse to create user profiling and sell targeted advertising, in a similar fashion to current social media, search, and online marketplace platforms.[160] For example, the company that operates Second Life currently collects, uses, processes, stores, and disclosed its user data in a manner and scope similar to other online platform operators' data practices.[161] Given the range of personal information that may be collected by metaverse technologies, some have noted the pressing need for data privacy protection while metaverse technologies are being developed.[162]

2021, at https://www.vox.com/recode/22799665/facebook-metaverse-meta-zuckerberg-oculus-vr-ar.

[156] Mike Swift, "Facebook's Metaverse Aspirations Tied to Privacy, Antitrust Regulation," *MLex*, November 1, 2021, at https://mlexmarketinsight.com/news-hub/editors-picks/area-of-expertise/antitrust/facebooks-metaverse-aspirations-tied-to-privacy-antitrust-regulation.

[157] Mark McGill, *Extended Reality (XR) and the Erosion of Anonymity and Privacy*, IEEE, The IEEE Global Initiative on Ethics of Extended Reality (XR) Report, November 2021, p. 7, at https://standards.ieee.org/wp-content/uploads/import/governance/iccom/extended-reality-anonymity-privacy.pdf.

[158] Ibid., pp. 7-8.

[159] Kate Kaye, "WTF Is Interoperability," *DIGIDAY*, July 6, 2021, at https://digiday.com/marketing/wtf-is-interoperability/.

[160] Mike Swift, "Facebook's Metaverse Aspirations Tied to Privacy, Antitrust Regulation," *MLex*, November 1, 2021, at https://mlexmarketinsight.com/news-hub/editors-picks/area-of-expertise/antitrust/facebooks-metaverse-aspirations-tied-to-privacy-antitrust-regulation.

[161] See Linden Lab, "Privacy Policy," March 12, 2020, at https://www.lindenlab.com/privacy.

[162] Paul Daugherty, Marc Carrel-Billiard, and Michael Blitz, *Meet Me in the Metaverse*, Accenture, The Technology Vision 2022 Report, p. 50, 2022, at https://www.accenture.com/_acnmedia/Thought-Leadership-Assets/PDF-5/Accenture-Meet-Me-in-the-Metaverse-Full-Report.pdf. See also Bradley Tusk, "Regulating the Metaverse(s)," January

In February 2022, three Members of Congress wrote a letter to Lina Khan, Chair of the Federal Trade Commission (FTC), regarding "the potential threats to children who use VR products and platforms."[163] In the letter, they urged the FTC to use its authority under the Children's Online Privacy Protection Act of 1998 (COPPA; Title XIII of P.L. 105-277) and the Federal Trade Commission Act of 1914, as amended, to protect children in the metaverse.[164] Among the concerns identified by the Members are "VR companies' plans to present commercial advertisements in the metaverse," which "could lead to harmful marketing practices that may be inherently manipulative of children."[165] The Members stated that under the laws the FTC "has a statutory obligation to ensure that powerful technology platforms treat young people fairly, comply with the platforms' own public statements [e.g., privacy policies], and protect children's privacy."[166]

Market Power and Competition[167]

Congress is considering bills that would create new antitrust standards specifically applicable to big tech companies.[168] According to some experts, market power in the metaverse may come primarily from network effects and scale.[169] Network effects refers to situations in which the value of a product, service, or platform depends on the number of buyers, sellers, or users who leverage it. Typically, the greater the number of buyers, sellers, or users, the greater the network effect, and the greater the value created by the offering. The willingness to pay for, offer, or use the product, service, or platform increases as the number of buyers, sellers, or users grows.[170] It is possible that a few companies could take advantage of network effects and seek to consolidate

31, 2022, at https://mirror.xyz/0x81dB200eD62Ce664B911C211b55F836a208Df868/n-8osyXEl8Dzv_qnrBR1ICdxF55zdIMLP6OI3yU9igY.

[163] Letter from Senator Edward J. Markey and Representatives Kathy Castor and Lori Trahan, to Lina Khan, Chair of the FTC, February 16, 2022, at https://www.markey.senate.gov/imo/media/doc/letter_to_ftc_-_vr_and_children.pdf.

