# Virtual Worlds (Metaverse): From Skepticism, to Fear, to Immersive Opportunities

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*The advancement of human–computer interfaces and computational power enables the creation of believable virtual worlds. These were once limited to the gaming community but are now used for business purposes, including industrial applications, health, education.*

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While there is no official definition of *metaverse*, the term first appeared in the 1992 science fiction novel *Snow Crash*, by Neal Stephenson. The plot involves an Internet-based virtual world featuring user-controlled avatars. It should not surprise anyone that the history of the metaverse is deeply entangled with the imaginings of science fiction writers, filmmakers, and gamers. Games such as *Dungeons & Dragons* allow players to enter and interact in an alternate universe with its own physical reality, laws, customs, and rewards. Films, novels, and games have not only provided ideas and inspiration for virtual worlds; the invention of enabling devices and technology as well as advances in computing were often driven by innovations in movies and computer gaming. Therefore, let's look at selected milestones in virtual reality (VR), the metaverse, and entertainment.

During 1896–1912, Georges Méliès, a stage magician, actor, and producer,

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began creating fantasy motion pictures that were intended to be both surreal and immersive. Many were based on the science fiction writings of Jules Verne. Movies such as *A Trip to the Moon* (1902) and *20,000 Leagues Under the Sea* (1907) astounded filmgoers with realistic windows into strange new worlds. Along the way, Méliès invented numerous special film techniques and technologies that are still used in filmmaking today and even entertainment computing.

By the 1920s, special effects techniques had improved enough to make movies seem even more realistic, bringing to the big screen new fantasy worlds that bordered on immersive. For example, director Fritz Lang's expressionist *Metropolis* (1927) portrayed a dystopian futuristic society that resembled some modern computer game settings and introduced new technologies, such as robots, to the public.

Eventually, more immersive, 3D movies were attempted, such as the now-lost silent drama *Power of Love* (1922), which used the familiar red–green glasses/film stock technology. The film allowed the viewer to select either a happy or sad ending by looking through either the red or green lens. However, this film was shown only once, and it was not until the 1950s that 3D movies, using red–green glasses, became relatively commonplace.

In a detour from entertainment, it is important to note the contributions of simulation technology that would eventually advance the metaverse as well. The first simple mechanical flight simulators appeared in the late 1920s, evolving into complex electromechanical ones that were used to train pilots during World War II. By the 1950s, heads-up displays—with avionics information superimposed on the real outside view—were developed for use in both simulators and aircraft. At the same time, advanced navigation systems technologies, such as mechanical and later piezoelectric gyroscopes and accelerometers, were perfected and reduced in size, making them suitable for later gaming devices.

In 1962, cinematographer Morton Heilig began experimenting with technologies that would allow moviegoers to feel like they were in the movie. His experiments led to the invention of an arcade-like ride, the *Sensorama* motorcycle simulator. The device simulated a motorcycle ride through the streets of New York using a stereoscopic color display, stereo sounds, and odor and vibration actuators.

By 1965, computer scientist Ivan Sutherland had invented "the ultimate display," a head-mounted device that provided stereoscopic vision. The device is now commonplace in simulation and VR.

Although not yet fully immersive, new cinematographic technologies were improving the realism of certain movies, and interactivity was introduced. For example, in the comedy *Kinoautomat* (1967), the audience voted for one of several predetermined outcomes for the movie's finale. New immersive sound technology appeared soon after. Sensurround, which was developed specifically for the film *Earthquake* (1974), was an advanced sound system with an extended bass range. With this technology, tremors and aftershocks could actually be felt in the theater, lending a frightening realism.

In 1982, the groundbreaking movie *Tron* introduced the concept of virtual worlds and total immersion in those worlds. Along the way, Disney Studios pioneered new computer graphics techniques that would be used in other movies and in computer games. While the movie largely takes place in cyberspace, it was not until the novel *Neuromancer* (1984) by William Gibson that the term *cyberspace* was defined and elaborated.

