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TECHNICAL REPORT

Metaverse: Technologies & Use Cases across verticals

TEC 31258:2026

Working Group: Metaverse and its use cases

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सत्यमेव जयते

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Foreword

As the technical arm of the Department of Telecommunications (DoT), Telecommunication Engineering Centre (TEC) serves as India's national standardization body for telecommunications and is the designated national enquiry point for WTO-TBT in the telecom sector. TEC plays a pivotal role in shaping India's digital transformation by developing national standards and aligning them with global best practices.

TEC has been actively engaged with international standardization bodies such as ITU, oneM2M, 3GPP, ETSI, APT, IEEE, etc and has successfully adopted oneM2M Release 2 and 3 specifications as National Standards. Complementing these efforts, TEC has released numerous Technical Reports in the IoT/M2M domain, covering key verticals like Transport, Agriculture, Power and Health, Smart Cities, as well as horizontal layers such as M2M architecture, communication technologies and security. These reports have contributed to policy formulation and standardization, fostering an inclusive and robust digital ecosystem in the country. TEC also serves as the nodal authority for Mandatory Testing and Certification of Telecommunication Equipment (MTCTE), ensuring compliance with Essential Requirements (ERs) for telecom products.

This Technical Report on Metaverse and its use cases is a part of TEC and IIT Madras joint effort to study emerging technologies that are poised to transform digital ecosystems. The report provides a comprehensive overview of the metaverse concept, its enabling technologies, architectural frameworks and sector-specific applications. It highlights the integration of virtual and physical worlds through digital twins, the role of IoT and ICT infrastructure and the

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importance of trust, safety, security and privacy in immersive environments. The report further elaborates metaverse as a transformative digital ecosystem whose realization depends on harmonized standards, interoperable frameworks and robust ICT infrastructure. The report also compiles diverse use cases across education, healthcare, entertainment, tourism, real estate and industrial applications, reflecting the potential of metaverse to reshape social, economic and cultural interactions.

I extend my appreciation to all the members of the Working Group, whose insights and domain expertise have enriched the quality of this Technical Report. I am confident that this document will prove valuable in shaping informed policy decisions, driving industry-led innovation and fostering collaborative actions, by serving as a good reference for stakeholders across industry, academia, government and encouraging alignment with global best practices for the development of secure, inclusive and scalable metaverse ecosystem in India.

(Syed Tausif Abbas)

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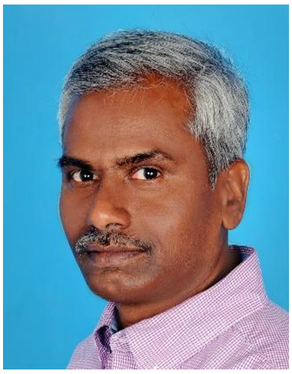

Foreword

The rapidly evolving metaverse, considered as 3D Internet, promises to reshape how people live, work, learn and transact. What began as a convergence of immersive graphics, networking and interactive platforms has matured into a complex ecosystem that spans telecommunications infrastructure, edge and cloud computing, artificial intelligence, spatial computing, digital identity and new economic models. For policymakers, technologists and industry leaders, understanding both the capabilities and the societal implications of the metaverse has become indispensable.

This technical report, produced jointly by the Telecommunications Engineering Centre (TEC), Department of Telecommunications (DoT), and the eXperiential Technology Innovation Centre (XTIC), Indian Institute of Technology Madras, brings together preliminary technical analysis, practical use-case studies and policy-relevant recommendations. It reflects a timely and collaborative effort to map the technical contours of the metaverse and to evaluate pathways for its responsible deployment in India's unique socio-technical landscape.

The report achieves four essential goals. First, it clarifies the core terminologies and technologies that enable immersive virtual environments, highlighting requirements for network latency, bandwidth, edge compute, security and interoperability. Second, it presents a curated set of use cases spanning education, healthcare, manufacturing, public services and cultural preservation, each with technical considerations, value propositions, and adoption challenges grounded in empirical and pilot findings. Third, it identifies regulatory, standards and governance considerations that will influence the metaverse's trajectory, including data protection, digital identity, platform openness and equitable access. Fourth, it compiles several diverse metaverse initiatives by different groups and individuals in India.

India stands at an inflection point. With a vast and diverse population, a rapidly expanding digital infrastructure and deep human capital in engineering and software, the country can both adopt and shape metaverse technologies in ways that reflect local needs and values. Realizing this potential will require concerted action across government, academia, industry and civil society—coordinated investments in network and compute infrastructure, clear standards to ensure interoperability and safety, incentives for responsible innovation and programs to develop skills and digital literacy at scale.

While India is focusing on the current AI missions, this document is to set the background for the next wave to come - XR Wave. This document is to prepare the Indian youngsters to face the upcoming bigger wave, but make sure that this time we do not miss the boat - contributions to the foundations of metaverse. The analyses and recommendations presented here should help decision-makers craft policies that promote innovation while safeguarding public interest. I encourage stakeholders across sectors to engage with this work, use it as a foundation for pilot projects and standards development and continue the interdisciplinary dialogue necessary to guide the metaverse's evolution for inclusive and sustainable benefit.

(Prof. M. Manivannan)

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Executive Summary

The concept of metaverse is emerging as a highly interconnected digital ecosystem integrating virtual worlds, digital twins, immersive communication technologies, Internet of Things (IoT), Artificial Intelligence (AI), Extended Reality (XR), cloud computing and other emerging technologies. The convergence of these technologies is enabling persistent and interactive environments where users, devices, digital assets and services can interact seamlessly across physical and virtual worlds.

This technical report provides a comprehensive overview of metaverse, its enabling technologies, architectural frameworks, communication requirements, performance evaluation metrics, etc. The report elaborates the integration of virtual and physical worlds through digital twins and highlights the critical role of telecom, ICT and IoT infrastructure in supporting immersive and real-time metaverse services.

The report discusses the ITU's reference model for metaverse systems based on digital twin integration, including Systems Integration Functions and Digital Twin Integration functions. These functions support interoperability, synchronization, data acquisition, service integration and collaboration between metaverse systems, digital twin systems and external third-party platforms. The report also highlights the importance of interoperability frameworks, standardized interfaces, identity management and secure service orchestration for enabling scalable metaverse ecosystems.

The report further examines the role of IoT systems, including IoT platform, in enabling real-time sensing, monitoring and synchronization between physical and virtual environments. Seamless IoT integration supports digital twin operations, immersive interaction and intelligent service delivery across various metaverse domains.

The report additionally addresses key issues relating to trust, safety, security, digital identity, privacy and data governance within metaverse environments. Challenges associated with digital identity, interoperability, cybersecurity, network reliability and trusted data management are discussed as paramount important considerations for the development of secure and trustworthy metaverse ecosystems.

To demonstrate practical applications, the report presents use cases across multiple sectors including manufacturing, industrial training, tourism, gaming, e-commerce, entertainment, cultural heritage, virtual museums etc. These use cases illustrate how metaverse technologies can enhance collaboration, learning, service delivery, operational efficiency and user experiences.

The report concludes that realizing the full potential of metaverse requires harmonized standards, interoperable frameworks and collaborative participation among stakeholders including telecom operators, ICT providers, IoT ecosystem participants, standards organizations, industry innovators and governments. As the evolution of metaverse technologies and services accelerates, it will continue to drive the need for scalable communication systems, intelligent infrastructure and

standardized architectures capable of supporting immersive, inclusive and sustainable digital environments.

The Working Group (WG) on 'Metaverse and its use cases' was constituted in TEC as a joint initiative of TEC and XTIC, IIT Madras. The WG comprised of diverse range of stakeholders including industry experts, academic institutions, start-ups and related members, with the following Terms of Reference (ToR):

1. To study metaverse and its related technologies.
2. To study the architecture / framework of metaverse.
3. To study and compile diverse use cases of metaverse that can be deployed in various sectors.
4. To consult all the stakeholders to envisage requirements of telecom/ ICT/ IoT in metaverse and its use cases.
5. To study national and international best practices, benchmarks, policies/ case studies, standards/ specifications being adopted for metaverse and its use cases.
6. To study security, privacy and trust related aspects within metaverse.
7. To study various challenges including ethical issues in metaverse environment.

