A LOOK AT THE TECHNICAL REALITIES OF A VIRTUAL METAVERSE

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OVERVIEW—MERGING THE REAL WITH THE VIRTUAL

The metaverse, a term coined in the 1990s, has burst onto the scene and captured the minds and imaginations of many. It has been billed as the future of the Internet, a catalyst and foundation that will usher in the next transformative changes that will shape how we work, communicate, seek information, and consume content and services. As with most transformative changes, the vision of this metaverse future comes with a wide range of opinions and perspectives on how, what, when, and where the metaverse will have its most significant impacts.

The metaverse is also a long-term vision and, therefore, carries elements of uncertainty, which when coupled with the diversity in opinion, can engender a healthy dose of skepticism. While some may view the metaverse negatively, believing it is overhyped and nothing more than a temporary fad, these perspectives tend to come from a position that too narrowly defines the metaverse (e.g., primarily virtual world-driven), relies on inputs that too heavily weigh current market activity (e.g., crypto market issues), or only considers the longer-term future without regard to the necessary layering and buildup to the metaverse. Even though the buildup to the metaverse will take time, it is based upon pre-existing market trends that, irrespective of what one chooses to call this future, at a minimum, is building toward something akin to the metaverse.

At its foundation, the metaverse broadly speaks to the convergence of connectivity, compute, and intelligence across networks, applications, and workflows. Building upon this groundwork are the key technology pillars, which include:

- **Three-Dimensional (3D) and Web3:** The transition from a Two-Dimensional (2D) to a 3D-based Internet is at the core of the metaverse. It speaks to the merging of the real and virtual worlds and depth of immersion. Web3 represents the decentralization, interoperability, and accessibility of the metaverse, bringing about new business models and classes of assets, such as digital goods. 3D will place additional demands on computing and computing resources (e.g., ultra-low latency and high data demands), while Artificial Intelligence (AI) will be a critical factor in 3D content generation and accessibility.

- **New and Updated Internet Protocols (IPs):** New demands on latency and data will require updated, if not new, IPs to accommodate the new modes of communication and channels for media & entertainment.

- **6G:** The next-generation mobile technology will be critical to accommodate the expansive number of connected devices and sensors, supporting both the heightened demands on traffic and latency requirements stemming from next-generation metaverse experiences. 6G networks will also be the nexus point for the convergence of connectivity, intelligence, and computing at the edge.

- **Augmented Reality (AR)/Virtual Reality (VR):** AR/VR represents the continuum from fully virtual to the merging of real and virtual worlds. The Head-Mounted Displays (HMDs) provide a new User Interface (UI) and in the case of AR, makes the strongest case for extending the metaverse into public spaces as an always-on device. Smart glasses will drive demand to the network edge, and cloud/hybrid Extended Reality (XR) will further create network (and computing) demands on data traffic and ultra-low latencies to drive cloud-based applications, data storage, personalization, and interactivity.

- **Distributed Computing and Networks:** These make 3D accessible (content creation and rendering) and pervasive, requiring significantly higher orders of computing resources. The need for ultra-low latencies and diversity of experiences will also require flexible and massively scalable computing resources that will span devices, from the network edge to the cloud. Computing resources will also be required within the network to bring intelligence and network optimizations.

- **AI/Machine Learning (ML):** AI will bring intelligence to networks (and data management, workflows, etc.), make content creation accessible (including digital twins and simulations), drive personalization, and power interactivity and communications (e.g., digital humans and virtual assistants, immersive collaboration).

The buildup to the metaverse deserves more attention than it typically receives, but the longer-term future also raises equally compelling opportunities and potential issues.

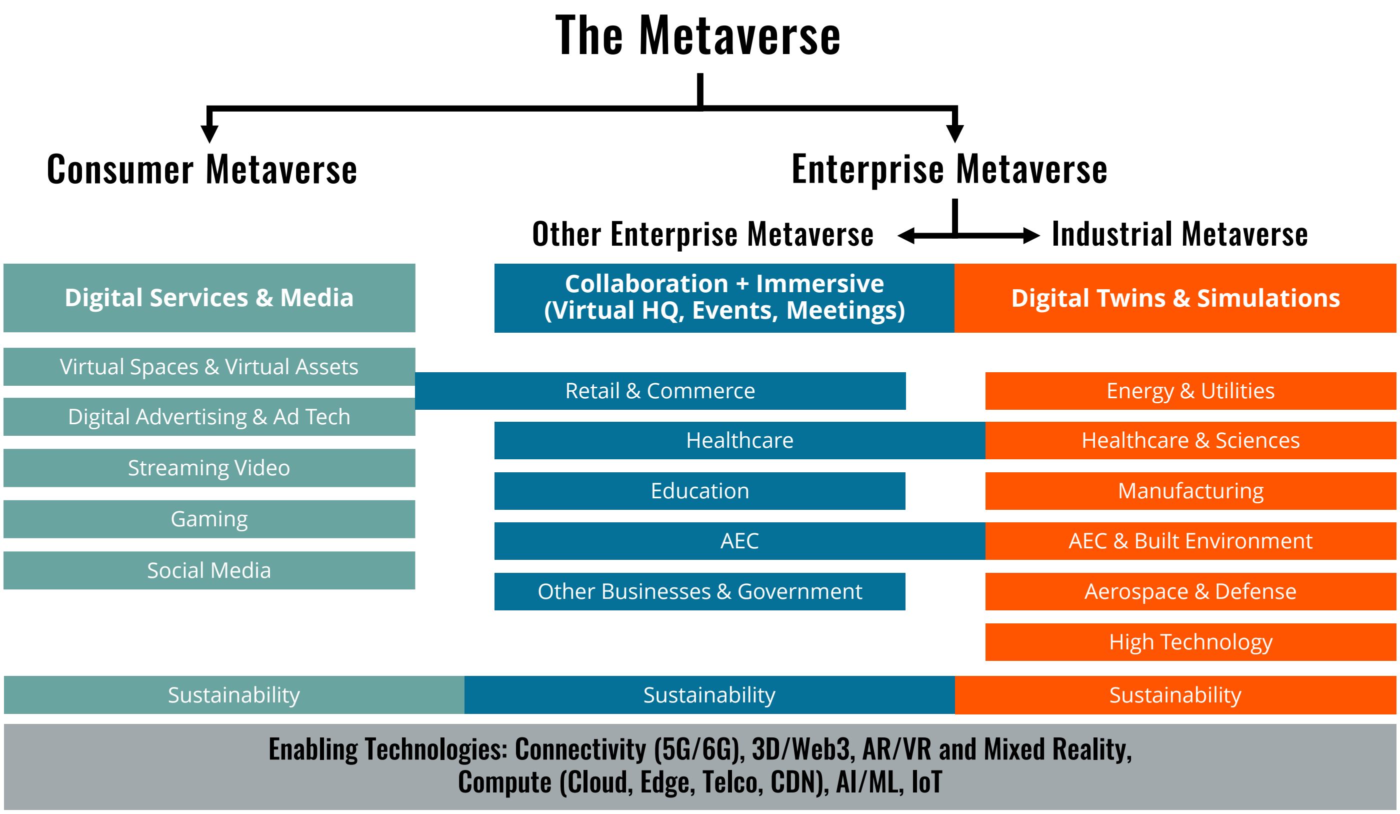
Huawei published a paper in 2020 that considered emerging and future use cases, and argued the need for new networking protocols for a future Internet to support these applications. While the paper does not mention the word metaverse, the authors' vision aligns well with this future, which similarly seeks to define the next generation of the Internet that transitions to 3D and merges the real and virtual. To this end, the authors discussed how today's versions of communications and immersive will become tomorrow's "Holographic Type Communications" (HTC) built upon a technological foundation that supports "Instantaneous Teleportation Systems" (ITS) and "Trustable Network Infrastructure" (TNI). These future applications will require high-volume data exchanges (Terabits per Second (Tbps)) and traffic to support new personal data management systems and immersive communications and workflows, many at super-ultra-low latencies (sub 1 Millisecond (ms)). With targets like these, it is clear the future (2030 and beyond) will need to evolve current IPs (or develop new ones) to support these use cases. Before this future arrives, however, the buildup to the metaverse needs to reach its potential.

The potential exists, but the metaverse may not live up to the most optimistic expectations if a number of technology and business challenges are not addressed and if the entire technology ecosystem is not aligned to address these challenges. However, the metaverse is not an all or nothing proposition, it is likely to evolve in stages, and the industry will progressively embrace some elements of it as enabling technologies and business models mature. This presents opportunities throughout this process to layer in new services, experiences, standards, and protocols to continue building toward this future.

This whitepaper examines the market conditions building toward this future and highlights market opportunities brought by the transition toward the metaverse. It identifies the potential hurdles that could delay progress or alter the metaverse's direction and provides guidance on how the industry should align to address these hurdles. The odds are in favor of a future metaverse due to the existing foundation in both the consumer and enterprise markets.

Figure 1: Key Markets of the Consumer and Enterprise Metaverses

(Source: ABI Research)



The structure of the metaverse can be divided broadly into two segments as shown above, with the enterprise segment further subdivided to reflect the unique characteristics of the industrial metaverse. Underpinning the metaverse are key technologies that will help enable the metaverse and be driven by new application and experiences discussed in the next sections.

CONSUMER METAVERSE: VIRTUAL SPACES, ASSETS, AND SOCIAL NETWORKING

The consumer metaverse is being anchored to the gaming and social media landscape, but as the buildup advances, it will extend to other segments, most significantly the broader advertising and streaming media markets. Over time, the metaverse will engender new benefits and opportunities that will transform the consumer landscape.

The more transformative changes are still several years away, requiring both further market developments and the proliferation of mainstream-level smart glasses, but early examples are already taking shape. New business models have been introduced and are key drivers needed to shift user behavior toward virtual spaces and assets. Increased user valuations of avatars, digital assets, and time spent in virtual spaces are necessary to establish the use cases that will merge the virtual and real worlds. This foundation is also critical for a longer-term future that envisions holographic avatars and communications.