[164] Ibid., p. 2. COPPA prohibits "an operator of a website or online service directed to children, or any operator that has actual knowledge that it is collecting personal information from a child" from collecting "personal information from a child," unless the operator provides an online notice about its information collection practices and obtains "verifiable parental consent for the collection, use, or disclosure of" the information to be collected. 15 U.S.C. §6502(a)(1), (b)(1)(A). The FTC Act prohibits "unfair or deceptive acts or practices in or affecting commerce." 15 U.S.C. §45(a)(1).

[165] Letter from Senator Edward J. Markey and Representatives Kathy Castor and Lori Trahan, to Lina Khan, Chair of the FTC, February 16, 2022, at https://www.markey.senate.gov/imo/media/doc/letter_to_ftc_-_vr_and_children.pdf.

[166] Ibid.

[167] For general information and analysis of antitrust issues related to big tech companies, see CRS Report R45910, *Antitrust and "Big Tech"*, by Jay B. Sykes.

[168] For more information on those bills being considered by the 117th Congress, see CRS Report R46875, *The Big Tech Antitrust Bills*, by Jay B. Sykes.

[169] Matthew Ball, *Payments, Payment Rails, and Blockchains, and the Metaverse*, MatthewBall.vc, The Metaverse Primer, June 29, 2021, at https://www.matthewball.vc/all/metaversepayments.

[170] See Tim Stobierski, "What Are Network Effects?" *Harvard Business School Online*, Business Insights Blog, November 12, 2020, at https://online.hbs.edu/blog/post/what-are-network-effects. Network effects occur because the number of relationships between network members grow exponentially with the number of users. Metcalfe's Law states that a network's impact is the square of the number of nodes in the network. For example, if a network has 10 nodes, its inherent value is 100 (10 * 10). The network nodes can be computers or connecting users. See Techopedia, *Metcalf's Law*, May 28, 2019, at https://www.techopedia.com/definition/29066/metcalfes-law.

Markets in which network effects play a major role are often referred to as winner-takes-all markets. Once a company obtains network effects, it tends to stay ahead of its competitors; the demand for its product and service could keep growing faster as it gets bigger; and it could achieve a dominant market power. See Tim Stobierski, "What Are Network Effects?" *Harvard Business School Online*, Business Insights Blog, November 12, 2020, at https://online.hbs.edu/blog/post/what-are-network-effects.

control over key metaverse platforms. Accordingly, some critics assert that the metaverse will provide new opportunities to those big tech companies to further increase their market power and extend their dominance beyond their 2D internet platforms.[171] Some experts also express concern that a large portion of users' digital lives, if the metaverse were to achieve sufficient scale, might be controlled by a handful of companies,[172] leading to further erosion of user privacy and autonomy.[173]

If this were to be the case, metaverse platforms might be able to prevent competing technologies, standards, and applications from being available on their platforms, similar to a controversial practice that some big tech companies currently implement at their online application stores.[174] The FTC is reportedly investigating whether VR headset maker Oculus VR, which is owned by Meta, is engaged in anticompetitive practices in its treatment of third-party applications and through the prioritization of its own software.[175]

Digital Divide[176]

Some Members of Congress have expressed concern about those who lack access to or cannot afford high-speed internet, given the importance of the internet to education, work, and social interaction. The gap between those do and do not have internet access is known as the digital divide. By the FCC's current broadband standard of 25/3 Mpbs, as of the end of 2019, 4.4% of the U.S. population, or 14.4 million people, did not have broadband access.[177]

Congress has authorized and appropriated federal funds for broadband to help bridge the digital divide, for example, in the Coronavirus Aid, Relief, and Economic Security Act (CARES Act; P.L. 116-136); the Consolidated Appropriations Act, 2021 (CAA, 2021; P.L. 116-260); the American Rescue Plan Act of 2021 (ARPA; P.L. 117-2); and the Infrastructure Investment and Jobs Act (IIJA; P.L. 117-58). Most of these funds, including the largest federal broadband grant program—the Broadband Equity, Access, and Deployment (BEAD) program administered by the National Telecommunications and Information Administration, prioritize support for broadband

[171] Cecilia D'Anastasio, "The Metaverse Is Simply Big Tech, but Bigger," *Wired*, November 4, 2021, at https://www.wired.com/story/big-tech-metaverse-internet-consolidation-business/.