1. Introduction

The term metaverse has gained significant attention in recent years due to the advancements in technologies such as Artificial Intelligence, Blockchain and Internet of Things (IoT). Metaverse is a shared, immersive and interactive virtual reality that has the potential to transform various sectors such as education, healthcare, entertainment, commerce etc. Countries with large youth population and growing technology landscape, are well positioned to leverage metaverse for its growth and development.

With the advancements in Virtual Reality (VR) and Augmented Reality (AR), new computer-generated world has emerged. These immersive environments, often in three dimensions, can be accessed through various devices such as VR and AR headsets, smart glasses, smartphones and computers. Users, represented by 3D avatars, can engage in a variety of activities that mimic either the real world or a fictional one. Although the concept of a virtual world has been around for decades, recent years have seen a surge in interest from companies, investors and researchers.

As per ITU-T Recommendation Y.4238[1], "metaverse is a collective virtual environment where physical and virtual worlds converge, that enables users to interact with shared digital spaces, objects and services". A metaverse can be virtual, augmented, representative of or associated with the physical world.

1.1. Evolution of metaverse

The idea of metaverse traces back to Neal Stephenson's 1992 novel "Snow Crash," where it was envisioned as a virtual reality space populated by avatars. Table 1 shows a rough timeline of the key milestones in the development of metaverse.

Table 1: Timeline of the development of metaverse[2]

Year	Milestones	Sector
1992	Neal Stephenson coins the term "Metaverse" in his novel, Snow crash.	Science fiction
1998	Introduction of B-money, which was intended to be an anonymous, distributed electronic cash system.	Underlying technology
2002	The concept of digital twin was first introduced and was envisioned for use to improve the design, operation and maintenance of complex systems.	Underlying technology
2003	Linden Lab launched Second Life, an online virtual world that allows users to create their own avatars and interact with others	Game

[1] https://www.itu.int/ITU-T/recommendations/rec.aspx?id=16509
[2] https://www.itu.int/dms_pub/itu-t/opb/fg/T-FG-MV-2023-PDF-E.pdf

2006	Roblox, an online game platform, was launched. Players can customize their avatars, buy and sell virtual items and interact with others.	Game
2007	Sandbox game starts taking shape for open world, free form games.	Game
2009	Blockchain technology was first introduced as the underlying technology for the cryptocurrency Bitcoin.	Underlying technology
	Minecraft, a voxel based virtual world game platform, infused community gaming.	Game
2011	Publication of the futuristic novel Ready player one	Science fiction
2014	Facebook acquires Oculus VR, a company that develops VR headsets.	Underlying technology
2015	Decentral and, a virtual world platform built on blockchain technology, was launched.	Game
2016	The concept of decentralized autonomous organization emerged. It is a type of organization running through smart contracts.	Underlying technology
	Pokémon Go by Niantic launched, brought the concept of augmenting the digital assets on the real-world.	Game
2017	Fortnite, multiple player game in virtual world, community gaming	Game
2018	Cline's work Ready player one is adapted into a film, which popularizes the concept of the OASIS(Metaverse).	Science fiction
	Niantic introduced Real World Platform, Lightship aiming to map the real world and build real-world metaverse	Industry
2019	Google Maps came with Augmented Reality View.	Industry
2020	The COVID-19 pandemic accelerates interest in virtual events and remote work, leading to increased investment in metaverse.	Industry interest
	NVIDIA launches Omniverse, a platform for industrial metaverse applications.	Industry interest
2021	Major tech companies announce plans to invest in and develop metaverse technologies. Facebook rebrands its parent company as Meta, launch Horizon Worlds. Microsoft also launches Mesh as a Metaverse platform service, as social collaboration platform.	Industry interest
	Seoul releases its 5-year metaverse plan. Barbados announces its plan for a metaverse embassy.	Government
2022	Dubai launches its metaverse strategy. European Commission's plans on thriving in metaverse. Shanghai's action plan on metaverse. Tuvalu plans to replicate itself in metaverse.	Government

	NVIDIA collaborates with Siemens to enable the industrial Metaverse.	Industry
	Samsung opened a Virtual Flagship Storefront in Decentraland	Industry interest
2023	Several UN agencies delve into research and pilot projects of metaverse. ITU establishes a new FG on metaverse.	United Nations
	Apple Vision Pro launched as spatial computing device to bring real and virtual world together	Industry
2024	52 deliverables of Focus Group on Metaverse were released. 1st UN Virtual Worlds Day	United Nations
2025	Digital Dubai, ITU & UNICC Launch UN Citiverse Challenge and Unveil Bold Vision for AI-Powered Virtual Worlds 2nd UN Virtual Worlds Day and 1st Citiverse Assembly	United Nations
2026	3rd UN Virtual Worlds Day and 2nd Citiverse Assembly	United Nations

1.2. Key Characteristics of metaverse

Metaverse can be understood as a dynamic fusion of digital and physical realities and following are its key characteristics that form the foundation of this evolving ecosystem, shaping how people interact, work, play and create in interconnected spaces:

- **Virtual worlds (or immersive):** encompass a range of computer-generated environments from immersive 3D spaces to text-based realms, serving diverse purposes beyond mere entertainment such as education and urban planning, reflecting their growing importance and versatility in various applications.
- **3D (or inter-dimensional):** represents a shift from traditional 2D interfaces to immersive, interactive 3D spaces that better reflect human experiences and interactions, significantly influencing how we engage with digital content and potentially transforming sectors like education through more dynamic and engaging online experiences.
- **Real-time rendering:** crucial for interactive virtual environments, it allows a virtual world to respond dynamically to user inputs by continuously generating visuals at high speeds.
- **Interoperability:** allows users to seamlessly transfer identity and content like avatars and items across different platforms.
- **Scalability:** Metaverse, akin to the Internet, necessitates a massive scale with countless virtual worlds to truly embody its concept, surpassing the limited scope of a digital theme park with few attractions.
- **Persistence:** extends the complexity of managing data and computational resources but enriches the user experience by making virtual interactions more meaningful and realistic.

- **Synchronicity:** crucial for shared experiences in metaverse, requiring high bandwidth, low latency and continuous internet connections. It is necessary to manage data efficiently and reduce latency, ensuring that users can interact seamlessly in these immersive environments.
- **Unlimited users & individual presence:** Metaverse supports multiple and concurrent users in functionality and quality.

In addition, metaverse is a unique and dynamic environment that offers new possibilities for social interaction, entertainment and commerce. Its immersive and interactive nature, combined with its decentralized and collaborative infrastructure, make it a potentially transformative technology that could reshape interaction with the digital world.

- **Decentralized:** Metaverse is built on decentralized technology such as blockchain, that allows for a decentralized infrastructure for identity management, ownership, authority, consent, access and control that is resistant to censorship and manipulation. This enables users to have greater control over their digital identity and virtual assets.
- **Collaborative:** Metaverse is a collaborative environment, where users can work together to create and develop virtual content and experiences. This can range from building virtual real estate to creating new games or virtual art.
- **Virtual Economy:** Metaverse has its own virtual economy, where users can buy, sell and trade virtual goods and services. These transactions are often conducted using virtual currencies and are secured through decentralized infrastructure technology.
- **Social:** Metaverse is a social environment, where users can connect with each other and form communities around shared interests. This can include socializing, gaming, or participating in virtual events and activities.
- **Contribution-based:** Metaverse is an open-ended environment, where users have the freedom to create and explore in whatever way they choose. This level of creative freedom allows for endless possibilities and innovation.

1.3. Metaverse Ecosystem and Stakeholders

Metaverse can be broken down into five components: infrastructure, human augmentation, digital identity, economic enablers and ecosystem. Consumers can seamlessly explore both virtual and physical worlds in metaverse, along with various software and hardware platforms and human interface technologies. With the support of digital identity and decentralized technologies, metaverse is increasingly offering immersive experiences that significantly impact economic and social aspects, thereby continuously evolving and nurturing its ecosystem.