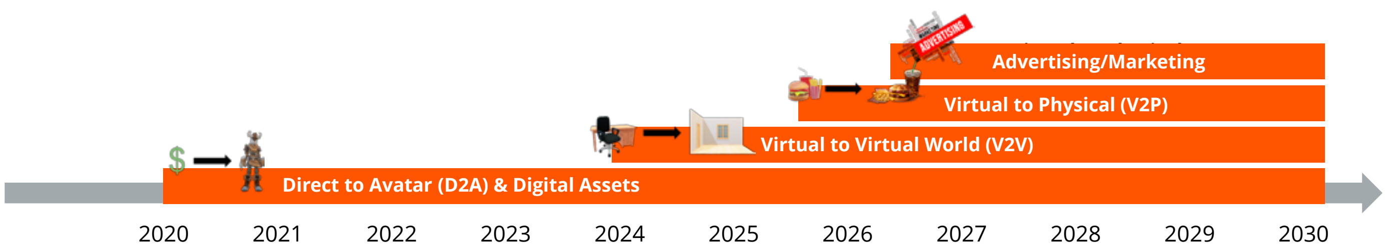
NEW BUSINESS MODELS

To best extract value in the buildup to the metaverse, companies need to look for opportunities to integrate and develop some of the new business models that link the real and the virtual. The following business models represent the key categories that will shape the consumer metaverse; note that Direct to Avatar (D2A), Virtual to Virtual (V2V), and Virtual to Physical (V2P) are all intrinsically tied to 3D and Web3 (advertising more broadly spans 2D and 3D) and this includes the need for 3D content creation tools as part and parcel to the development of these business models to create the necessary supply of virtual goods (and spaces) to populate the metaverse.

Figure 2: Timeline for Metaverse-Centric Business Models Related to the Consumer Market

(Source: ABI Research)

Business Model	Time to Broad Commercial Implementation	Key Enabling Technologies	Opportunities	Challenges
Direct to Avatar (D2A): D2A refers to virtual items acquired or purchased for a virtual avatar.	Has origins in video game industry and already established, mostly tied to cosmetic items – will shift to ownership of digital goods.	Out in public – smart glasses, edge compute for hybrid/cloud XR, and ultra low latency (5G and later 6G for connectivity).	Increase value in digital assets, plus the creation of secondary markets. Drives content creation.	Current lack of cross-platform support and crypto challenges (if used). Lack of standards and best practices.
Virtual to Virtual World (V2V): V2V as the name implies speaks to virtual assets sold within a virtual world – this could include avatars, goods, land, content, etc.	Requires further developments on the virtual world side. Expect broader commercialization by the 2024 time frame.	XR devices for deepest level of immersion, Web3 & blockchain, cloud computing for accessibility.	Same as D2A and encourages more time spent in virtual spaces. Stronger opportunities in V2P and advertising.	Same as D2A – still limited use cases in virtual spaces. Graphics dependent on end devices without cloud support.
Virtual to Physical (V2P): V2P refers to virtual items or services acquired in the virtual space for consumption in the real world.	Requires users to spend more time in virtual spaces, needing both D2A and V2V to be better developed – expect broader commercialization past 2025.	Same as D2A with additional requirements for AI/ML for use targeting, virtual assistants, and operations management.	Creates strong ties to virtual and real worlds – encourages broader participation. Better target younger audiences. Speaks to network convergence of connectivity, compute, and intelligence.	Quality of assets/visuals and avatars limits V2P opportunities in 3D virtual spaces. Better opportunities in hybrid applications (video + 3D assets).
Advertising in the Metaverse	Advertising has some early traction, but largest opportunities will come with smart glasses – pushing this out to at least 2026.	Same as V2V, with an emphasis on the network edge and computing for personalization (MEC, 5G/6G).	Potential for more measurable ad targeting, both in virtual and hybrid environments – plus more touchpoints.	Data protection and privacy remain key challenges for the industry - gaining and maintaining user trust will be key.



While these business models are used at some capacity within the nascent metaverse, the timeline above reflects when they are expected to hit an inflection point and begin in earnest to reach wider audiences. D2A has established roots in gaming and has the strongest ties to the digital goods market, and an increasing focus on digital identity. V2V will lag behind, due in part to the lull in the crypto market, but additional development is necessary to move past the initial speculative hype cycle.

Relatedly, once the virtual spaces and their economies become better established, V2P will gain wider opportunities to create a more direct connection between the virtual and real worlds. There are precursors to wider-scale V2P, such as AR applications that allow users to virtually try on fashion items and virtual malls like Alibaba's Taobao Metaverse Mall and the Tmall Luxury

Pavilion, but these experiences will become more commonplace later in the buildup to the metaverse. Advertising's time will come toward the tail end of the decade, having to overcome a shift in business model (from premium/paid to hybrid ad-based for non-free-to-play titles) and through the growing presence of smart glasses.

NEW OPPORTUNITIES

The new opportunities should be viewed across three time-based segmentations: early years, rise of the smart glasses, and then the longer-term vision when immersive becomes ubiquitous (or nearly so). These time periods also overlay the previously discussed new business models, with the arrival of mainstream tier smart glasses a driving force to extend the new business models to a wider audience.

The Early Years

Over the course of the next several years (through 2025/2026), the buildup to the metaverse will largely focus on pre-existing trends and sowing the seeds of the metaverse. These trends will help acclimate users to the business models and use cases tied to virtual spaces, digital goods, and the crossover between the virtual and real worlds. Many of these trends stem from activity in video gaming (e.g., live service games and 3D worlds), social media (growth in virtual spaces), and direct-to-consumer media.

During this period, the emphasis will be on the virtual worlds and assets, which corresponds to the focus on V2A and V2V business models. This period will also see significant activity on the Web3 front (more on this in Section 2), which will influence the new business models, begin to reshape value chains and platforms, and push interoperability. The growth in V2V and V2A business and use cases will further create new secondary markets (i.e., where users will sell their virtual goods) and bring an emphasis to content generation.

Content generation refers to the creation of 3D assets by both companies and user communities (user generated). To populate the virtual worlds and economies of the metaverse with enough content, the creation of 3D assets needs to be more accessible to content developers. There are already platforms that offer low to no-code 3D asset content creation tools and new fields of graphics like neural graphics, which combines AI and graphics to accelerate graphics workflows, and could make content creation for the metaverse more accessible. Neural graphics, for example, could help with one of the key hurdles for virtual shopping, the creation of 3D assets from real-world items, which could, in turn, accelerate business models like V2P.

On the technology front, there are some opportunities for 5G—SK Telecom's Ifland metaverse platform (and soon, with Deutsche Telekom in Europe) is paired with its 5G services. Cloud gaming services offered by Mobile Network Operators (MNOs) have also been paired with 5G services, although, in most cases, 5G is not a technology-based requirement—these services can often work over 4G as well. Principally, this stage is about setting the foundation to help drive forward the future segments.

Accessibility is an essential consideration during these early years with any metaverse-related service. This means applications could support VR HMDs, but the UI and User Experience (UX) need to be optimized first for standard mobile devices and Personal Computers (PCs). While specific applications that require deeper levels of immersion could be optimized for VR, at this stage, the goals should target higher user bases by supporting multiple devices over higher penetration rates for VR alone.

Even before the new business models take hold, however, companies need to focus more on customer relationships to adapt to a changing market for data security and privacy. This includes viewing opportunities to become a central aggregation point or hub for services, managing customer relationships, etc., effectively serving as a center of trust for the end users. These arrangements will also help set the groundwork for future implementations of personalized my-cloud data storages.

Rise of Smart Glasses

Mainstream-level smart glasses are expected to arrive in the 2025/2026 time frame and, as the penetration rate of these devices grow, the markets will begin to showcase some of the more transformative elements of the metaverse. This segment also represents the start where new and significant demands on 3D content, connectivity, compute, and interoperability will come to the forefront; expanding the need and use cases that will target (and greatly benefit from) 5G-Advanced and, in the latter years, into the arrival of next-generation networking technologies like 6G.

By bringing more touchpoints and applications into the public spaces, smart glasses will drive a need for ultra-low latency connections (less than 1 second, pushing to sub-20 ms), generate high data traffic (up and downstream), and make immersive more accessible (cheaper devices, better form factors, longer battery life), with further demands for edge networks and computing (e.g., edge/hybrid XR computing). This period will focus on the expansion of edge infrastructure and the development of location-based content, services, and applications (see Section 2 for more details).

On the point of latency, this period will see increased opportunities for IPs, such as User Datagram Protocol (UDP) (e.g., through WebRTC, QUIC, and SRT) and optimized solutions like Huawei's Real-Time Communications (RTC) SparkRTC platform. This period is also the ideal time to begin work on next-generation protocols that will carry the Internet and metaverse into the 6G era and beyond. Further market developments in personal data storage and control should also provide the groundwork to begin work on more advanced implementations like a personalized my-cloud.

Consumer behavior will change with more value assigned to virtual goods, services, and spaces. Digital identity, including the storage and control of users' data will see significant changes during this time. While different ideas have been put forth, one common thread—stronger user control of their data—fits the general direction in which industries, regulations/policies, and consumer sentiment are moving. In Huawei's paper, a personalized "my-cloud" that is powered by edge compute and storage was suggested, which would secure all personal records in one place, ideally at the edge of the network. These data would move seamlessly between network edges, without leaving any data trails. This implementation would require moving vast volumes of data quickly between edge networks to support all of the users and applications, pushing the conversation into the longer-term horizon and future networks, with 6G at the forefront.

Efforts around distributed computing, leveraging multiple edges and the cloud, during this period will serve as the groundwork for future networks that will see the convergence of computing, intelligence, and connectivity. The 6G era will need computing and intelligence to be implemented natively in the network and be integral parts of the 6G standard. Intelligence will be necessary to manage data, applications, and services as users move across networks. Distributed computing is also needed to help with accessibility by making the immersive experience available to the mases. Hybrid and cloud computing will drive this initiative by making devices cheaper, yet powerful enough to produce an experience closer to parity with more premium devices.

Longer-Term Horizon (2030s and Beyond)

Building upon the foundation and advancements made in the previous stages, the longer-term horizon will bring significant evolutionary changes to these more immersive experiences. There will certainly be stronger crossover between AR and VR; extending well beyond what today's market offers with video passthrough in Mixed Reality (MR) VR HMDs and even what will be possible during the growth in consumer-grade smart glasses. This speaks to the potential for holographic communications, avatars, and experiences (e.g., location-based advertising), where immersive becomes part and parcel to users' digital lifestyles and identities, but that is a significant leap from where the market is today. To reach a holographic future, steps need to occur during these ensuing years, to prepare for the future demands on networks and computing (see Section 2 for more details); today's standards and protocols could prove inadequate to support these changes.