[172] Quinta Jurecic and Alan Z. Rozenshtein, "Mark Zuckerberg's Metaverse Unlocks a New World of Content Moderation Chaos," *Lawfare*, November 3, 2021, at https://www.lawfareblog.com/mark-zuckerbergs-metaverse-unlocks-new-world-content-moderation-chaos.

[173] Janna Anderson, Lee Rainie, and Emily A. Vogels, *Experts Say the "New Normal" in 2025 Will Be Far More Tech-Driven, Presenting More Big Challenges*, Pew Research Center, February 18, 2021, at https://www.pewresearch.org/internet/2021/02/18/experts-say-the-new-normal-in-2025-will-be-far-more-tech-driven-presenting-more-big-challenges/.

[174] See CRS Legal Sidebar LSB10219, *Antitrust and the iPhone: Supreme Court to Consider Whether App Store Customers Can Sue Apple for Monopolization*, by Jay B. Sykes.

[175] See Naomi Nix and Mark Gurman, "Meta's Oculus Unit Faces FTC-Led Probe of Competition Practices," *Bloomberg*, January 14, 2022, at https://www.bloomberg.com/news/articles/2022-01-14/meta-s-oculus-unit-faces-ftc-led-probe-of-competition-practices.

[176] For more information of digital divide, see CRS In Focus IF12030, *The Broadband Digital Divide: What Comes Next for Congress?*, by Colby Leigh Rachfal; CRS Report R46613, *The Digital Divide: What Is It, Where Is It, and Federal Assistance Programs*, by Colby Leigh Rachfal.

[177] FCC, *Fourteenth Broadband Deployment Report*, FCC 21-18, January 19, 2021, pp. 19-20, at https://docs.fcc.gov/public/attachments/FCC-21-18A1.pdf.

deployment in unserved locations that lack access to reliable broadband service with at least 25/3 Mbps.[178]

To access the metaverse and many of its potential services, however, users would likely require broadband download and upload speeds in excess of 1 Gbps.[179] By the end of 2020, about 3% of mobile connections in the United States were on 5G, which could provide the speed and wireless connectivity needed for the metaverse. By 2025, it is estimated that 5G connections will increase to 68%, but that would still leave 32% of mobile connections without 5G access, potentially exacerbating the digital divide.[180]

Opportunities and Challenges

A survey in January 2022 found that 37% of respondents agreed with the statement that "the metaverse would be more fun than real life," and 38% agreed with the statement that "the metaverse would make their life better."[181] Another survey in 2021 found that 38% of Gen Z (those born between 1997 and 2012) and 48% of millennials (those born between 1981 and 1996) agreed with the statement that "the metaverse is the next big thing and will become part of our lives in the next decade."[182] According to the research firm Gartner, by 2026, one-fourth of people would replicate their real-world activities by spending "at least one hour a day in the metaverse for work, shopping, education, social and/or entertainment."[183] In December 2021, Bloomberg estimated that the metaverse would become a $783 billion-plus digital market by 2024 based on 2020 data and an assumption of a double-digit annual growth rate.[184] Citing the convergence of online games, social media, and user-generated content, the analysts expected that the metaverse would present an opportunity particularly for online game and social media firms to generate revenue streams from online live entertainment events, sales of software and services, sales of AR/MR/VR headsets and other XR hardware, and digital advertising, among other activities.[185]

However, some experts do not believe that the technological infrastructure required to support the metaverse currently exists.[186] They note that the absence of open technical standards and toolkits

[178] See Section 60102(a)(1)(A) of the Infrastructure Investment and Jobs Act (IIJA; P.L. 117-58).