- **Ecosystem:** Economic, environmental, social and cultural perspectives.
- **Economic enablers:** Decentralized financial system, blockchain, cryptocurrency, NFT, commerce, advertising, payment and transactions.
- **Digital identity:** Digital identity, avatar, agent, multiuser and multitasking.
- **Human argumentation:** Mobile devices, headsets (VR), smart glasses (AR), other wearables, haptics, holographic; creation platform, interaction platform, content moderation platform, 3D design/modelling, game engines, AI/ML services, creator tools, search/visual search; asset, 3D interoperable assets, asset market.
- **Infrastructure:** Networks/connectivity, computing power, graphic processing units, storage capacity, sensing/perception, cloud/edge infrastructure, semiconductor (chips/processors).

Metaverse is a complex network of interconnected stakeholders who collaborate to create a persistent, immersive virtual world. These stakeholders include service providers, platform providers, content creators, users, digital asset providers, payment managers, advertisers and other third-party developers.

Following are the stakeholders of metaverse

i. **Service provider (SP):** Service providers provide the applications and services for metaverse. They create and operate metaverse services and applications that users would prefer. Following are various roles of service providers in metaverse ecosystem
  - **Providing infrastructure:** Service providers provide the underlying infrastructure that supports metaverse such as the networks, data centers and security systems.
  - **Providing financial services:** Service providers offer financial services that are needed to support metaverse economy such as payments, lending and insurance.
  - **Providing content:** Service providers offer content that users experience in various metaverse services and applications. In addition, service providers add or merge new contents as per user's preference in their services and applications.
  - **Enabling access to metaverse:** Service providers develop and manufacture the hardware and software that users need to access metaverse, such as VR headsets, AR glasses and software platforms. In addition, service providers educate and train users on how to use metaverse and its various services and applications.
  - **Providing legal and regulatory framework:** Service providers provide the legal and regulatory framework that is needed to govern metaverse, such as intellectual property laws and privacy regulations.

ii. **Platform provider (PP):** Platform providers provide the technology and infrastructure for metaverse. They create and operate the virtual metaverse platforms with which users interact. The roles of platform providers are as follows:

- **Providing an open platform:** For users to create, experience and interact with virtual worlds, platform providers offer the infrastructure and tools that users need to create their own content, as well as the space for users to interact with each other and with the virtual world.
- **Enabling user-generated contents:** Platform providers allow users to create and share their own content, such as experiences and avatars. This helps to make metaverse a more dynamic and engaging place.
- **Providing marketing infrastructure:** Platform providers offer the infrastructure for users to make payments and transactions with rules for the creation and exchange of virtual goods and services.
- **Enforcing security and privacy measures:** Platform providers protect user data and ensure that they are safe from fraud and other malicious activity.
- **Promoting interoperability:** Platform providers ensure that different platforms can communicate with each other and that users can move their data and assets freely between different platforms.

iii. **Content creator (CC):** Content creators are individuals or organizations that create and develop the virtual content and experiences that users can engage in metaverse. These can include anything from virtual real estate and gaming experiences to virtual fashion and art. The roles of content creators are as followings:

- **Creating and developing new content:** Content creators are constantly coming up with new ideas for content that will engage users in metaverse.
- **Providing instructions on using content:** Content creators can educate users about effective use of metaverse. This will help to make metaverse more accessible to users.
- **Promoting their content:** Content creators need to find ways to get their content in front of users. This could involve using social media, creating trailers or demos, or attending industry events.
- **Collaborating with other content creators:** Content creators often collaborate with each other to create even more engaging experiences. This could involve working together on events or social spaces.

iv. **Users:** Users are the individuals who participate in metaverse, either as casual users or as active participants in various metaverse activities such as socializing, gaming or consuming content. The roles of users are as followings:

- **Experiencing metaverse:** Users experience metaverse and they are able to interact with each other, customize content and explore virtual worlds.
- **Contributing to metaverse:** Users are able to contribute to metaverse by providing feedback for its development.
- **Influencing metaverse:** Users are able to influence metaverse by their actions and interactions to shape the future of metaverse.

v. **Digital asset provider (DAP):** These are the companies and organizations that provide virtual assets such as virtual currency, virtual real estate and virtual goods. They play a crucial role in facilitating the growth of virtual economies and enabling users to monetize their content and creations. The roles of digital asset providers are as followings:

- **Creating digital assets:** Digital asset providers create digital assets, such as NFTs, virtual land and in-service items. These assets can be used to create virtual worlds, customize avatars and participate in services and applications.
- **Trading digital assets:** Digital asset providers buy or sell digital assets to users. This can be done through virtual markets or other means.
- **Managing digital assets:** Digital asset providers manage digital assets on behalf of users. This can include storing assets, tracking ownership and resolving disputes.
- **Providing liquidity:** Digital asset providers offer liquidity to the market for digital assets. This means that they make it easy for users to buy and sell digital assets.
- **Ensuring security and safety:** Digital asset providers need to ensure that their platforms are secure and safe for users. This means protecting users' data, preventing fraud and other malicious activity.

vi. **Payment manager (PM):** These are the economic systems that exist within metaverse, in which virtual goods and services can be bought, sold and traded by payment managers. Virtual markets are often built on blockchain technology to ensure transparency and security. The roles of payment managers are as followings:

- **Providing a secure and reliable payment system:** Payment managers need to provide a secure and reliable payment system that protects users' financial information.

- **Making payments easy and convenient:** Payment managers need to make payments easy and convenient for users. This means supporting a variety of payment methods and making it easy for users to find the payment method that best suits their needs.
- **Enabling cross-platform payments:** Payment managers need to enable cross-platform payments so that users can make payments between different metaverse platforms.
- **Providing and adhering to regulations:** Payment managers need to provide and adhere to all applicable regulations, such as those related to anti-money laundering and fraud prevention.

vii. **Advertiser:** Advertisers play a role in metaverse economy by helping to generate revenue for businesses and create new opportunities for marketing. The roles of advertisers are as followings:

- **Reaching new customers:** Advertisers can reach new customers who are not typically reached through traditional advertising channels. For example, they can target users who are interested in specific products or services.
- **Growing brands:** Advertisers can create immersive and interactive experiences that help to grow their brands. For example, they can create virtual stores, events, or games that allow users to interact with their brands in a new way.
- **Building relationships:** Advertisers can build relationships with their customers. For example, they can host virtual events, provide customer support or simply interact with users in a friendly and engaging way.
- **Generating leads:** Advertisers can generate leads for their businesses. For example, they can collect contact information from users who are interested in their products or services.
- **Collaborating with other businesses:** Advertisers can collaborate with other businesses to create more engaging and effective advertising campaigns. This can help to reach a wider audience and achieve their marketing goals.

viii. **Third party:** Third parties in metaverse are companies that provide services and products that are not directly related to metaverse itself. However, they play an important role in supporting metaverse and making it a more enjoyable and accessible experience for users. Third parties can support the following roles:

- **Supporting legal advice and regulations:** Third parties provide support to ensure that metaverse is a safe and compliant environment for users and businesses. They give legal advice, develop regulations and enforce compliance.

- **Supporting financial services:** Third parties support the facilitation of financial transactions in metaverse. They can provide payment processing, lending and other financial services.
- **Supporting technology:** Third parties develop and maintain the underlying technology that powers metaverse. They provide hardware, software and networking infrastructure.
- **Supporting the other services:** There are many other types of third parties in metaverse that provide services; these include marketing agencies, advertising platforms and security providers.