It is important to note that this future does not presuppose that all users will be wearing HMDs. Some users may remain reluctant to wear HMDs, while others will be unable to wear these devices for extended periods (if at all). The presumed reliance on HMDs is one of the criticisms put forth against the metaverse, especially regarding accessibility, but this argument does not consider the potential for other devices and interfaces (in addition to advancements for VR and AR HMDs). Contact lenses, for example, could make AR both more widely appealing and accessible to users. Companies like Mojo Vision are currently working on very early designs and prototypes, which, by the 2030s, could become a viable alternative to smart glasses. Projectors and new displays could also create holographic projections to bring these types of experiences to most users.

Whether or not this longer-term future arrives within the 2030s or not is largely dependent on the degree of success of the previous stages.

ENTERPRISE METAVERSE: SIMULATIONS, DIGITAL TWINS, AND IMMERSIVE COLLABORATION

The enterprise metaverse has received less attention from mainstream audiences, but in many ways, it is in a more advanced stage of development than the consumer segment. This is particularly true of the industrial metaverse where digital twins and simulations have a notable history of using 3D. Immersive collaboration (supporting 3D environments/assets and virtual events), is more nascent, but it received a lift during the global pandemic. While this segment has experienced market corrections to adjust to workers returning to the office and in-person events, the hybrid workforce is a longstanding change.

The enterprise metaverse is also further ahead of the consumer segment on the standardization front. Standards and regulations are discussed in greater detail within Section 4, but key examples like Universal Scene Description (USD) and the GL Transmission Format (glTF) file format show the direction the metaverse needs to take to reach its full potential.

ENTERPRISE METAVERSE BENEFITS

Coming from a position with established markets, use cases, and business models means the benefits are readily achievable and generally better understood.

Figure 3: Key Enterprise Metaverse Use Cases

(Source: ABI Research)

Use Case	Description	Key Enabling Technologies and Standards	Opportunities	Challenges
Hybrid Remote Work	Hybrid work creates unique demands on C&C, security, and corporate culture. It spans from C&C tools like video conferencing to virtual offices and events.	Ultra-low latency communications, AR and VR, cloud and edge computing, AI (e.g., video conferencing: language translation, transcription, avatars, etc.).	Initial focus on C&C and security, with buildup to metaverse expanding to more immersive experiences and integrations with on/offsite workers. Reduced costs due to travel, maintaining office space, etc.	Conflict between remote and return to office limits growth opportunities. Maintaining security and providing tools/equipment across distributed workforce .
Collaborative Tools	In context of the metaverse this includes immersive collaboration and virtual events. Immersive C&C includes 3D virtual spaces but supports all major devices. Includes pure virtual and hybrid events.	Same as hybrid remote work, with added need for AI to create 3D assets and engines, merge virtual and real, virtual assistants, content management, etc. Longer term could include holographic communications.	Increased efficiencies and better interdisciplinary work across teams (remote and in-office). Collaborative work/design with 3D assets and models. Extensibility to digital twins.	VR and MR device cost at the premium end for immersive experiences. Interoperability is improving but is far from a state of maturity.
Virtual Training	Virtual training spans education (e.g., medical school), business (HR, corporate informational sessions, onboarding, etc.), and technical fields. VR is a leading immersive device, but training can span all major devices.	XR devices, AI (e.g., evaluating attention and performance), 3D content generation and engines. Future training could leverage digital twin environments for true to life experiences.	Increased performance and skills retention, lower costs (no need to train with actual machinery, less costly mistakes, etc.), improved safety, greater accessibility to training.	XR technology has significant room for improvement and cost reductions. Development of virtual training exercises requires expertise in 3D content generation or outsourcing/partnering.
Digital Simulation & Testing	Simulation includes aspects of Computer-Aided Engineering (CAE), physics-based models, and AI to assist design teams with evaluating and testing their designs and models.	AI, on-premises and cloud computing, CAD and CAM (computer aided design and manufacturing), physics-based models, 3D engines.	Digital simulations are used extensively in industrial markets, but will see more opportunities in other areas like sustainability, smart city planning, etc. The cloud is another growth vector to help with accessibility. Synthetic data can increase robustness and lower costs.	Lack of expertise is a key challenge that impacts both simulation and digital twins.
Digital Twins	Digital twins are models of real-world assets and locations (from buildings to cities and the planet) – these models also leverage real-world data from sensors.	Connectivity (IoT devices, 5G/6G connections), cloud and edge computing, AI, 3D engines, XR devices.	Improved predictive measures for maintenance, optimization of workflows, addressing climate change, monitoring and improving workflows.	In addition to lack of expertise, cost and relatively high returns on investment are potential hurdles for digital twins.

Efficiencies and Cost Savings

Hybrid/remote work and virtual events reduce or limit costs associated with travel, maintaining office space (either in total or reduction in space), and setup and fees for conference booths/space. Immersive training, and immersive operations particularly when XR HMDs are used, can not only reduce costs (e.g., training on virtual tools and equipment), but also improve the effectiveness of the training and operations. Studies have given credence to the effectiveness of immersive training in place of less immersive alternatives like text or video-based training sessions.

Digital simulations can create efficiencies and cost reductions throughout a product's lifecycle from design to operation. Digital twins (which typically include simulations) can improve operational efficiencies, such as predicting maintenance needs of factory machines, optimizations in factory floor workflows, and impacts of environmental factors. Simulation testing can also leverage synthetic data generated with AI to replace or supplement the costlier collection of real-world data—it's also possible to test more variables and conditions than would be feasible with real-world data alone.

Recreations of real-world environments can also reduce the cost of producing content on-site and greatly reduce the ecological impact of sending full production teams. Creating a virtual environment for a commercial or scene versus filming on location (e.g., in a forest preserve) would limit the impact of sending a full crew (i.e., equipment, vehicles, staff) to the site and the associated costs.

Interoperability, Improved Flow of Data and Information

Immersive collaboration, which includes virtual events, makes Communications and Collaboration (C&C) more accessible, reducing travel, connecting users who are unable to make particular meetings or events in person, and bringing access to tools to a wider audience. Moving some of the workflows to the cloud, for example, can allow more participants direct access to the project to directly provide their insights and inputs in real time. Interoperability helps bridge the divide between disparate applications and work processes, potentially moving previously serial workflows to work in parallel.

Digital twins and the rise in leveraging sensor data will push the need for "Telecoms Native Intelligence," which are telecommunications systems that consider AI and computing as integral parts of its architecture, rather than add-on optional features. AI and cloud/edge computing will be necessary to filter and process the data and manage and track assets as they traverse across networks to optimize supply chains and workflows. 5G can begin to fulfill this role by adding computing and intelligence functions as add-ons to connectivity, but this will be core to the 6G era and the longer-term metaverse horizon.

NEW OPPORTUNITIES

While the enterprise metaverse will apply to all markets, several industries have had better traction during these early stages of the buildup to the metaverse; most notably the Architecture, Engineering, and Construction (AEC), manufacturing, and automotive industries and among creative/designers—all of which have preexisting 3D workflows. Extending this to simulations and digital twins means it spreads to the broader industrial segment, aerospace and defense, and sciences. Immersive training also reaches most industries, but healthcare, education, retail, and manufacturing stand out with early traction.

The growth of immersive and 3D workflows will create new and expanded opportunities for incumbent vendors that will see more opportunities from existing and new customers alike. The buildup to the metaverse will also propel the migration to the cloud, bringing unprecedented demand on compute and networks, which speaks to the key metaverse foundation and pillars that were introduced earlier and are discussed in greater detail within Section 2. Further on the opportunity front will be the broad digital transformations that companies will undergo in the coming years. Companies will be undertaking this digital transformation from different points within their journeys, which creates opportunities to bring to market tools and solutions to help with accessibility (for those with higher levels of expertise) and professional services for those lacking in-house expertise.

RECOMMENDATIONS

Focus and efforts need to be placed on further development and evangelization of metaverse-enabling technologies, standards, and best practices. The enterprise segment is ahead in this regard and already has better buy-in from the industry than the consumer space to target interoperability. Some of these market opportunities, such as immersive collaboration, are still best served in specific workflows and applications like design, training, and Human Resources (HR) (e.g., new employee onboarding and corporate communications). It is, therefore, best to view these solutions for these targeted purposes, rather than a broader C&C replacement—at least until further advancements are made in the technologies and platforms.