[179] Doug Dawson, "Network Requirements for the Metaverse," *CircleID*, March 12, 2022, at https://circleid.com/posts/20220312-network-requirements-for-the-metaverse. In July 2022, FCC Chairwoman Jessica Rosenworcel proposed to set a national goal of 1 Gbps for download and 500 Mbps for upload for the future. See FCC, "Chairwoman Rosenworcel Proposes to Increase Minimum Broadband Speeds and Set Gigabit Future Goal," press release, July 15, 2022, at https://docs.fcc.gov/public/attachments/DOC-385322A1.pdf.

[180] GSMA Intelligence, *The Mobile Economy North America 2021*, GSM Association, The Mobile Economy series, 2021, p. 11, at https://www.gsma.com/mobileeconomy/wp-content/uploads/2021/10/GSMA_ME_NorthAmerica_2021_WebSingles.pdf.

[181] The Harris Poll, *Americans Are Interested in AR, VR, and the Metaverse*, Brief, January 25, 2022, at https://theharrispoll.com/briefs/future-of-ar-vr-metaverse/.

[182] Harry Robertson, "Wall Street Hopes Young People Will Drive a Metaverse Boom—But Only 38% of Gen Zs Think It's the Next Big Thing," *Business Insider*, December 8, 2021, at https://markets.businessinsider.com/news/stocks/metaverse-gen-z-millennials-crypto-land-sales-investing-virtual-worlds-2021-12.

[183] Gartner, Inc., "Gartner Predicts 25% of People Will Spend at Least One Hour Per Day in the Metaverse by 2026," press release, February 7, 2022, at https://www.gartner.com/en/newsroom/press-releases/2022-02-07-gartner-predicts-25-percent-of-people-will-spend-at-least-one-hour-per-day-in-the-metaverse-by-2026.

[184] Matthew Kanterman and Nathan Naidu, *Metaverse May Be $800 Billion Market, Next Tech Platform*, Bloomberg, Bloomberg Intelligence Research and Analysis, December 1, 2021, at https://www.bloomberg.com/professional/blog/metaverse-may-be-800-billion-market-next-tech-platform/.

[185] Ibid.

[186] Matthew Ball, *The Metaverse: What It Is, Where to Find It, and Who Will Build It*, MatthewBall.vc, The Metaverse

for either developers or users to create metaverse applications and content would inhibit the realization of the metaverse and its ability to reach the scale of the internet.[187] Such scaling is likely to require substantial investments in research and development.[188]

Policymaking around the metaverse may be challenging while its development trajectory is uncertain.[189] It is not clear whether there will eventually be an interoperable global metaverse or multiple proprietary metaverse platforms. While some suggest a wait-and-see approach, others argue that policy leaders should explore proactive regulation.[190] The **Appendix** lists legislation introduced in the 117th Congress, which contains provisions related to metaverse technologies (i.e., AR/MR/VR). Some of these provisions would provide federal resources for research and development in metaverse-related technologies, identified as one of key technology focus areas that may help "enhance the competitive advantage and leadership of the United States in the global economy."[191] Other provisions focused on regulating practices of online platforms, including those that offer AR and VR services.[192] While no legislation has addressed policy issues specifically in the context of the metaverse yet, the development and growing adoption of extended reality, next-generation wireless communication, and blockchain technologies may present policymakers an opportunity to work with stakeholders—including scientists, engineers, technology experts, academic scholars, business leaders, and civil society—to help shape the evolution of the metaverse.

In April 2022, the Biden Administration launched a global partnership and initiative articulated in the Declaration for the Future of the Internet.[193] The declaration reaffirms and recommits its 61 nation-state partners to "an open, free, global, interoperable, reliable, and secure internet."[194] The declaration stresses the internet as a single, decentralized network of networks, which should be non-fragmented; facilitate global communications and commerce; foster competition, privacy, and respect for human rights; and support innovation, trust, and freedom.[195] A similar vision and policy framework might be developed to guide the development of the metaverse.

Primer, January 13, 2020, at https://www.matthewball.vc/all/themetaverse.