1.4. Relationship with Enabling Technologies

Metaverse is a vast and interconnected digital universe, which relies on a range of technologies to function effectively and offer immersive experiences. Each technology plays a unique role in creating, maintaining and enhancing this complex virtual environment. Some of the key technologies as shown in figure 1 have been elaborated below –

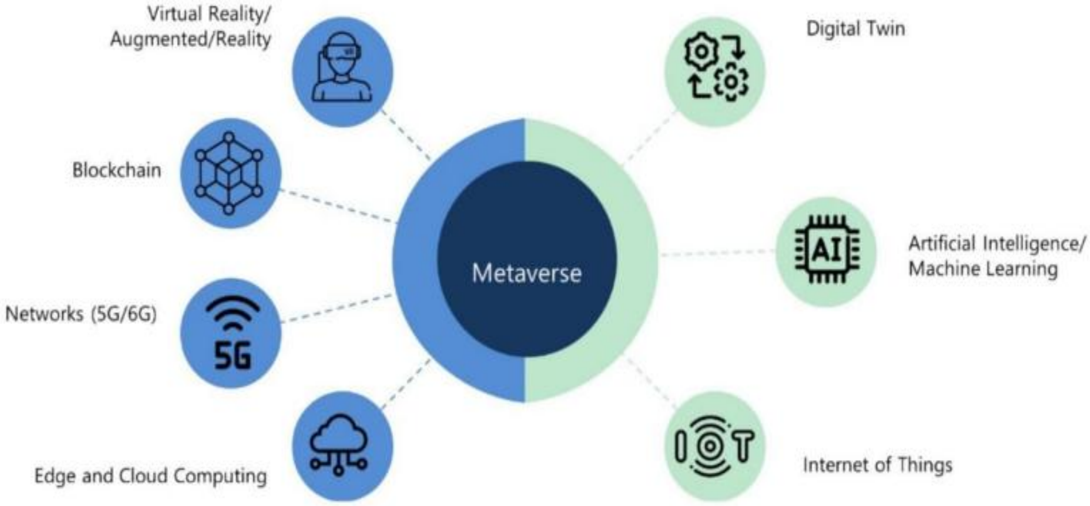

Figure 1: Key technologies of metaverse
[Source: ITU-T FGMV-37] [3]

1.4.1 Virtual Reality (VR)

VR creates a fully immersive digital environment that users can interact with using specialized hardware such as VR headsets and motion controllers. In Metaverse, VR allows users to enter into the virtual worlds where they can engage in activities like gaming, socializing and attending virtual

[3] https://www.itu.int/en/ITU-T/focusgroups/mv/Documents/List%20of%20FG-MV%20deliverables/FGMV-37.pdf

events. The immersive nature of VR provides a sense of presence, making users feel as though they are physically present in the virtual space.

1.4.2 Augmented Reality (AR)

AR overlays digital information onto the real world, enhancing the user's perception of their environment. This is typically achieved through devices like smartphones, tablets or AR glasses. In metaverse, AR can be used to blend digital and physical worlds, allowing users to interact with virtual objects in their real-world surroundings. Applications of AR in metaverse include navigation, education, interactive marketing etc.

1.4.3 Mixed Reality (MR)

MR combines the elements of both VR and AR, allowing digital and physical objects to coexist and interact in real-time. This technology uses advanced sensors and spatial mapping to create a seamless integration of virtual and real-world elements. In metaverse, MR can be used for collaborative work environments, training simulations and interactive entertainment, providing a more dynamic and engaging user experience.

1.4.4 Extended Reality (XR)

XR is an umbrella term that encompasses VR, AR and MR as depicted in figure 2 below. These technologies are pivotal in creating immersive and interactive experiences within metaverse.

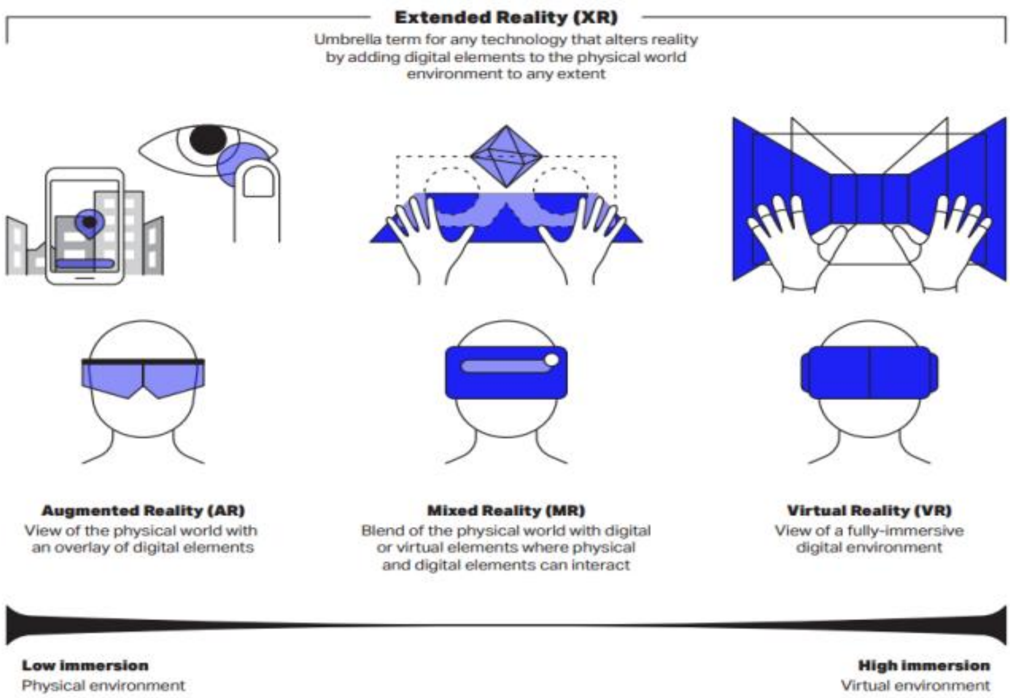

Figure 2: Distinction between AR, VR, MR and XR[4]

However, extending reality is no longer limited to native XR devices alone. WebXR is making immersive experiences increasingly interoperable, enabling users to access them across a wide range of devices—from smartphones and tablets to advanced head-mounted displays. At the same time, emerging technologies such as volumetric and glasses-free 3D displays allow immersive content to be experienced without the need for head-worn devices.

The ecosystem continues to expand with innovations such as heads-up displays, automotive windshield projections, smart mirrors and peripherals including smart gloves and haptic suits, all of which are enhancing the richness and realism of metaverse experiences. Entertainment venues are also pushing immersion beyond traditional 3D experiences. Motion-enabled roller coasters, physically moving seats synchronized with virtual environments and location-based VR attractions that combine real-world movement with digital content are creating unprecedented levels of presence and engagement.

[4] https://www.mctd.ac.uk/wp-content/uploads/2023/07/MCTD-SecuringTheMetaverse-Report-WEB-1.pdf

1.4.5 Spatial Reality (SR)

Spatial reality describes 3D and depth perception used in XR, robotics navigation and spatial audio to create more immersive, intuitive interactions. It also improves mapping, urban planning and experiential learning through 3D models and mixed-reality demonstrations.

1.4.6 Spatial Computing (SC)

Spatial computing is a technology that merges the physical and digital 3D worlds, allowing computers to understand and interact with 3D space.

1.4.7 Internet of Things (IoT)

ITU in its recommendation ITU-T Y.4000, has defined IoT as "a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies". The integration of IoT into metaverse enhances its interactivity and realism by bridging the physical and virtual worlds. IoT devices, such as sensors and wearables collect and transmit real-time data, which can be used to enrich virtual experiences. For example, IoT sensors can monitor environmental conditions in real life and replicate these conditions in virtual spaces, creating more immersive and responsive metaverse environments.

IoT enhances interactivity by tracking physical actions and biometric data, allowing these real-world movements to be translated into the virtual space, thus making interactions more responsive.

1.4.8 Artificial Intelligence (AI)

AI is a crucial technology for the development and operation of metaverse, providing the computational power and intelligence needed to create immersive and interactive virtual environments. Key aspects of AI in the context of metaverse includes:

i. AI enables more natural and intuitive interactions within metaverse. Through technologies like Natural Language Processing (NLP) and Machine Learning (ML), AI can understand and respond to user inputs, whether they are text, voice or gestures. This allows for more engaging and personalized experiences.
ii. AI-powered spatial computing bridges the gap between the physical and virtual worlds by continuously understanding real-world environments and user interactions. Through intelligent obstacle detection, scene awareness and environmental understanding, it enhances both the safety and realism of metaverse experiences. Beyond real-time interaction, users can record, pause, replay and simulate real-world scenarios, unlocking new possibilities for immersive learning, training, collaboration and digital twin experiences
iii. AI powers autonomous agents and avatars that can interact with users in metaverse. These virtual entities can perform a wide range of tasks, from providing customer support to

participating in virtual events. AI-driven avatars can also learn and adapt over time, improving their interactions and making them more lifelike.

iv. AI plays a significant role in the creation and management of content within metaverse. Generative AI/Large Language Models (LLMs) can create realistic virtual environments, characters and objects, reducing the time and efforts required for manual content creation.

v. AI-driven predictive analytics can analyze user data to anticipate needs and preferences, providing personalized recommendations and experiences. This can enhance user engagement and satisfaction by delivering content and services that are customized to individual users.

vi. AI can enhance security and privacy within metaverse by detecting and mitigating threats in real-time. ML algorithms can identify suspicious activities and potential security breaches, ensuring that user data and interactions are protected.