Throughout the 1980s, the home computer gaming industry was booming as more affordable microcomputers appeared. By the mid-1990s, affordable VR goggles and gloves were developed by scientists, notably Jaron Lanier, and soon became available for use in early VR computer games. In the 1985 award-winning novel *Ender's Game*, the titular protagonist and his classmates use these technologies in computer battle simulations. Unbeknown to them, they are really virtually controlling spaceships and battling an existential threat of invasion.

During the 1990s, researchers at the University of Illinois Chicago developed the room-scale Cave Virtual Environment VR system (whose name was actually a witty pun on Plato's cave allegory). Here, stereoscopic images are projected onto the walls of a room, providing a sense of partial immersion. This technology has been deployed for museums, preconstruction building walkthroughs, and other simulations.

Meanwhile, advances in realistic 3D and VR gaming continued, culminating in the multiplayer *Second Life* environment, launched in 2003 by Linden Labs. *Second Life* established not only realistic virtual work, play, and explore environments with customizable avatars but also introduced a monetary exchange system in this metaverse through its Linden dollars.

The openness of *Second Life* and its breakthrough idea of a virtual economic exchange system allowed third parties to develop and monetize enhancements to the avatars' abilities for all kinds of behaviors, including obtaining superpowers and indulging sexual fantasies. Tracking these developments, the movie *Avatar* (2009) featured organic humanoid robots that are virtually controlled by genetically matched humans.

In the 2010s, computer science advancements led to the development of the first consumer-grade VR head-mounted displays or headsets. Today, consumer-grade wireless, stand-alone VR headsets are widely available. These devices appear prominently in the fictional massively multiuser online VR game OASIS, described in the 2011 science fiction novel *Ready Player One* by Ernest Cline and subsequent movie (2018).

Perhaps signaling that the metaverse already exists, in October 2021, Facebook changed its name to *Meta* and its mission, accordingly, by announcing its plans to focus on building the metaverse. Recognizing the need for continued openness and standards for the metaverse, in 2021, IEEE committed to help set standards to define the operating principles of virtual worlds.

## TECHNOLOGY OF THE METAVERSE

The underlying technologies that enable the metaverse have evolved over the years, making many of the features that were predicted in fiction possible. However, achieving a believable virtual world requires a confluence of new technologies and real-time, low-latency networking that can enable many participants to experience seamless interaction. Necessary advances include sense and even brain interfaces, which will further enhance immersion into the virtual world. These are the basis for augmented reality (AR) and VR achieved through advanced devices connected into a cloud computing back end. The geographic distribution of massive computation enabled by cloud computing is also needed to facilitate low-latency computation. In addition, running multiple metaverse deployments requires interoperability, which, in turn, requires standards and oversight. A metaverse ecosystem, including an informal architecture, is presented in Figure 1.

All objects in the virtual world have to exist in some context. Each physical artifact or individual requires representation in virtual worlds. People would be represented by avatars or simulations. Artifacts could be a digital twin or a simple object representation. Automating the virtual behaviors of both living things and moving/evolving objects requires automation and intelligence achieved using advances in artificial intelligence (AI) and data analytics. Each object in the virtual world should also have equal or similar security, privacy, and even personal or object boundaries that protect its real-world counterpart.

In the metaverse, the intersection between the economic and technological dimensions of virtual worlds is enabled by blockchain technology and nonfungible tokens (NFTs). Transactions and charges in virtual worlds can be tracked even more naturally than in the physical world by using a distributed ledger. NFTs may achieve a degree of adoption regardless of the metaverse, but they are required in metaverse. Other economic aspects of the metaverse include trading and virtual markets as well as a number of verticals, such as gaming, manufacturing, and robotics.