[187] Edd Gent, "What Can the Metaverse Learn from Second Life?" *IEEE Spectrum*, November 29, 2021, at https://spectrum.ieee.org/metaverse-second-life.

[188] Matthew S. Smith, "Meta Offers Nothing New to the Metaverse," *IEEE Spectrum*, December 17, 2021, at https://spectrum.ieee.org/meta-offers-nothing-new-to-the-metaverse.

[189] See Jule Pattison-Gordon, "Should State and Local Governments Care About the Metaverse?" *Government Technology*, April 28, 2022, at https://www.govtech.com/products/should-state-and-local-government-care-about-the-metaverse.

[190] Ibid. See also Bradley Tusk, "Regulating the Metaverse(s)," January 31, 2022, at https://mirror.xyz/0x81dB200eD62Ce664B911C211b55F836a208Df868/n-8osyXEl8Dzv_qnrBR1ICdxF55zdIMLP6OI3yU9igY.

[191] See, for example, Sections 2003(3) and 2005(a)(1)(F) of the United States Innovation and Competition Act of 2021 (S. 1260 and H.R. 4521, 117th Congress).

[192] See, for example, Sections 5 and 6 of the Digital Services Oversight and Safety Act of 2022 (H.R. 6796, 117th Congress).

[193] White House, "Fact Sheet: United States and 60 Global Partners Launch Declaration for the Future of the Internet," press release, April 28, 2022, at https://www.whitehouse.gov/briefing-room/statements-releases/2022/04/28/fact-sheet-united-states-and-60-global-partners-launch-declaration-for-the-future-of-the-internet/.

[194] White House, "A Declaration for the Future of the Internet," April 28, 2022, p. 1, at https://www.whitehouse.gov/wp-content/uploads/2022/04/Declaration-for-the-Future-for-the-Internet_Launch-Event-Signing-Version_FINAL.pdf.

[195] Ibid., pp. 1-2.

Appendix. Summary of Legislative Efforts on Metaverse-related Technologies in the 117th Congress

Bill	Title	Related Provisions
H.R. 4461	21st Century Jobs Act	The bill would establish an independent agency of the Federal Institute of Technology to provide federal funds to support programs and research in certain technology sectors including blockchain, telecommunications, and VR and AR. (Sections 3(a) and (g)(4)(C)(i)(IV), (XI), and (XIII))
S. 1260 and H.R. 4521	United States Innovation and Competition Act of 2021	The bills list "advanced communications technology and immersive technology" as one of the "initial key technology focus areas." According to the bill, increasing capabilities in those areas is one of the ways to "enhance the competitive advantage and leadership of the United States in the global economy." The bill would make federal funding available for research and development, education and training, and transfer and commercialization of the key technologies. The bill would also require a report on whether federal investment in those areas results in new domestic manufacturing capacity and job creation. (Sections 2003(3), 2005(a)(1)(F), 2005(f), 2106(d), 2107(a), 2108(a)(1), and 2109(a))
H.R. 4609	The National Institute of Standards and Technology (NIST) for the Future Act of 2021	The bill would task NIST in consultation with the National Telecommunications and Information Administration (NTIA), the National Science Foundation (NSF), and other appropriate federal agencies with conducting "advanced communications research" in areas including AI systems to enable internet of things networks and immersive technology, among others. (Section 210)
S. 2918 and H.R. 5439	Kids Internet Design and Safety Act (KIDS Act)	The bill would regulate acts and practices on online platforms targeting individuals under the age of 16, which include those that offer AR and VR experiences. (Section 2(2))
H.R. 6796	Digital Services Oversight and Safety Act of 2022	The bill would direct the Federal Trade Commission (FTC) to issue regulations regarding content moderation on covered platforms including those providing AR and VR services. (Sections 5 and 6)

Source: CRS analysis of the legislative information available at http://www.congress.gov.

Notes: CRS used the terms "metaverse," "immersive technology" "augmented reality," "mixed reality," "virtual reality," and "extended reality" to search for legislation introduced in the 117th Congress as of June 2022. The bills identified in the table are listed in chronological order.

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