1.4.9 Cloud Computing

Cloud Computing is a critical technology for metaverse, providing the necessary infrastructure to support the vast amounts of data and computational power required for immersive virtual environments. Cloud Computing provides the following key features:

i. Scalability: Cloud platforms can dynamically allocate computing power, storage and bandwidth to ensure smooth and uninterrupted experiences for users in metaverse, as number of users in virtual environments can vary significantly.

ii. High-Performance Computing: Metaverse requires significant computational power to render complex 3D graphics, process real-time interactions and manage large-scale simulations. Cloud computing provides access to high-performance computing (HPC) resources, enabling metaverse platforms to handle these intensive tasks efficiently. This ensures that users can experience high-quality graphics and seamless interactions.

iii. Data Storage and Management: Metaverse generates and relies on vast amounts of data, including user interactions, virtual assets and environmental details. Cloud computing offers robust data storage solutions that can securely store and manage this data.

iv. Edge Computing: Edge computing reduces latency by minimizing the distance data needs to travel between the user and the server. In metaverse, edge computing is crucial for real-time applications, such as VR and AR, where low latency is essential for a smooth and immersive experience.

v. Live Streaming Experience: Advances in 3D streaming and shared spatial environments enable people to meet, collaborate and interact in real time as if they were physically together, creating highly immersive and engaging virtual experiences

vi. Cloud Rending: Cloud rendering offloads the computational burden from Metaverse devices to powerful cloud infrastructure, allowing for more complex and realistic experiences. By leveraging cloud resources, metaverse content can be rendered remotely and streamed to the devices in real time. This enables the delivery of high-quality, immersive content that would be otherwise difficult to achieve on the device.

vii. Cloud Spatial Anchors: Cloud Anchors are a fundamental component for enabling shared real-world metaverse experiences, allow these identified feature points for various metaverse assets to be securely stored and shared. Geospatial APIs further have the potential to take the open AR experience to the next level in metaverse.

1.4.10 Decentralization and the Role of Blockchain

Metaverse needs to be open, interoperable and accessible to everyone. A decentralized metaverse has gained significant traction to avoid central ownership or control.

Blockchain technology become essential element in the development and operation of the decentralized metaverse, providing a secure and transparent framework for transactions and digital asset management. Several key aspects of blockchain technology in the context of metaverse includes:

i. Distributed ledger technology such as blockchain enables decentralization, which is crucial for metaverse. This decentralization enhances security and trust, as transactions and data are verified by multiple nodes, making it difficult for malicious actors to alter or manipulate information.

ii. Focuses on empowering users by giving them control over their data. It emphasizes user consent, data protection and privacy, ensuring that individuals have the authority to decide how their information is shared and used within the digital ecosystem. Promotes collaborative governance involving multiple
stakeholders in decision-making processes.

iii. Blockchain is used to create and manage digital assets, such as virtual real estate, nonfungible tokens (NFTs) and in-game items and ensures that these assets are unique, verifiable and transferable. This is particularly important for establishing ownership and enabling secure transactions within metaverse.

iv. Smart contracts which run on blockchain networks can facilitate a wide range of transactions, from virtual property sales to service agreements, without the need for intermediaries.

v. Blockchain provides a transparent and immutable ledger of all transactions and activities within metaverse, which helps in preventing fraud and ensuring accountability.

1.4.11 Digital Twins

Digital twins are virtual replicas of physical objects, systems, or processes that can be used for real-time monitoring, simulation and optimization. In metaverse, digital twins enable creation of accurate and dynamic representations of real-world entities, facilitating seamless interaction between the virtual and physical worlds. Digital twins have a wide range of applications in metaverse, including Real-Time Monitoring of status and performance of physical assets, enabling proactive maintenance and optimization. Figure 3 describes the concept of the digital twin-based integration between virtual and physical worlds in metaverse.

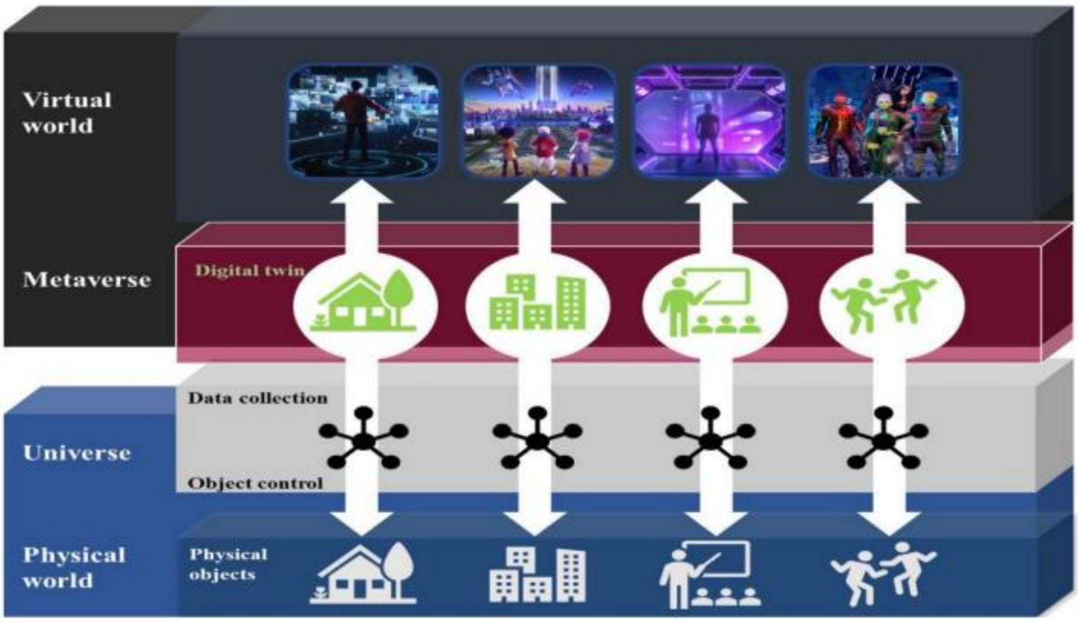

Figure 3: Concept of the digital twin-based integration between virtual and physical worlds

[Source: ITU-T FGMV-28] [5]

1.4.12 Cellular Connectivity (5G & beyond)

In the 5G era, there are three usage scenarios identified based on the user demands namely, the enhanced mobile broadband (eMBB), massive machine-type communications (mMTC) and ultra-reliable and low latency communications (URLLC). 5G networks offer following features crucial for creating seamless and immersive virtual experiences:

i. High-Speed Connectivity: 5G networks offer significantly higher data transfer rates compared to previous generations. This high-speed connectivity is essential for transmitting large volumes of data required for detailed and interactive virtual environments.

[5] https://www.itu.int/en/ITU-T/focusgroups/mv/Documents/List%20of%20FG-MV%20deliverables/FGMV-28.pdf

ii. Low Latency: One of the most critical features of 5G is its low latency, often less than 1 millisecond. Low latency is essential for real-time applications in metaverse, such as multiplayer gaming, virtual meetings and remote surgeries. It ensures that actions and responses occur almost instantaneously, providing a more natural and immersive experience.

iii. Enhanced Capacity of Connected Devices: 5G networks can support a much higher number of connected devices simultaneously. This is particularly important in metaverse, where numerous users and devices interact within the same virtual space. Enhanced capacity ensures that the network can handle the increased demand without degradation in performance.

iv. Network Slicing: 5G technology allows for network slicing, which means creating multiple virtual networks within a single network. Each slice can be optimized for different types of services or applications. For example, one slice can be dedicated to high-bandwidth applications like VR, while another can be optimized for low-latency applications like real-time gaming. This flexibility ensures that the specific needs of different metaverse applications are met efficiently.