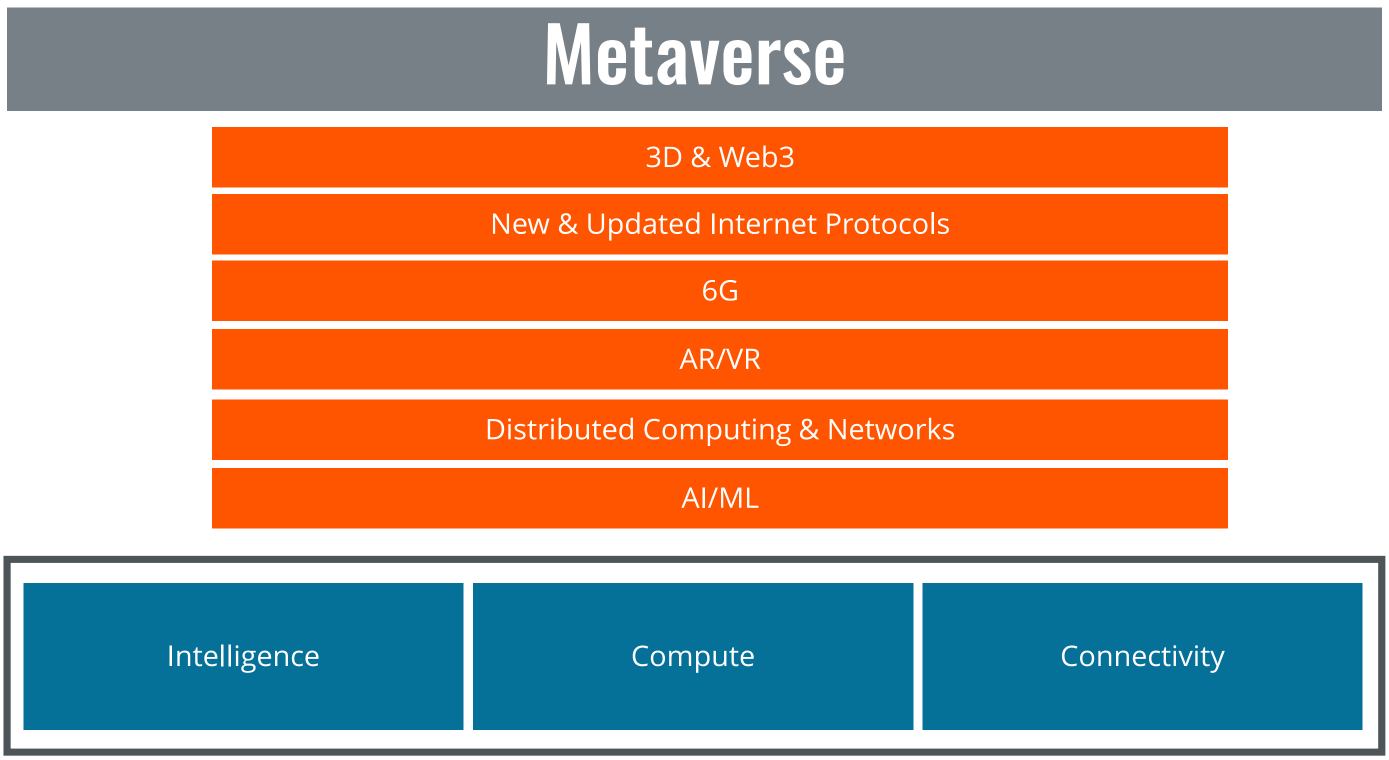
Even though some aspects of the enterprise market like simulation and design already widely use 3D by nature, this does not mean the market will rapidly expand to large-scale digital twins or more advanced forms of simulation. Considerations for cost and ROIs tend to be shorter term and could slow adoption for some of these newer opportunities, so this should temper some expectations.

TECHNOLOGY PILLARS OF THE METAVERSE

The future metaverse will be built on a wide breadth of technologies, but there are six principal pillars: 3D and Web3, new and updated IPs, 6G, AR/VR, distributed computing and networks, and AI/ML. These pillars stand on top of a foundation formed by the network and technology convergence of connectivity, computing, and intelligence.

Figure 4: Key Pillars of the Metaverse

(Source: ABI Research)



These pillars speak to the core and foundation of the metaverse, its interconnectedness, the requisite machinery to power the experiences, and the transformational changes coming to the UIs and UXs.

3D AND WEB3

3D is at the heart of the metaverse and speaks to the transition from a largely 2D environment and the merging of the real and virtual worlds. The demand for, and the creation of, 3D content is critical to the development of and buildup to the metaverse. The critical nature of 3D and digital assets is a driving reason for why Web3, a term that encapsulates the push for blockchain and cryptocurrencies, has come to the forefront as a pillar of the metaverse. It is important to note that while Web3 (blockchain based) has created the strongest ties to the metaverse it is not universally accepted as the definition of Web 3.0; where the term Web 3.0 is used to formally denote the next generation of the Web (See Figure 5). This version of Web3 is also differentiated from previous Web 3.0 visions, such as a semantic web. This paper focuses on Web3 due to its lead and currently strong ties to the metaverse and should be viewed as an analysis of its role and potential (including challenges), rather than an endorsement (or prediction) of Web3 becoming the de facto version of Web 3.0. It is still too early to reach such definitive conclusions.

While a universally accepted definition of Web 3.0 does not yet exist, there are some mostly common attributes across definitions such as decentralization of data, control, and resources, heightened importance of 3D (merging of real and virtual), and by default the need for accessibility. In this regard Web3 speaks to federated service platforms that are interoperable and distributed computing to support the decentralized architecture and bring accessibility.

For Web3 proponents, blockchain and crypto represent the foundation of the metaverse, which would give rise to among the metaverse's most transformative elements, a redistribution of control and wealth through decentralization. Decentralization, in this case, speaks to a redistribution of control (e.g., of users' data) and value. There would be a transition from dominant tech companies and ecosystems to a market landscape where end users have greater control over their data and activities and, hence, monetization opportunities. Decentralization also speaks to more technical elements. Blockchain, for example, would handle proof of trust over today's digital gatekeepers or platforms. The decentralization of data also engenders a need for more distributed computing. Instead of a company like Meta collecting and processing users' data centrally, this will happen closer to the network edge across users, versus in aggregated data lakes, reinforcing the need to bring connectivity and intelligence into the network. Content, in a similar fashion, will not be predominantly stored or managed in a centralized way, and it, too, will become further decentralized to allow for more network efficiency, service robustness/reliability, data privacy, and flexibility. These changes can be viewed across the evolutions of the web, as highlighted in Figure 5.

Figure 5: Evolutions of the Web

(Source: ABI Research)

	Web 1.0	Web 2.0	Web 3.0
Characterized by:	Static webpages, information-centric, with minimal interactivity (in some cases read-only).	Rich media and interactivity, rise in user generated content. eCommerce, social and streaming media, blogging, etc. – rise in the big tech companies and ecosystems. Growth in data consumption (streaming video).	Interoperability across networks, services, applications, workflows. 3D UX and content generation. Decentralization of data and control, content, network resources. Merging of the real and virtual worlds, deeper immersion. Emphasis on ultra-low latencies.
Key Technologies:	HTML	AJAX, CSS, JavaScript, 3G, 4G, 5G, AI, cloud computing.	Potentially USD, OpenXR, glTF, FBX, etc. 5G Advanced, 6G, AI, decentralized tech, edge computing, 3D engines.
Key Devices:	PCs	Mobile devices, PCs, connected CE.	AR and VR devices and mobile devices.
Typical Use Cases:	Browsing websites, collecting information, basic communication.	Media consumption, ecommerce, rich communications, social networking.	Digital marketplaces and economies, simulations and digital twins, connected cities, immersive communications.

While the degree of decentralization is debatable, some redistribution of control is inevitable. Pre-existing trends and regulations targeting privacy, anti-competitiveness, and management of digital identities are already favoring the end users (and smaller players), but the nearly complete reimagining of the technology landscape takes this future to a whole new plane. While no one company or a limited set of entities can control the metaverse, let alone create it, this does not preclude the existence of significant platforms or ecosystems; they will just need to offer better accessibility to third parties. This is where universal industry standards come into place to enable common interfaces between enabling technologies and interoperability frameworks between platforms and ecosystems.

Irrespective of one's stance on Web3, ownership of digital assets will be an integral part of the metaverse, serving as the basis for the new metaverse business models discussed previously and to drive 3D content creation. Ownership is a critical element to the development of the three stages discussed within the consumer metaverse section. Ownership of digital assets increases both the perceived and real-world value of these items. Consumers, therefore, who purchase digital assets and retain ownership of the item could, in turn, sell these items on the same platform or other marketplaces. This contrasts with most digital assets acquired by users where "purchases" pay for access to the virtual items, but do not acquire the rights to sell the item or, in most cases, transport them to other platforms. It is also important to note that digital asset ownership does not typically grant the purchaser rights to the intellectual property behind the item—this is no different than purchasing a good from a retailer. This is a critical step because it enhances the value of the entire 3D landscape and helps legitimize the new business models for virtual property, avatars, assets, etc.

Without transportability of assets and ownership, many of the longer-term visions will not develop as imagined. Holographic graphic avatars that do not have strong ties to the user, or virtual spaces that users are not particularly invested in, will not push users and businesses to make these elements core to their digital lives and workspaces. It is the interoperability of assets and the valuation of these digital spaces and assets that will result in changes to user behavior. These changes in user behavior, in essence, speak to the five Ws (who, what, where, when, why) of what will fuel the metaverse, with the enabling technologies and updates to protocols and standards answering the just as critical "how."

With regard to ownership, Web3 proponents point to Non-Fungible Tokens (NFTs), which are unique records on the blockchain linking to virtual or physical assets, as the nexus of this redistribution of control and value. NFTs in the Web3 framework are also critically used to denote ownership of the assets linked to the blockchain records. NFTs have also been closely associated with cryptocurrencies, which have impacted user and market perceptions (see more on the potential regulatory ramifications of crypto and NFTs in Section 3). Changes in crypto and blockchain, such as moving from proof of work to proof of stake can also have implications on energy consumption for future transactions (proof of stake requiring less energy). Beyond the underlying technologies of these virtual assets, companies need to create a stronger value proposition to spur demand. Cross-platform interoperability and portability of assets would enhance value and lay the groundwork when these virtual items will play a stronger role in the convergence between the real and virtual worlds. Standardizations, taxonomies, classifications, and rules are all required to ensure content is rendered properly in the different virtual spaces and appropriate.

Content creation and accessibility need to come to the forefront; while some platforms already offer tools to create assets (low or no-code environment) these applications still target individual platforms or worlds. Companies should also follow initiatives like NVIDIA's efforts to advance neural graphics or its GET3D AI model to generate 3D objects that will further make 3D content creation more accessible. The generation and rendering of 3D content and worlds will also increase demands on computing with stronger demand coming to the cloud and edge of networks to increase accessibility. In addition to content generation, AI has a strong role to play in the future web.

Prior to the rise in blockchain and crypto, which now predominates Web3 discussions, there was talk of a semantic web. The semantic web would use machine-interpretable metadata to enable and improve the effectiveness of key applications like virtual assistants and other AI-driven workflows. Search and recommendation engines, contextual advertising, and the ad tech industry more broadly would also benefit significantly with this additional layer of metadata.

As the digital marketing and advertising industries move away from third-party tracking devices and the market shifts toward first-party data and customer relationships, a form of a semantic web could help with this transition. Marketers, for example, need to increasingly work without Personally Identifiable Information (PII) or secure user opt-in approval—this includes users setting consent preferences in a global setting versus site to site. While efforts are underway to replace third-party trackers through identity platforms like The Trade Desk's (now managed by IAB Tech Labs and the Partnership for Responsible Addressable Media initiative) Unified ID 2.0 or Google's Privacy Sandbox initiatives, the broader industry would benefit from a universally supported and standardized option that a semantic web could help enable.