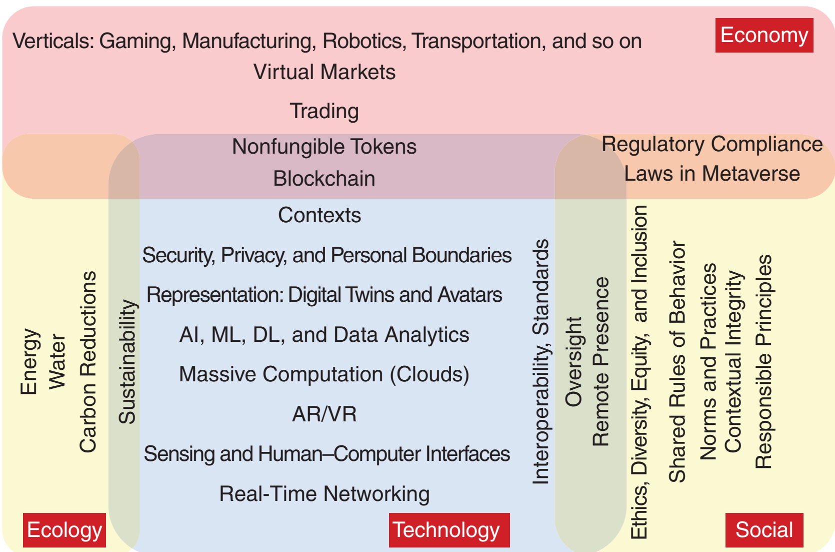


**FIGURE 1.** The informal metaverse architecture.

## METAVERSE LAYERS

A possible representation—there are, of course, many others—can be the one in Figure 2, which compares the structure of the metaverse to the International Organization for Standardization (ISO) layers. The seven ISO layers connect the physical infrastructure to its "use" in such a way that the various components needed are decoupled one from the other, ensuring flexibility and independent evolution. Similarly, the reference architecture for the metaverse can have, on one end, the physical access point and, on the other, the "life in the metaverse," which is how we perceive it:

- *Device layer*: As with the telecommunication infrastructure, where we need a physical link (a radio or wire), we need some way to access the metaverse. This is possibly, at least today, one of the biggest hurdles we are facing because we do not have devices providing seamless access, turning the metaverse into a continuous presence that merges with our life ambient. Ideally, brain–computer interfaces (BCIs) could provide that, but we are very far from a seamless BCI, and it will remain so at least through this decade. Interfacing at our senses level, like using electronic contact lenses for sight, earbuds for sound and acceleration, haptics for touch, and so on is possibly closer, but not that much more. We must live with devices that provide nonseamless access, although, in some domains, like gaming, simulation, industrial design, and entertainment, they may offer a good second choice.

- *Communication layer*: This connects the device(s) to the data support space, that is, to the cloud(s). Here, we are all set. The current telecom infrastructure—in most places—can support the required bit flow (in terms of both capacity and latency); 4G is okay, 5G would be better, and 6G will be able to create a mesh infrastructure among devices and the cloud.
- *Cloud layer*: This provides the hosting of data and software. It is a fuzzy layer from a functional boundary viewpoint since it could extend into the device(s), into the communication layer (the fog or edge), and up toward a virtual cloud. Here, too, there are no stumbling blocks. The technology available today can support whatever is needed.
- *Virtual cloud layer*: More and more actual data and software can be distributed on several (physical/owned) clouds that can be merged into a virtual one from the point of view of usage. This is already happening, with many system integrators offering a virtualization of cloud services provided by the likes of Amazon Web Services, Azure, and Google.
- *Data space layer*: This is where the ontology of the metaverse is defined, and it is a crucial part for its implementation in terms of the open data framework. In other words, this layer is crucial for the creation of an ecosystem of functionalities provided by third parties (both for effective creation and interoperability). Work is going on in several places, such as Gaia-X,[1] a European initiative that has become a worldwide effort. This is also the area where standardization activities are needed.
- *Digital twin layer*: This layer is the crucial one for ensuring the personalization of the metaverse, that is, to create the personal experience. It will orchestrate and provide a home for the interaction among the digital twins of resources and the personal digital twins of the people living in the metaverse. There is quite a bit of work in this area at the European level[2] as well as worldwide. It is also an area requiring research and standardization efforts.
- *Perception layer*: This layer is the one where people will interact within the metaverse. It will provide a landscape where a variety of services are becoming embedded in the ambient for seamless fruition.