The three usage scenarios of 5G i.e. eMBB, mMTC and URLLC are further enhanced to immersive communication, massive communication and hyper reliable & low-latency communication respectively in 6G. Beyond these, three non-communication usage scenarios, namely, ubiquitous connectivity, integrated sensing and communication (ISAC) as well as artificial intelligence and communication envisaged in 6G. Therefore, 6G will offer enhanced overall user experience in metaverse. In addition, emerging technologies such as quantum-enabled networking and LiFi (Light Fidelity) have the potential to significantly enhance connectivity for immersive experiences.

1.4.13 Brain-Computer Interfaces (BCIs)

Brain-Computer Interfaces (BCIs) are a groundbreaking technology that can enable direct communication between the brain and external devices. This technology has significant implications for metaverse, enhancing user interaction and immersion. BCIs are systems that detect and interpret brain signals, allowing users to control computers or other devices directly with their thoughts. This is achieved through sensors that capture electrical activity in the brain, which is then processed and translated into commands. BCIs can be non-invasive, using external sensors like EEG (electroencephalography) caps, or invasive, involving implants that connect directly to brain tissue. BCIs can revolutionize Metaverse by providing more intuitive and immersive ways for users to interact with virtual environments. BCIs for metaverse can be promising but currently it is still in an early-to-intermediate stage of deployment.

1.5. Relationship with Sustainable Development Goals

The Sustainable Development Goals (SDGs) are most relevant to metaverse use cases. The SDGs give a policy and ethics lens for discussing metaverse use cases, helping show not just what the technology can do, but whether it advances inclusive and sustainable outcomes.

The relevant use cases include SDG 4 (Quality Education), SDG 3 (Good Health and Well-Being), SDG 9 (Industry, Innovation and Infrastructure), SDG 10 (Reduced Inequalities), SDG 11 (Sustainable Cities and Communities) and SDG 17 (Partnerships for the Goals), because immersive virtual environments can expand access to learning, healthcare training, collaboration and inclusive participation across distance and physical limitations. At the same time, metaverse adoption should be guided by SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action) and SDG 16 (Peace, Justice and Strong Institutions) to address energy use, data privacy, safety and ethical governance so that digital innovation supports, rather than undermines, sustainable development.

2. IoT platform for metaverse applications

In metaverse, integrating a wide array of IoT devices, each operating on different protocols, into a unified system presents a complex challenge. An IoT platform for metaverse addresses this challenge by utilizing standardized interfaces and protocols, ensuring smooth connectivity across diverse devices. It also streamlines the management and coordination of these devices, enabling efficient data flow and consistent behaviour within the virtual environment.

The IoT platform for metaverse applications offers users a persistent and immersive interactive experience by enabling seamless transitions between the physical and virtual worlds. The IoT platform collects data from the physical environment and transforms it into virtual representations, thereby facilitating a coherent integration of both environments. This platform also supports real-time monitoring of physical-space conditions and layouts within the virtual space.

Furthermore, the platform maps physical IoT devices into the virtual world, allowing users to remotely manage and control these devices through virtual interfaces. A conceptual diagram for the IoT platform is provided in Figure 4 below:

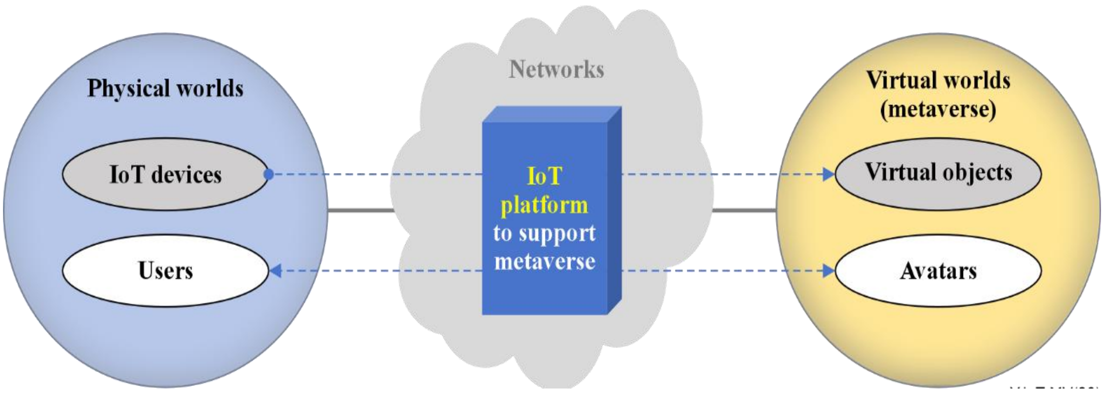

Figure 4: Concepts of IoT platform for metaverse applications

[Source: ITU-T Y.4515]

2.1. Object linking in virtual things and physical things in metaverse

Metaverse is a collective virtual environment where physical and virtual worlds converge, that enables users to interact with shared digital spaces, objects and services. Metaverse can be categorized into the following three types by virtual object features.

i. **No-linked object metaverse (NL-MV):** In this type, the virtual world in metaverse consists of virtual objects in metaverse that do not link to the physical objects directly. To offer immersive experiences to users, the virtual objects in metaverse may be mapped to the physical objects in the world conceptually. However, in this type, the change of physical objects will not be reflected to virtual objects in metaverse and vice versa.

ii. **One-way (uni-directional) linked object metaverse (L1-MV):** In this type, the virtual objects in metaverse are linked to their physical objects directly, but the connection is uni-directional - from the physical world to the virtual world. This means that changes in the physical world are reflected in the virtual world, but not vice versa.

iii. **Two-way (bi-directional) linked object metaverse (L2-MV):** In this type, two types of L1-MV are available. In this type, the virtual objects in metaverse can interact with the physical objects in the physical world. The changes in virtual objects are reflected in the change in the physical world and vice versa.

2.2. Functional framework of IoT platform for metaverse applications

According to the IoT reference model in [ITU-T Y.4000] and an implementation view of the IoT functional framework in [ITU-T Y.4401], the functional framework of the IoT platform for metaverse applications is composed of four layers, as well as management capabilities and security capabilities that are associated with the four layers, as shown in figure 6 below. The four layers are: application layer, service support and application support layer, network layer and device layer.

The functional capabilities described in [ITU-T Y.4401] are also necessary to implement the IoT platform for metaverse applications. The entities defined with solid-line boxes are the functional entities specific to the IoT platform for metaverse applications.

The IoT platform includes functionalities for supporting metaverse applications, which are mapped to service support and application support layer functional entities. The functional framework defined here is based on the reference model of IoT with newly defined functional entities, which are designed to meet the functional capabilities of the IoT platform for metaverse applications.