The arrival of mainstream smart glasses will create the need to quickly identify user preferences and adapt the ads and marketing they receive as they travel through public locations. Out of Home (OOH) signage, for example, could be rendered dynamically for each user based on their preferences; AI, in this case, would create curated ads and content, in a similar vein as how AI is being used today to customize video box art or previews/trailers. To make these experiences seamless and natural will require reliable, robust, and low-latency connections, particularly for hybrid cloud-enabled devices.

AR/VR

Calling out the arrival and spread of smart glasses in the second stage between the early years and long-term vision of the metaverse draws attention to the transformative nature of these devices. Smart glasses will push more touchpoints into the public spaces, creating new demand for edge computing and lower-latency connections. The always-on and mobile nature of these devices will also drive the need for network intelligence to ensure that users maintain access to the necessary computing and storage resources as they move between access points and networks. Further, virtual assistants, live language translations, targeted opt-in (location-based) marketing, capturing the environment, etc., will also drive the need for AI both on-device and at the edge.

VR will continue to target the most immersive use cases, but include video passthrough to allow for MR applications, although these devices will see the most use indoors with some opportunities in the public domain through autonomous vehicles and tourism. These public-facing opportunities are likely to use the cloud and the edge for connectivity and most of the compute (some compute on-device like motion tracking), which will push data rates (8K and higher resolution video) and latency (sub-20 ms) demands to the edge of the network.

On the connectivity front, 5G-Advanced will support the early latency demands through Ultra-Reliable Low Latency Communications (URLLC), while Enhanced Mobile Broadband (eMBB) will continue to support the higher data rates. As densities of users increase, device specifications advance, and latency needs push lower (eventually hitting sub-1 ms), this environment will push into the longer-term horizon, starting with the 6G era. As Standards Development Organizations (SDOs) and companies work on 6G and future protocols, it is important to build toward the confluence of network intelligence, computing, and connectivity to support the longer-term demands on data and ultra-low latencies. In time, the demand increase seen with smartphones over feature phones will be a similar progression with smart glasses and the metaverse, albeit with significantly higher individual user demands compared to mobile devices. While the growth rate of smart glasses is anticipated to be slower than smartphones, localized demand peaks will still be significant in densely-populated and high-traffic areas.

CONNECTIVITY—USHERING IN THE 6G ERA

In the leadup to the arrival of 5G, some of the prospective drivers like cloud VR or 5G-connected factories did not meet these early, lofty expectations. While 5G is still critically important to support increasing consumer data traffic, some of its advanced features like URLLC and positioning will see significantly more demand as discussed in the AR/VR section, with most opportunity pushing into the 6G era.

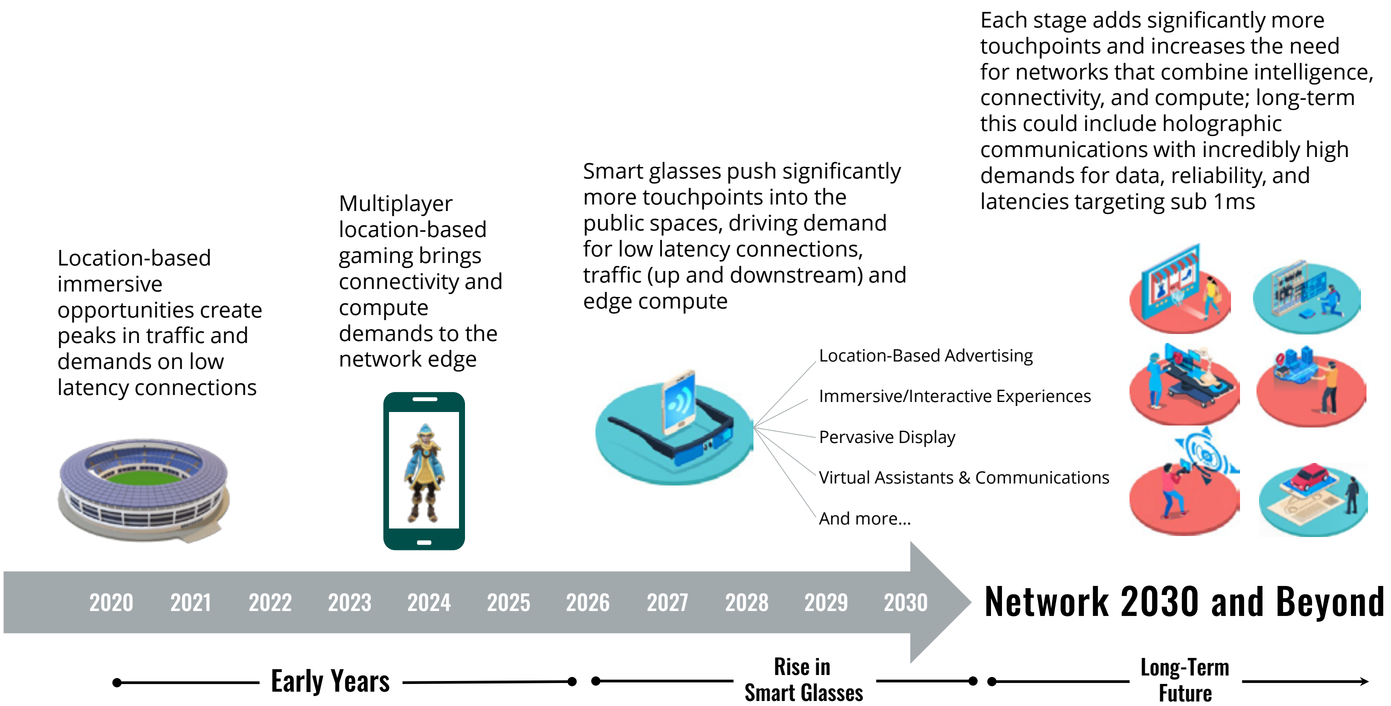
Connectivity Opportunities in the Consumer Space Bring Latency to the Forefront

As discussed in the previous section, smart glasses represent a significant change in the demands placed on networks. Besides the potential to be an always-on/active device, smart glasses will also greatly benefit from synchronous data connections to support the use of onboard cameras/sensors to understand the users' environments. Higher data requirements are standard upgrades for future generation networks (albeit the metaverse will push these harder), but beyond that, the new experiences and use cases will generate new demands on latency and intelligence within the network. Pushing further out in the timeline, newly envisioned use cases like holographic communications will exceed what is possible with today's IPs.

Markets today are already seeing demand for lower-latency connections. Video with Adaptive Bitrate (ABR) has evolved from the 30-second to 40-second range down to broadcast levels (under 10 seconds) and ultra-low latency video and Real-Time Communications (RTC) already use UDP (e.g., SRT, and WebRTC in most cases) over Transmission Control Protocol (TCP). UDP-based QUIC and its variants (Microsoft's MsQUIC, Meta's mvfst) are also providing improved performance across web-based applications and already used by a significant portion of mobile traffic. While these protocols will support use cases during most of the buildup to the metaverse, the long-term vision will require enhancements to existing protocols or new protocols to support the more advanced use cases like holographic communications. Even before a holographic future, the use of smart glasses will push more media-rich RTC and experiences that will demand ultra-low latencies and put further demands on edge computing resources.

Figure 6: Timeline for Consumer Metaverse Use Cases and Connectivity Requirements

(Source: ABI Research)



Connectivity also refers to the broader IoT market, because the metaverse will rely on a widespread deployment of interconnected sensory networks consisting of a range of cameras and sensors. This sensory network will play a key role in bringing physical assets into the virtual spaces and creating richer (and more real-to-life) digital twins of the world. As part of this sensory network, 6G will need to bring multiple network technologies (e.g., fixed, mobile nomadic, and satellite communications) under a single framework; convergence of these networks, including short-range communications through Local Area Networks (LANs) and device-to-device communication protocols, are necessary steps to enable the flow across devices, infrastructure, and assets.

While the six pillars are illustrated as discrete technologies, there is significant crossover between these categories with connectivity serving as a nexus point. 6G will need to implement computing and intelligence natively in the network as integral parts of the 6G standards. Some of the use cases driving this need at the network level were discussed in the AR/VR section, but this also applies equally to the enterprise markets with some more stringent requirements.

Connectivity Opportunities in the Enterprise Space Put the Spotlight on Secure and Reliable Workflows

Connections in the consumer space will need to be secure and reliable, but the enterprise has more stringent requirements. The migration of applications, platforms, and content/data to the cloud, for example, by necessity must be secure and reliable to avoid any workflow interruptions. Further, the progression from simulations (at the component level) and digital twins (at the asset level) to larger scales like factory, supply chain, city, and eventually global levels will place significantly more demand on both networks and compute resources.

With each step up in complexity, the potential to include additional sensors and data grows significantly, translating to increasing demands on connectivity and compute resources. While installations of private cellular networks have not yet hit some early projected possibilities, the increasing complexity of the sensor network and need for near real-time data could justify the investment for larger manufacturers and companies that need to connect broader supply chains and workflows.

There are also Research and Development (R&D) initiatives looking at sensory networks or "super smart sensing" in 5G (and future) networks to combine sensing and communications. China Unicom and Huawei, for example, are exploring this technology for applications like drone track detection, Intelligent Transport Systems (ITSs) and autonomous vehicles, Vehicle-to-Everything (V2X), and other cases with large-scale use of sensors. China Unicom is working with The 3rd Generation Partnership Project (3GPP) and the China Communications Standards Association (CCSA) to standardize this super-smart sensing in cellular networks.

Immersive C&C in the enterprise market will also increasingly place demands on lower latencies and higher data traffic both upstream and downstream. While smart glasses will increase the use of more immersive forms of communication, tablets and smartphones are already being used to good effect in today's market. As more parts of the workflows move to the cloud, these immersive collaboration platforms will allow for more real-time work between on-site and in-office workers.

Like the consumer segment, hybrid and cloud XR will demand ultra-low latencies and higher data rates, especially for the enterprise markets, which are more likely to use higher-grade HMDs with higher resolutions. Demands on upstream data channels will also see much higher demands as users send back video feeds and other data collected by the HMD's sensors. Cloud VR (with passthrough for MR) has stronger use cases within the enterprise space, as users are less likely to have issues or concerns wearing an HMD outside of the home/office. Examples like cloud VR will likely leverage both edge compute to render the experience (with onboard/device sensors for motion detection) and the cloud to run the software.

On the longer-term horizon, the sensory networks will generate a wealth of data that intelligent networks will need to both parse and distribute as required by applications and users. These data will feed into and enhance what is possible within the holographic future; for example, real-time visual updates to virtual environments based on real-world conditions and data.