## SOCIAL, ECONOMIC, AND ENVIRONMENTAL IMPACT

Perhaps the biggest mystery of this large-scale societal experiment that we call *the metaverse* is its effects on human and interpersonal interactions. The human species is highly social owing to its success, relative to other species, in interactions and collaborations. Conversely, humans are also reliant on social interactions for much of their well-being and welfare. Like all animals, we evolved to interact with each other via physical cues.

The overwhelming majority of human interactions throughout history, therefore, took place necessarily in the physical realm, with face-to-face interactions. The relatively recent advent of telecommunications, such as telephones, the Internet, and smartphones, enabled some of these interactions to bridge physical distances and take place online, but these were always seen as augmenting, not replacing, the face-to-face model, such as working in shared offices, learning in a classroom, or meeting with family and friends. The culmination of integrating remote and virtual presence technologies into the metaverse that simulate many aspects of physical interactions does suggest that, for the first time, technology can offer a sustainable, high-fidelity replacement for many of these interactions. In a curious coincidence of timing, the isolation brought upon us by the recent pandemic also led many people to question the sustainability and necessity of some of the same physical interactions society used to rely on.

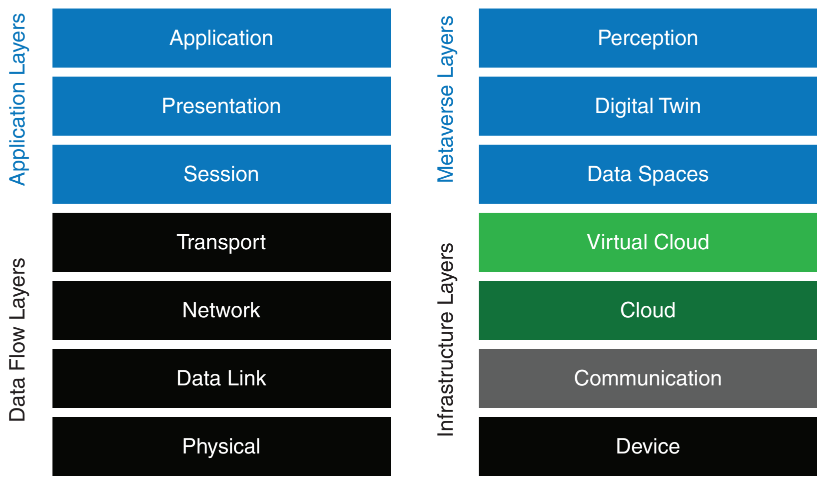


**FIGURE 2.** The metaverse versus the seven International Standards Organization layers.

The intersection of social and technological aspects in the metaverse is based on remote presence, which is becoming widely adopted due to COVID-19. Diversity, equity, and inclusion can be just as challenging to achieve in virtual worlds due to the large scale and rapid conversion of individuals of all types. On the positive side, it can be more easily programmatically assessed, and, on the negative side, avatars and digital twins hide identities, so biases and inequalities could be well hidden. Other aspects of social dimensions include shared rules and behaviors, norms, and practices, all of which are yet to be developed for the metaverse. The same is true for context integrity, and all of this should lead to responsible principles. Finally, regulatory compliance and laws will be needed in the metaverse, as they are in the real world, although the legal foundation, norms, and enforcement might be different. For example, should actions that are socially unacceptable (or even unlawful) in the real world be allowed in the metaverse?