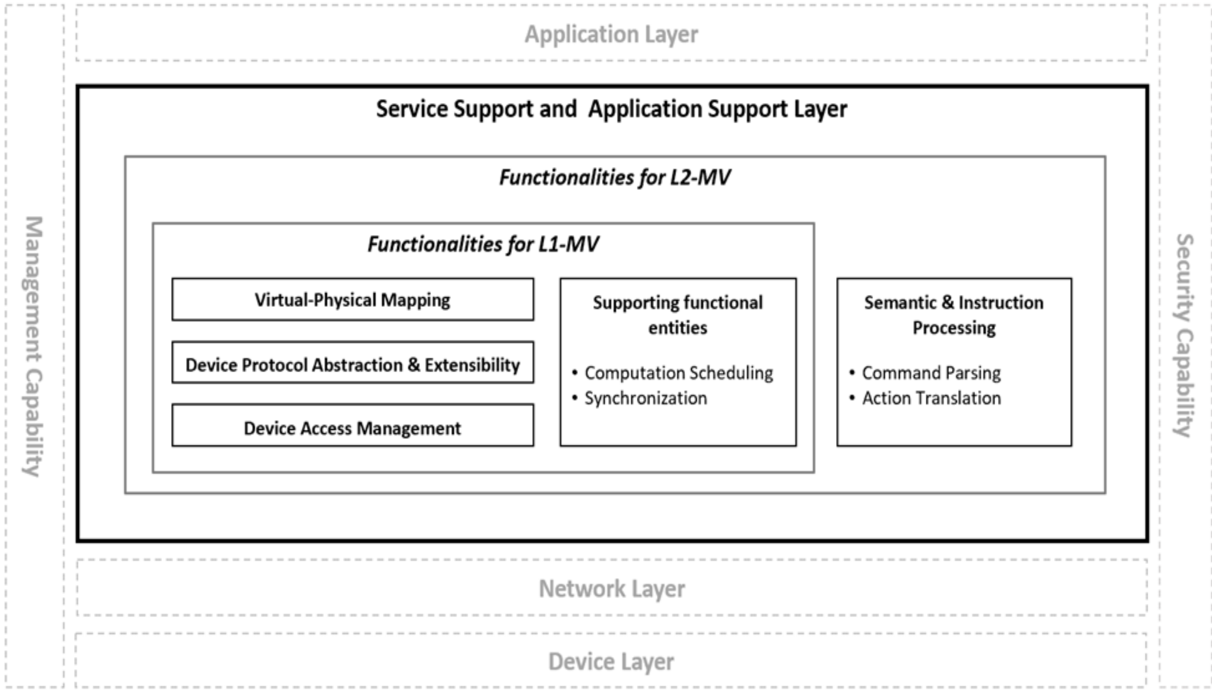

Figure 5: Functional Framework of IoT platform for metaverse applications

[Source: ITU-T Y.4515]

2.3. Functional entities of IoT platform for metaverse applications

The 'Service support and application support layer' consists of one enabling functional entity grouping, namely the IoT platform. The IoT platform contains two main entities: the functionalities for L1-MV and the functionalities for L2-MV, according to the two types of objects linking.

i. **Functionalities for L1-MV:** The functionalities for L1-MV include the following:
   a. **Device access management:** This entity provides functions for registering, authenticating and managing IoT devices connected to the IoT platform. It ensures secure and efficient onboarding, real-time status monitoring and lifecycle management of physical devices.
   b. **Device protocol abstraction and extensibility:** This entity provides functions for delivering a unified interface to support heterogeneous IoT devices. It enables protocol identification, adaptation and dynamic extension to seamlessly integrate new device protocols into the IoT platform.
   c. **Virtual-physical mapping:** This entity provides functions for establishing and maintaining the one-to-one or one-to-many correspondences between physical things and their virtual representations in metaverse. This ensures consistent synchronization of state and behaviour across physical and virtual domains.

d. **Supporting functional entities:** The 'Computation Scheduling' entity provides functions for heterogeneous computing power interconnection, including, but not limited to, computing resources perception, identification, measurement and management. The 'Synchronization' entity provides functions for automatically sensing and tracking timing, location, status information for synchronization between virtual and physical objects.

ii. **Functionalities for L2-MV:** In addition to the functional entities of L1-MV, the functionalities for L2-MV also include 'semantic and instruction processing' to interpret commands or contextual intents from metaverse applications and translates them into actionable tasks by incorporating domain-specific semantics. It has the following two main functional entities:

a. **Command parsing:** The entity provides functions for analyzing and decomposing instructions received from virtual things into structured and executable command sets. It ensures that each instruction is validated, sequenced and prepared for further processing.

b. **Action translation:** The entity provides functions for converting parsed and validated commands into device-specific operations or protocol-compliant messages. It adapts abstract actions to concrete instructions executable by physical devices in real time.

3. Reference Model for Integrating virtual and physical worlds through digital twins in metaverse

Metaverse is a vast virtual space made up of many different virtual worlds, each with its own unique purpose and characteristics. Similar to the way our universe is composed of different planets and countries, metaverse is comprised of different virtual environments, such as homes, towns, classrooms and playgrounds. In these virtual worlds, users create avatars to represent themselves and interact with digital objects and other avatars in various ways. The concept of the integration based on digital twins enabling integration of virtual and physical worlds is shown in figure 3 above in section 1.4.9.

Digital twins serve as a key component for integrating virtual and physical worlds, allowing users to extend their experience beyond the confines of the virtual environment. As digital representations of physical objects, digital twins comprise the virtual worlds. Avatars representing users are an example of digital twins in virtual worlds. For the integration of virtual and physical worlds, the digital twin is an interface between them. For example, as an avatar, the digital twin of a user can mirror the facial expressions captured by the user's equipment. Digital goods are another example of digital twins integrating the worlds. Users can watch digital goods like pictures or clothes. In virtual worlds, users can even dress up their avatars. If a user purchases any digital good in the virtual world, the physical objects corresponding to the digital good will be delivered to the user. The virtual world for engineering can also be integrated with the physical world. Avatars of geographically dispersed engineers may meet together and design a machine using the digital twins of the real component of a product. After finalizing the design, the machine can be built in the physical world according to the design made in the virtual world.

The integration of virtual and physical worlds relies on a reference model[6] that utilizes digital twins as a key enabling component, supporting seamless interaction and interoperability across metaverse ecosystem.

Figure 6 shows a reference model for integrating virtual and physical worlds through digital twins in metaverse as per ITU-T Recommendation Y.4239.

[6] https://www.itu.int/ITU-T/recommendations/rec.aspx?id=16510

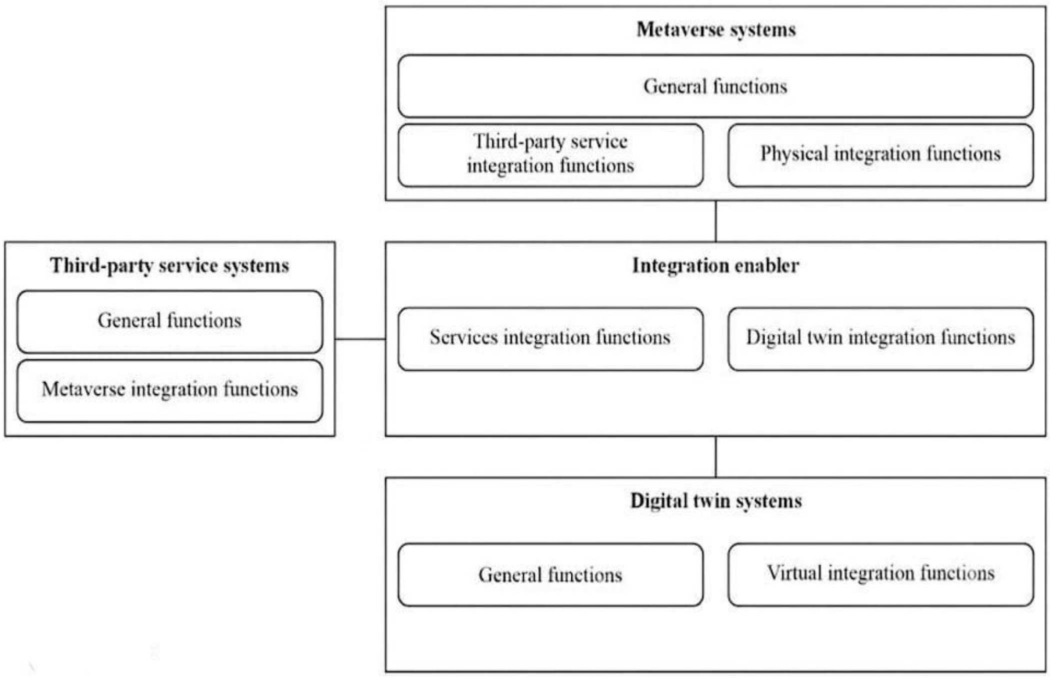

Figure 6: Reference model for integrating virtual and physical worlds through digital twins in metaverse

[Source: ITU-T Y.4239]

NOTE 1 – Integration enabler is not a system but a set of functionalities which can be within metaverse system, digital twin system and/or third-party service system.

NOTE 2 – A digital twin can correspond to a physical object.

NOTE 3 – Third-party service system does not consider another metaverse system and digital twin system that are related to interoperable metaverse services.