AI/ML

In this paper, AI is positioned as an essential component of the network architecture and range of external metaverse applications that will be needed anytime and anywhere. On the network front, AI will enable intelligence on-demand, both for automated network operations and service management and orchestration, while also providing AI services for the external applications. Within the context of the metaverse foundation, AI represents the principal component for intelligence, but it is also a key driver for computing within the network as well.

While 5G-Advanced will set the foundation for AI implementation within the network, implementation of AI as a native function of the network in 6G will promote large-scale deployments of self-optimized and automated networks. Native AI implementation in 6G, by nature, would also bring intelligence and computing closer to more end users. Intelligence at the edge will be essential to ensure end-to-end orchestration of workloads across communication and computing domains.

Of all the pillars, AI has the broadest role across the metaverse—critical for the network, managing and processing data/information, optimizing workflows and processes, and enhancing and powering end-use cases. AI will power digital humans (e.g., customer care and virtual assistants), personalization, digital identity management, and more. AI will also play an essential role in content creation.

3D CONTENT CREATION

3D content creation is essential to the metaverse to drive accessibility, advance new business models, and expand the base of users. Today, most forms of 3D content creation require skillsets that most of the population does not have and without efforts to increase accessibility, this would mean a dearth of 3D content. A wealth of 3D content will be needed to populate the virtual spaces, which will eventually span the virtual and real worlds. AI and cloud computing will be critical to bring 3D content creation to the masses.

Some metaverse platforms already have tools to allow users to create new digital assets through Graphical User Interfaces (GUIs) that are low to no-code. These examples are suitable to support the early stages, but are typically not applicable to external platforms and are often too limited to work more widely across different platforms and applications. This is an area where neural graphics can play a key role in extending the accessibility of 3D content creation.

Neural graphics leverage AI, physics, and animation models to facilitate the creation of 3D assets and environments. This includes using 2D images to automatically create a 3D representation of the object that has lifelike movements and follows the laws of physics. Making these tools accessible to more users would allow retailers to fill virtual shelves more easily (and economically) with digital goods—serving V2A, V2V, and V2P business models. Many of the virtual shopping experiences today lack the necessary realism to adequately support V2P use cases.

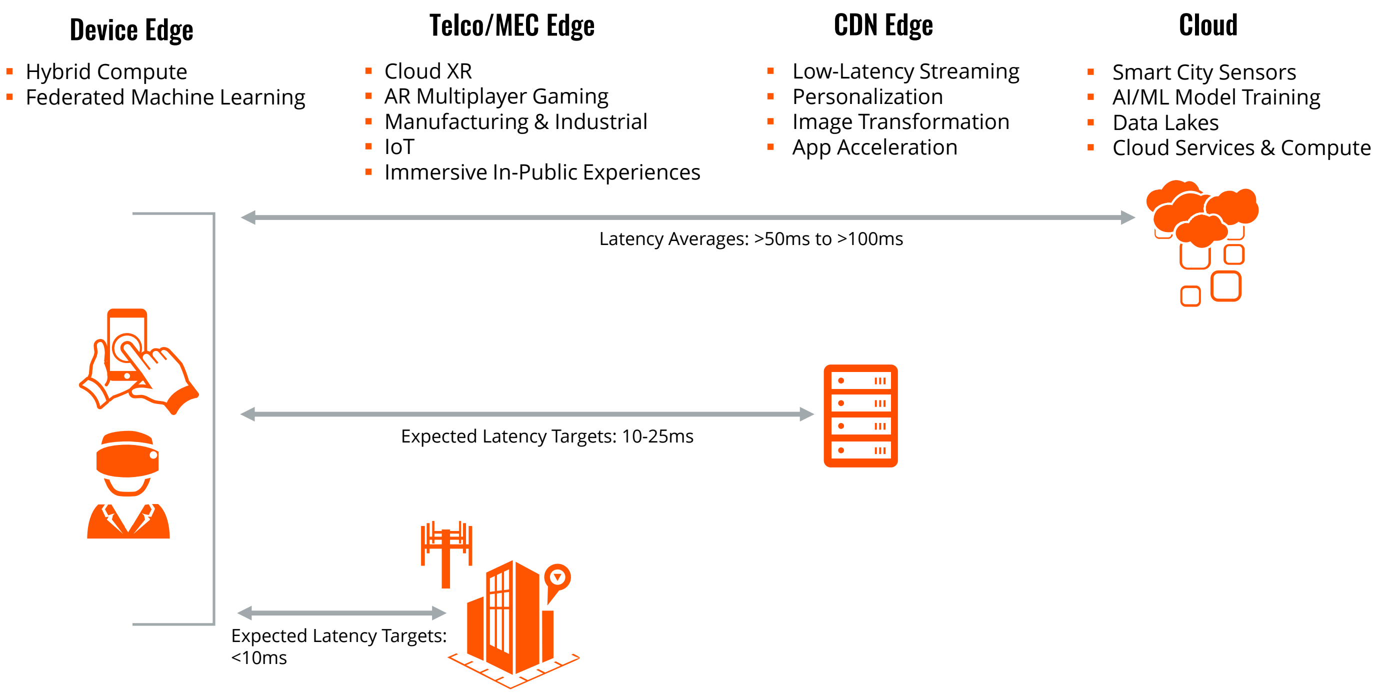
Cloud compute, for many, will be an essential component of the 3D content creation process. Most users will not have access to workstations or Graphics Processing Units (GPUs) powerful enough to efficiently generate 3D assets; therefore, cloud computing will represent the most economical solution for many. Interoperability is also a critical consideration for 3D content creation and the growth of 3D marketplaces, and will require work on the standardization front.

DISTRUBUTED COMPUTING TO POWER THE METAVERSE

Digital transformations are already moving workflows to the cloud, but the expansiveness and scope of the metaverse will push the demands on cloud and edge compute to considerably higher levels than current organic growth. These demands will come from both the consumer and enterprise segments, but the former will see a sharper increase once mainstream-level smart glasses enter the picture. To meet this demand, the edge, cloud, and telco networks will address specific demand requirements and, in time, operate within a distributed computing framework.

Figure 7: Multi-Edge and Cloud Networks—Satisfying Varying Latency Requirements

(Source: ABI Research)



There are three main edges sitting downstream of the cloud: the devices themselves, telco/Multi-Access Edge Computing (MEC), and Content Delivery Network (CDN) edges. Target applications and use cases are segmented by latency need with the most latency-sensitive functions like motion tracking remaining on-device in a hybrid cloud arrangement. Other applications like federated ML will also leverage devices to store and process (e.g., to anonymize the data) sensitive data.

Moving to the next level, the telco/MEC edge will target use cases in the sub-20 ms range. Examples here include cloud XR, multiplayer location-based gaming, industrial and manufacturing applications, the IoT and smart city, and location-based immersive experiences. These applications have stringent latency requirements due to UI requirements, such as hitting a low motion to photon latency in XR, or data needs (e.g., data for Vehicle-to-Vehicle (V2V)/V2X).

The edge computing opportunity at the CDN edge is the least developed, but it will have among the earliest growth opportunities with the arrival of mainstream smart glasses. In addition to caching and processing/packaging content at the CDN edge, these network operators will have an opportunity to play a larger role in the personalization of content and advertising. With some activity in the virtual spaces like the social networking and gaming markets, the advertising and marketing industries have started to lay a foundation for the metaverse, but it remains conspicuously underdeveloped.

While not an imminent need, CDN operators should make more integrations into advertising workflows to prepare for this future opportunity. Expanding coverage into these workflows will be particularly important for core CDN operators, which will find themselves at a disadvantage to the hyperscalers that already have operations covering media, advertising, and cloud/edge computing workflows.

As the metaverse scales up and user counts grow, the need for cloud and edge computing will accelerate well beyond today's current growth trends. Devices and services will become reliant on connectivity and distributed cloud/edge computing. The transition from the 2D Internet to 3D will require significant infrastructure buildout to make these experiences more accessible (e.g., content creation and rendering of 3D assets and spaces), which will place additional weight on managing sustainability and energy consumption.

FUTURE TECHNOLOGIES AND PROTOCOLS

While the previous metaverse pillars, in many regards, speak to future technologies, there are two areas that are worth calling out separately. Next-generation IP and networking is both foundational to the Internet and an area that has generated different views of how it will address new market demands, especially those introduced by the metaverse. The second area was highlighted within the Web3 discussion, but its critical nature deserves a standalone section—3D content creation.

NEXT-GENERATION IP PROTOCOL AND NETWORKING

In many respects, the current IP suite and TCP, in particular, are not well suited to the buildup to the metaverse and certainly not for the longer-term vision. As previously discussed, TCP is inadequate for the most latency-sensitive applications, which will grow in kind as the buildup to the future metaverse progresses. Furthermore, in a rich sensory network, IP headers, which are only 20 bytes to 60 bytes, will become a considerable expense in the communication link due to the high volumes of small data packets transmitted by the sensors. TCP is also inefficient with handovers (e.g., switching cell towers), and while QUIC is a better alternative here, it still falls short of supporting the future holographic use cases.

Efforts are already underway to both address some of these shortcomings and work on evolving preexisting protocols and potential future protocols. The ITU Network 2030 Focus Group, for example, was established to review and evaluate existing technologies, platforms, and standards, and identify shortcomings toward Network 2030. The ITU focus group will consider all aspects of Network 2030, including: vision, requirements, architecture, novel use cases, etc., and establish the necessary connections to other SDOs.

ETSI announced a new Industry Specification Group (ISG) called Non-IP Networks (NIN), which is focused on protocols that can replace or complement TCP/IP. The NIN group is building upon work done by a previous group (Next Generation Protocols (NGP)) and, in particular, the Flexilink protocol, which separated packet routing information from the packets themselves; reducing packet size by removing the header and potentially increasing processing times. Flexilink critically supports guaranteed services that include low-latency, high-quality synchronous services that are not supported in the current IP suite.

There are also initiatives to facilitate changes to the communication process from a host-centric to content-centric ideology—the Internet Research Task Force (IRTF) Information-Centric Network (ICN) Research Group is among the more prominent research efforts here. While the implementation of ICN faces significant hurdles, and could come in the form of a hybrid ICN implementation, it would support many of the principles of decentralization and data that are able to be easily transported, cached, and replicated.