One of the economic areas that could potentially be profoundly affected is the everyday workplace for knowledge-intensive workers. The pandemic has already created both incentives and case studies for distributed, remote, and hybrid workplaces, but not all employers embrace this shift.[3] The physical interactions in a shared workplace still have some important structural advantages, such as spontaneous collaborations; serendipitous discovery; nuanced, unencumbered communication; and informal social connection. To the extent that virtual worlds can recreate these advantages, they could support and accelerate the transition to distributed and remote teams.

The economic impact of this transition goes far beyond the mere reduction of commute hours and their associated waste and may be associated with increased productivity and higher efficiency in the job market, perhaps transforming it altogether.[4] Some economists estimate the gross value added to the U.S. economy alone from hybrid workplaces at more than US$2 trillion[5] or that the metaverse economy of digital goods could be worth more than US$3 trillion in a decade.[6] On the other hand, it could also lead to increased economic inequality and a decline of big city centers.[7]

An interesting question then arises: who controls and profits from this growing economy? If the trade of digital goods is controlled by one or few companies in a "walled garden" environment, similar to today's major app stores, the impact on these companies alone would be enormous, as seen with Apple and Alphabet, but it will also obviously impact and limit the economics of digital goods for consumers. If, on the other hand, digital goods will trade freely in virtual worlds under open standards, in a way we are not currently seeing with any major platform, the impact on consumers may be even more far reaching.

The reduction in commuting and business travel holds with it the promise for meaningful reductions in travel for business or even personal activities and, consequently, a reduction in their carbon footprint. It may not be realistic yet to predict how much of our carbon footprint would be eliminated, but the potential is certainly there: according to some estimates, the business travel represents approximately 15–20% of all travel,[8] while the average American emits an estimated 3.2 tons of $CO_2$ annually from commuting alone.[9]

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The intersection of technological and ecological development is based on sustainability. The metaverse inherently contributes to sustainability by eliminating the need for people to travel to meet and to produce physical artifacts. At the same time, running a metaverse consumes significant energy both in the data centers and at the edge. This shortcoming also applies to carbon emissions and water consumption.

Environmental impacts are only one of the health-related aspects of the metaverse. The technology is still early in its evolution, and we have only just started discovering the effects of the metaverse on human health, both negative and positive. On the negative side, physical health risks include eye strain, visually induced motion sickness, epileptic seizures, and collisions with nearby objects.[10–12] These risks are still areas of active research and development and may be addressed as the technology evolves. Nonphysical (mental) health risks include social isolation; dissociation from reality; the inability to interact with other human beings in the real world; anxiety; and false memory, especially in children. As with any technology, the metaverse can be also used and abused in harmful ways, especially for children. Some of these risks include privacy violations; abusive, harassing, or explicit behavior; bullying; and addiction.

On the other hand, virtual worlds also have many potential novel and beneficial applications in health care. Examples include telemedicine,[10,12] immersive therapy sessions and diagnosis,[13] exercise and fitness, and training surgeons in an environment tolerant of mistakes.

Health and safety concerns naturally lead to regulation, as these are fundamental societal concerns. In particular, regulators may be interested in curbing illegal and harmful activities while promoting economic and development opportunities. Large-scale economies such as the metaverse can potentially grow to a point where they become interesting to regulators. The metaverse may necessitate changes to taxation, job creation, the monitoring of criminal activities, and economic incentives, much as cryptocurrencies have. Regulators may also be interested in promoting and enforcing interoperability and antitrust laws for the metaverse.

Similarly, regulators may also be interested in expanding the positive aspects of the metaverse to a broader population base. Since entry into the metaverse requires hardware, and hardware has a cost, it presents a barrier to entry to low-income populations. This barrier could further the digital divide and hinder efforts toward increased diversity, equity, and inclusion in the metaverse. Societies and governments that are committed to bridging other social gaps in education, housing, health, and technology in general may, therefore, also introduce regulatory policies to increase access to the metaverse.