Huawei has also contributed to the Network 2030 discussion, defining many of the key cornerstones of future networks discussed within the longer-term horizon. This includes holographic communications, instantaneous teleportation system, and intrinsic trustable security. Huawei's NEXT IP also proposes a new IP packet format. While work is underway to address future demands on networks, there is still a longer runway before Network 2030 and longer-term applications like holographic communications become commonplace. The area of 3D content creation, however, is more pressing, as it is a key contributor to the growth rate of the buildup to the metaverse.

In fact, before any of these use cases and technologies become part of a true metaverse, a great deal of work is needed on standardizations and key regulatory considerations to consider that are already directing the trajectory of the buildup to the metaverse.

STANDARDS AND REGULATIONS

Even though the recent attention devoted to the metaverse and the buildup to this future is relatively recent, there are already significant developments on the standardization front and pre-existing trends (and regulations) impacting the market. The development of standards and bringing interoperability have solid support, but they are still in the early stages of development.

METAVERSE STANDARDS AND BEST PRACTICES, STILL EARLY DAYS

While there have been several groups and initiatives covering the metaverse (e.g., Open Metaverse Interoperability Group, Metaverse Foundation, Japan Metaverse Association, etc.,) and others targeting immersive industries and other specific industries that could be viewed as metaverse related, the Metaverse Standards Forum (MSF) (publicly launched in June 2022) and the Digital Twin Consortium (DTC) (publicly launched in May 2020) are two standout groups. The Metaverse Standards Forum (MSF) already boasts hundreds of members (principal members already stand at around 600) and includes many key SDOs, including: the Consumer Technology Association, the Institute of Electrical and Electronics Engineers (IEEE), the Khronos Group, OMG, Open AR Cloud, and the World Wide Web Consortium (W3C). The core areas of focus for the MSF are as follow:

- Interactive and interoperable 3D assets and photorealistic rendering
- Human interface and interaction paradigms, including AR, VR, and XR
- User-created content
- Avatars (and apparel), identity management and privacy, safety, data security, and inclusion
- Financial transactions/payments and economy
- IoT and digital twins
- Teaching and education
- Geospatial systems, real/virtual world integration

The DTC targets the industrial markets for simulation and digital twins, and has more than 150 members. In both cases, it is still early and many of the conversations are very nascent, so it is difficult to assess the full impact these groups will have on the metaverse, but it is, at a minimum, testament to the positive direction the broader industry is taking.

The MSF is intriguing because, as it currently stands, it is designed to determine what standards are needed to be pursued versus crafting the standards itself. It is also notable because the DTC has been added as a principal member, creating some cohesion between the two groups.

An example of where the two groups could come together is on 3D asset interoperability. If the MST and the DCT both embrace Universal Scene Description (USD) for creating assets and virtual spaces, and glTF as the standard file format, this would certainly accelerate the buildup to the metaverse from the standardization front. Without a current compelling alternative, USD certainly stands a good chance of fulfilling this role.

While the DTC, the MSF, and USD are addressing more of the early technical standards and best practices, there are also considerations, particularly on the consumer front, that could alter the foundation of the current landscape for big tech companies and ecosystems.

Underpinning much of the consumer metaverse discussions are market trends that are pushing stronger data protection and privacy. While the United Nations Conference on Trade and Development (UNCTAD) lists 70.6% of countries (137 out of 194) as having legislation in place to secure the protection of data and privacy, the EU's General Data Protection Regulation (GDPR) and California's Consumer Privacy Act (CCPA) stand out as setting the tone for current trends. This includes Apple's changes to its Identifier for Advertisers (IDFA) tracker and Google's eventual end of support for third-party cookies in its Chrome browser.

Differences in U.S. and European regulatory environments for privacy and personal data have created some distinct differences and engendered some complications. The Privacy Shield arrangement between the United States and EU, for example, was invalidated in 2020, leading to concerns about how companies like Meta and Google would send data from the EU to the United States. It was not until earlier in 2022 that a new framework was announced (Trans-Atlantic Data Privacy Framework (TADP)). Differences in regulatory environments and regulations have also created general operating environments where Europe is viewed as an opt-in market, while the United States is viewed as opt-out. While differences exist, the general trend continues to push toward greater protections for user data and privacy with more control shifting to the individuals. Efforts are also underway to make markets more competitive.

BIG TECH REGULATION

Part of decentralization is the shifting of control and value from large company ecosystems or gatekeepers to both third-party platforms and eventually down to the users. The redistribution of control helps ensure that the broader metaverse and markets are not controlled or driven by just a select few companies. Shifting value also helps bring in new competitors and incentivizes the production of user-generated content. This shift in control and value started with privacy regulations, but regulators are increasingly seeking to create more competitive marketplaces.

In July 2022, the European Council, for example, adopted the "Regulation on contestable and fair markets in the digital sector" (aka the "Digital Markets Act" or DMA). The EU also approved the Digital Services Act (DSA), which holds online service providers responsible for their content moderation practices and removing illegal content.

The DMA specifies ten "core platform services" with specific requirements to fall under these guidelines. The core services include:

> Online intermediation services [such as online marketplaces]; online search engines; online social networking services; video-sharing platform services; number-independent interpersonal communication services [such as messaging services]; operating systems; web browsers; virtual assistants; cloud computing services; and online advertising services

The requirements to fall under the scope of the DMA ensures it targets larger companies (identified as "gatekeepers") based on revenue (e.g., annual turnover in the European Economic Area equal to or above €7.5 billion in each of the last three fiscal years) and reach (e.g., core platform with more than 45 million Monthly Active Users (MAUs) in the EU and more than 10,000 yearly active business users in the EU within the last financial year). The DMA seeks to create a more competitive environment by ensuring that third-party businesses have access to the necessary data and tools for their operations, and can establish direct business contracts with customers outside of the gatekeeper's platform. Other countries, such as South Korea, have also implemented regulations that similarly target large ecosystems or gatekeepers to ensure a more competitive landscape (e.g., requiring gatekeepers to accept third-party payment systems).

Taken collectively, the efforts around data protection and privacy, and pushing for more competitive marketplaces all speak to ideals put forth by visions of the metaverse. These are not likely to be metaverse specific-driven initiatives, because all are either based on previous legislation/policies or predate the more nascent attention given to the metaverse. In fact, many of the nearer-term opportunities highlighted, thus far, are extensions of pre-existing trends. This should offer some confidence that much of what is envisioned for a future metaverse is not solely the visions of a few big tech firms like Meta, but rather organic progressions of technological and market advancements. One area, however, that remains somewhat of a wildcard is Web3.

The same conversations around data protection and privacy, and more competitive environments also underpin tenets espoused by Web3 proponents. The movement toward end-user control and decentralization of data warehousing, for example, supports messaging from Web3. Shifting control and value further downstream to the end users would also weaken the position of big tech ecosystems and create more opportunities for smaller players to gain share; users would have the control to make these decisions. Decentralization of data and resources also speaks to the network needs discussed in Section 2, which espoused the need for network convergence of intelligence, computing, and connectivity to support the new usage models and the greater metaverse. Further development, acceptance, and demand for digital assets/goods will fuel the content creation market and expand the opportunities to merge the real and virtual worlds, especially with the arrival of mainstream smart glasses, highlighting the layered approach to the buildup toward the metaverse. While Web3 parallels these market directions, its focus on blockchain and cryptocurrencies could create some potential headwinds that may slow progression in the longer-term future.

WEB3 AND ITS CRYPTOCURRENCY PROBLEM

While organizations like IEEE have questioned the role of Web3 and the metaverse, the majority views Web3 as a core element. This sentiment, in turn, typically extends to cryptocurrencies and investments continue to flow to crypto companies, even in a down market. The connection between the metaverse and crypto, however, could slow the buildup to the metaverse, especially if digital assets and NFTs remain tied to cryptocurrencies.

Depending on one's home market, the perspectives of cryptocurrencies and NFTs may be dramatically different, along with significant disparities in how governments regulate or view cryptocurrencies. In the North American and European markets, for example, cryptocurrencies have a much stronger footing, with little in the way of explicit or implicit bans on cryptocurrencies—only Georgia, Moldova, and North Macedonia have bans on cryptocurrencies.

Countries within these regions have also put forth bills that would regulate aspects of the crypto market like stablecoins and taxes (e.g., eliminate taxes on small-scale purchases with cryptocurrencies) to bring cryptocurrencies closer to traditional currencies; the United States and the United Kingdom, for example, have entered bills like these for consideration. While the regulatory environment in the European and North American markets are far from a state of maturity, they are still conducive ongoing market developments. Even in countries like Russia, which banned civil servants from owning crypto assets as part of its first laws issued to regulate crypto (in effect in 2020), potential concerns around further restrictions have eased with its ongoing war with Ukraine; crypto is viewed as another vector to bolster its economy.

Latin America follows closer to the North American and European markets, but the foundation is currently less secure. Bolivia, Ecuador, and Guyana have cryptocurrency bans in place, while Mexico's Central Bank does not view cryptocurrencies as lawful currency and they are not offered or traded by Mexican regulated financial institutions. Overall, however, the expectation is that Latin America is taking a more cautious approach, but seeks to foster development of the crypto markets, rather than curtail it. Colombia, like Mexico, does not recognize cryptocurrencies as legal currency, but more recently, it is working to better regulate the industry to bring some controls and legitimacy.

Figure 8: Percentage of Regional Populations with Cryptocurrency Bans

(Source: ABI Research)

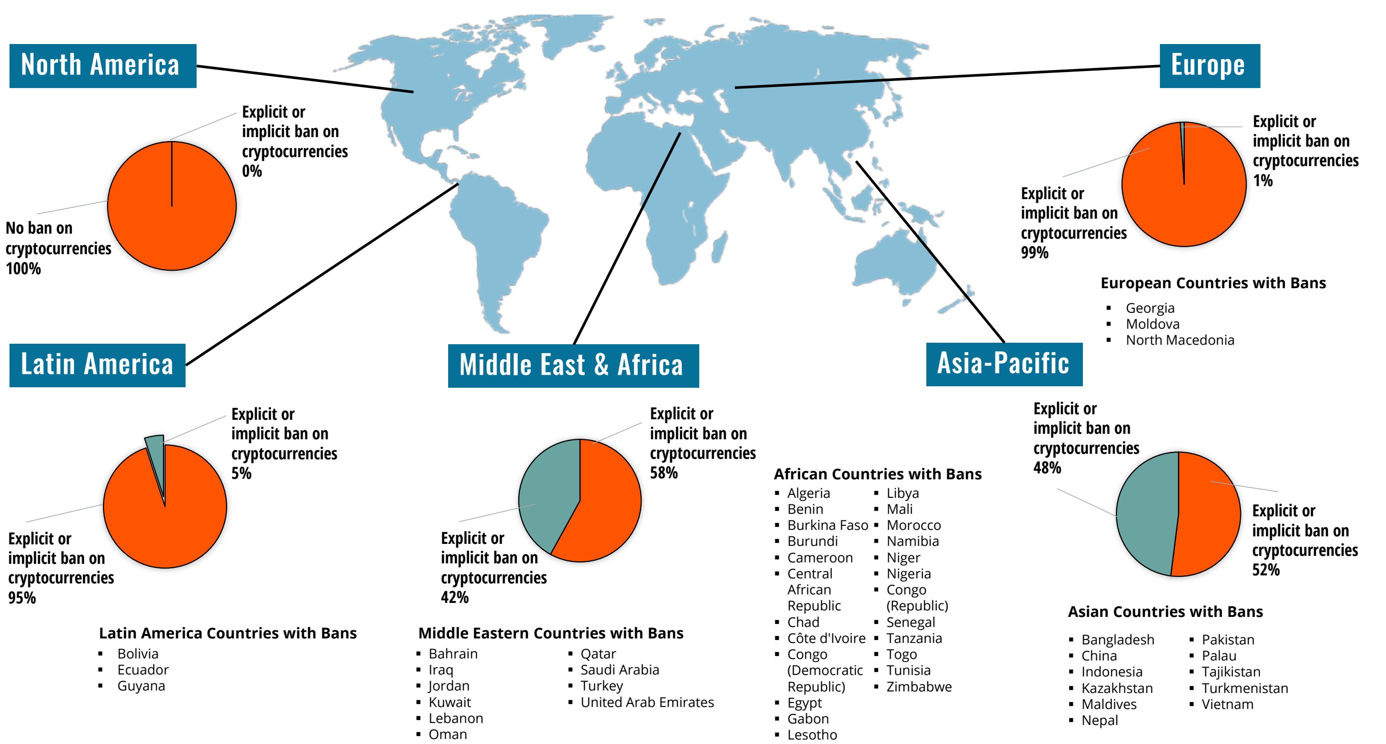


Figure 8 paints a markedly different picture within the African, Middle East, and Asia-Pacific regions where greater than 50% of their respective populations are in countries with some form of cryptocurrency ban. The Middle East & Africa region, in particular, has a large number of countries with bans, compared to the Asia-Pacific region, which has significantly more countries with bans than the Western regions, but the population measure is heavily impacted by China's ban on cryptocurrencies.

India is another potential wildcard with the country's central bank stating it believes that cryptocurrencies should be banned within the country. If India were to ban cryptocurrencies, by population, this would push the Asia-Pacific region to 84% coverage for some form of cryptocurrency bans. While many countries tax cryptocurrencies, Japan has imposed corporate taxes on cryptocurrency holdings (classified as miscellaneous income) of up to 55% with an average rate of around 30% (including unrealized gains); although Japan is considering lowering the tax on crypto to 20% with an exception on unrealized gains.

The fluidity of the crypto market and shifting regulatory environments is a significant reason the better approach to the digital asset/NFT markets is through fiat currencies, at least as an alternative to crypto. Looking beyond cryptocurrencies, the metaverse will, of course, require significant work on the standardization front to help with best practices, interoperability, and accessibility.

While the Middle East & Africa region is important, the Asia-Pacific region's stance on cryptocurrencies is more impactful because it, along with North America and Europe, are the leading regions for Web3 and the buildup to the metaverse.

OTHER KEY METAVERSE TECHNOLOGIES

Other technologies have been discussed in this paper, among the most critical, 6G and the need to bring intelligence and connectivity together. Bringing intelligence, connectivity, and computing together also opens the door to sensory networks, which will be essential to power consumer metaverse experiences and for digital twins that extend to supply chains, cities, and eventually a simulation of the world. Other SDOs like ETSI have also called out the need for smart infrastructure as part of a sustainable and smart society—comments here mirror the call for the integration of computing, storage, communications, and intelligence as part of smart infrastructure and overall digital transformations.

While some of the more advanced used cases like holographic communications are further off, if the buildup to the metaverse hits its milestones, these applications will come during the 6G era, so it is important to begin the work leading up to Network 2030 to best position the industry to reap the benefits of the future metaverse.

There are other areas in the near term that are already underway, which, at some levels, speaks to decentralization. Open caching, for example, is an open architecture developed and endorsed by the Streaming Video Alliance that facilitates service providers to deploy edge CDNs and eventually to monetize this infrastructure by offering its network as another option to content providers. This Open Caching-as-a-Service model was announced in 2020 by Cisco and Qwilt, and Digital Alpha—the latter was an investing partner, Qwilt served as the content delivery platform using open caching, and Cisco provided edge computing and networking infrastructure.

It is possible the future Internet could become more fragmented in the sense that there will be large networks controlled by a company or set of partners that will need to be interconnected. Regulations and standards will need to be put in place to ensure interconnectivity and, more importantly, ensure accessibility and access is not lost through this network structure. Open caching is an early iterative step of extending networks and decentralizing data and workflows. This will be accelerated as the buildup to the metaverse continues, especially with opportunities for reimagined digital identity and data storage in concepts like Huawei's My-Cloud.

Growth in the market of digital assets and spaces will move the metaverse toward a future when the next evolutionary steps will move toward holographic communications. As previously discussed, during the time leading up to this future, work needs to look at updating existing IPs, likely beyond what alternatives like QUIC can provide today. While it is still uncertain if this means a new protocol is necessary, or if the existing standards can be adequately updated, significant advancements will be required.

PERSPECTIVE ON REGIONAL DIFFERENCES

Across the key pre-existing consumer and enterprise markets, the North American, European, and Asia-Pacific regions represent the largest market opportunities throughout this current decade. This is true for digital media & entertainment markets, immersive collaboration, and the digital twin and simulation market, which is driven by larger manufacturing and AEC industries. This does not mean there is homogeneity among these three markets—the differences in cryptocurrency regulatory environments alone create separation.

While many Western consumers (speaking of the mainstream) have exhibited a reluctance to accept NFTs, consumers in Asia-Pacific have been more receptive. Large Web3 companies and investors like Animoca Brands have seen these differences first-hand, and even in a challenging tax market like Japan, they are still investing in the country. Considering historical trends in the gaming industry, this level of acceptance does not come as a surprise, as Asian gamers were ahead of their Western counterparts in accepting digital assets and paying to access content in "free to play" titles. This again speaks to the need for Web3 companies to be flexible in linking cryptocurrencies with NFTs and digital assets.

The Asia-Pacific region has also led other areas in the early buildup to the metaverse. In the social networking segment, SK Telecom's Ifland social metaverse platform (which is being ported to Deutsche Telekom for the European market) and Naver's Zepeto represent early initiatives to target younger audiences less accustomed to prevailing social networking platforms—these platforms have established larger user bases than similar efforts in other regions. In China, companies like Alibaba are trailblazing in the virtual malls and shopping segment, including (among others like Tencent) powering a vibrant market around live ecommerce, which has strong potential within a metaverse setting. On the media front, companies like ZTE and Huawei continue to have robust solutions for immersive content, and Huawei has developed an intriguing platform (MetaStudio) to address these early metaverse workflows. Huawei Cloud, through its solutions and partner ecosystem, launched its MetaStudio platform for digital content production that specializes in 3D; this includes model creation, asset management, content editing, physical simulation, and cloud rendering. The North American and European markets, however, have led in other aspects of the buildup to the metaverse.

U.S.-based companies like Meta, NVIDIA, and Microsoft have already made significant investments in the buildup to the metaverse, and on the AR/VR front, a significant number of the stronger performers in the enterprise markets have been Europe based, including European auto manufacturers like BMW and the VW Group. This does not imply that large tech companies in Asia-Pacific have not been investing in immersive and the metaverse, far from it, as evidenced by the previous paragraph, but broader traction and the level of targeted investments have been higher in some aspects of the North American and European markets.

Over time, most expectations view opportunities as equitable between the three leading regions than not. There are certainly differences in regulatory and cultural environments, but the metaverse, serving as a future version of the Internet will need to support this level of diversity. To reach a metaverse future that lives up to the long-term visions, such as holographic communications and avatars, these early milestones with decentralization, adoption of digital assets/NFTs, and immersive devices must be met. This will go a long way to determining the type of demand both consumers and the enterprise will place on networks pushing into the 6G era and computing.

KEY TAKEAWAYS

At a high level, the metaverse needs to be viewed as an organic progression of advancements in technologies, content, services, and workflows to a future that does more to merge the virtual and physical worlds. As part of this progression, there will be a broader 2D to 3D transition, and while 3D is core to the metaverse, this does not mean everyone will be wearing HMDs or spending most of their time in virtual spaces. Rather, the foundation and focus on the metaverse needs to be on the convergence of connectivity, computing, and intelligence across networks, workflows, and user experiences. The six pillars covered in this paper will be built upon this foundation to support key metaverse elements like interoperability, accessibility, and decentralization.

This future will require AI to automate and manage the vastly higher volume of data and information coming from sensors and users. More applications and services will need to operate at or near real time (under 1 ms), necessitating network and computing resources to be distributed and scalable to adapt to the needs of the users and workflows. Smart glasses will act as a catalyst to the buildup of the metaverse by enhancing the value and applicability of digital assets, creating a pervasive screen, and bringing significantly more touchpoints to public spaces.

Work on next-generation technologies like 6G, updated and future protocols (e.g., IPs), and efforts by more targeted metaverse SDOs will be critical to enable future metaverse use cases. This work during the buildup to the metaverse and into the 6G era will be critical to support the longer-term horizon of the metaverse, which could see holographic communications and very localized storage of data/content/information/etc. and applications throughout a highly interconnected network of networks. In many ways, the end goal of a future metaverse (or something like it) is already in place; however, how close we get to this destination and when are still very much in play.

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