## APPLICATIONS AND BUSINESS CASES

Social networking (including Meta), industrial use, scientific discovery, and remote work—certainly, the business world has recognized the metaverse as a unique "commodity," and there are many metaverse focused investment funds and exchange-traded funds. Industry started to operate in the "metaverse" some 40 years ago with the adoption of CAD technologies. Over the years, those digital models created through CAD started to get used for simulation and became virtual components in libraries that could be used to design other products.

Soon after, these digital models became specifications to suppliers that, in turn, started to develop digital models of their parts, and engineers looked at the compliance of the various parts through the digital models. Then, those digital models created by different parties started to interact with one another in a global simulation of the product. In the beginning of this article, we also provided a brief history of flight simulators, which long ago became a mandatory element of a pilot's curriculum.

Recently, these digital models have evolved to become digital twins. In addition to the digital model and its metadata, a digital twin has the capability to "shadow" the physical entity (providing up-to-date information on its status through data from embedded and ambient sensors) and keep the record of the evolution of the physical entity. Digital twins are now used in manufacturing as a component of the industry and as a bridge to explore the emerging metaverse. An engineer can, through VR goggles, explore a digital twin and learn about the associated physical entity. The digital twin can be used to train the operators of the physical entity. Sometimes this operation, as in the case of the backhoes produced by Mevea, occurs in the metaverse before the actual physical entity is manufactured. It can continue in the metaverse as a way to operate from a remote physical entity.

Digital twins can also be used to better manage complex data sets, for example, in Earth observation applications, that come from sensors and satellites. Several efforts around the world are underway to create an "Earth digital twin" to process, monitor, consolidate, fuse, and assimilate Earth environment observations. This can improve the quality control of the data themselves and broaden the access to the model itself without exposing the raw data.[14]

Another interesting and emerging use of digital twins is to generate synthetic training sets to teach AI/machine learning systems corner cases that may rarely occur in reality or to deal with domains in which manual labeling is too expensive. For example, imagine training an autonomous driving AI system. By using real test cars, it may take too long for rare events to occur, and the consequence of a bad decision in the real world may also be severe. In contrast, one could train an autonomous driving algorithm in the metaverse and "drive" millions of virtual miles, with all possible conditions of weather, unexpected behaviors, and so on, without harming anyone and with a more affordable and sustainable approach. The same can be said for virtual wind tunnels and so on.

The digital twins technology could also bring a deep economic impact. Combined with the metaverse and real-time communication, the digitization of real objects could transform economic experiences, such as online shopping or customer meetings.[15] It may also boost scientific and economic development through the advent of the high-fidelity virtual simulation of complex physical objects and phenomena, such as architecture, traffic modeling, civil engineering, and manufacturing.

We can expect further evolution of the industry around the metaverse as the digital transformation shifts more activities to the digital space. An important aspect is that some of the entities populating the metaverse, like digital twins, can be used to deliver functionalities directly to the end user or indirectly via the physical entity/product. This can also be seen as a progressive service delivery (servitization) of products and will contribute to a transformation of many industries.

The metaverse is real, and it is coming—we even consider it a megatrend that will be an umbrella for many other technologies. While gaming was initially a popular application, there are many new practical applications, including industrial, financial, Earth sciences, and many others. Like any technology, there is always a fear that it could be misused. From the first days of machines, there has been such fear. Technology in its own right is not dangerous; rather, its use can be. Transparency and a well-regulated and governed metaverse should alleviate most concerns. As humanity embarks on more aggressive space exploration, leveraging the metaverse for such purposes could be essential in simulating where and how future communities will evolve.

The metaverse will become truly immersive once there are ways to experience it in a seamless way, with AR and VR devices that would bring our everyday life in a space where bits and atoms are seen as a continuum. It will also need to be persistent, live and interoperable as ell as include a fully functioning economy. This will not likely happen before the end of this decade. Until that time, we will see the metaverse as a different space that can be used, exploited, and entertained. ■

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