This reference model defines the integration enabler to facilitate seamless integration among third-party service systems, digital twin systems and metaverse systems, enabling integration between the virtual and physical worlds. The integration enabler serves as a core management framework that facilitates the seamless integration of digital twin systems, third-party service systems and metaverse systems. It provides functionality for interacting with digital twin systems, allowing physical objects to be utilized as virtual objects in metaverse. It supports interoperability with third-party service systems, enabling services offered by these systems to be seamlessly integrated into the virtual world.

The integration enabler is composed of two key functions: Services Integration Functions (SIF) and Digital Twin Integration Functions (DTIF).

A digital twin system manages digital representations of physical objects, known as digital twins and performs synchronization between physical objects and their corresponding digital twins. A metaverse system enables metaverse services by designing and providing virtual worlds customized to satisfy user preferences. A third-party service system offers external services, such as payment processing, logistics, or online shopping, which can be integrated into metaverse to enhance functionality and provide users with a richer and more interactive experience.

3.1. Functions of metaverse system

Metaverse system comprises three functions: General Functions (GF), Third-party Service Integration Functions (TSIF) and Physical Integration Functions (PIF). Figure 7 below shows the functions and their functional entities of metaverse system

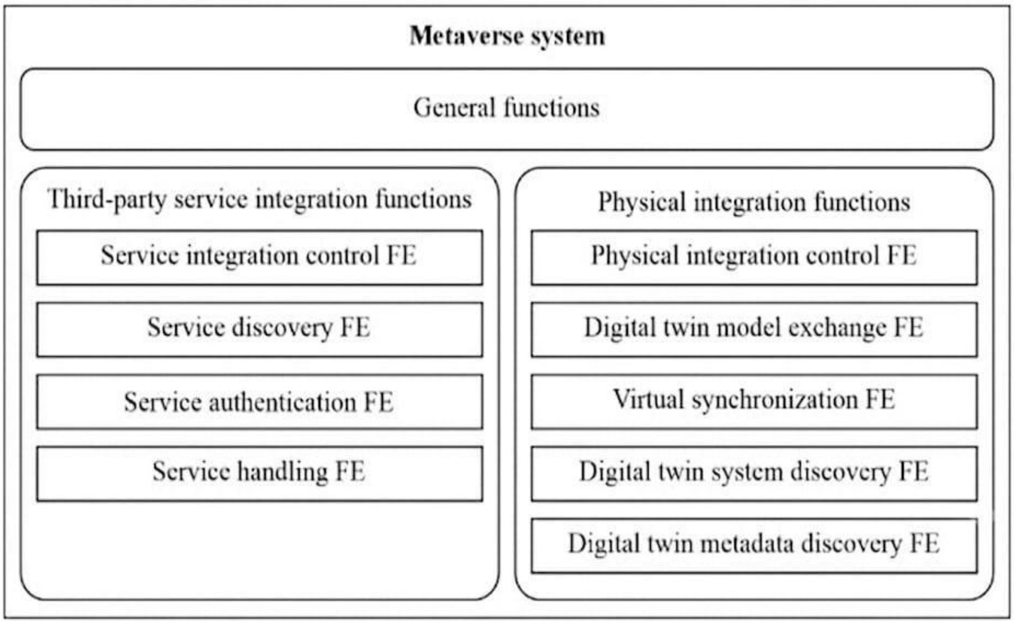

Figure 7: Functions and functional entities of metaverse system

[Source: ITU-T Y.4239]

3.1.1 General functions

The general functions are the functions required to offer standalone services which metaverse system is supposed to offer. General functions are required to have one or more functionalities for integration between a digital twin, as a virtual object and the corresponding physical object.

3.1.2 Physical integration functions

The Physical Integration Functions support the integration of metaverse system with digital twin systems, enabling interaction between virtual and physical worlds. These functions provide capabilities for connecting the managed virtual world with physical entities through integration with digital twin systems and third-party service systems. They support the discovery of registered digital twin systems, retrieval of digital twin model metadata and the import and export of digital twin models between metaverse and digital twin environments. In addition, the functions manage synchronization between virtual objects and their corresponding physical entities, ensuring that changes occurring in either the virtual or physical world can be reflected in the other. Through coordination of model exchange, metadata discovery, system discovery and synchronization processes, the Physical Integration Functions facilitate seamless integration and interaction between virtual environments and real-world systems.

3.1.3 Third-party service integration functions

Third-party Service Integration Functions support integration between metaverse system and external third-party service systems. These functions determine whether a user request requires interaction with external services and coordinate the corresponding service flow, including service discovery, authentication, service invocation and session management. They provide capabilities to retrieve metadata about available third-party services, identify services that meet user requirements and support decision-making for service execution. In addition, the functions manage authentication processes to validate user credentials and ensure authorized access to external services. They also handle service invocation, data exchange and session lifecycle management, enabling secure and consistent interaction between metaverse system and third-party service systems while ensuring seamless service integration and execution.

3.2. Functions of digital twin system

The digital twin system comprises of two functions: general functions and virtual integration functions. Figure 8 below shows the functions and their functional entities of the digital twin system.

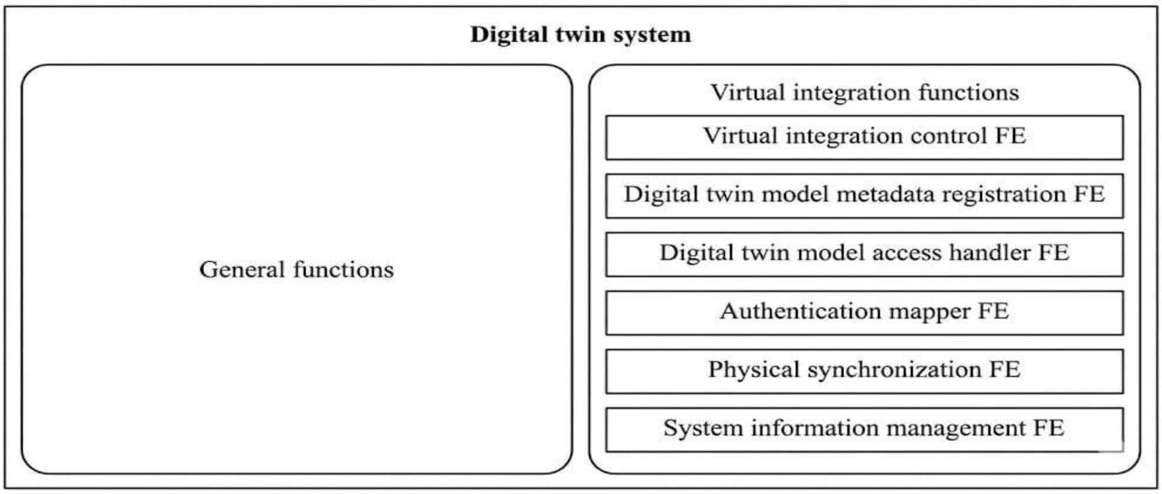

Figure 8: Functions and functional entities of digital twin system

[Source: ITU-T Y.4239]

3.2.1 General functions

The general functions are the functions required to offer standalone services which the digital twin system is supposed to offer. General functions are required to have one or more functionalities for integration between a physical object and the corresponding digital twin.

3.2.2 Virtual integration functions

The Virtual Integration Functions support integration between the digital twin system and metaverse system through the integration enabler. These functions govern the overall interaction flow by coordinating digital twin model exchange, metadata management and synchronization support, while interacting with the general functions of the digital twin system for decision-making and control. They provide capabilities to register and manage metadata of digital twin models and system-level information, enabling cataloguing, discovery, identification and access by metaverse system. In addition, the functions support synchronization between virtual objects and their associated physical objects, ensuring that changes in either the virtual or physical domain are properly communicated. They also manage authentication mapping between the integration enabler and the internal authentication schemes of the digital twin system to validate access requests. Furthermore, the functions handle the import and export of digital twin models by processing authenticated requests and facilitating model upload and retrieval operations, thereby enabling seamless integration and interaction between digital twin systems and metaverse environment.

3.3. Functions of third-party service system

Third-party service system comprises of two functions: general functions and metaverse integration functions. Figure 9 below shows the functions and their functional entities of the third-party service system.

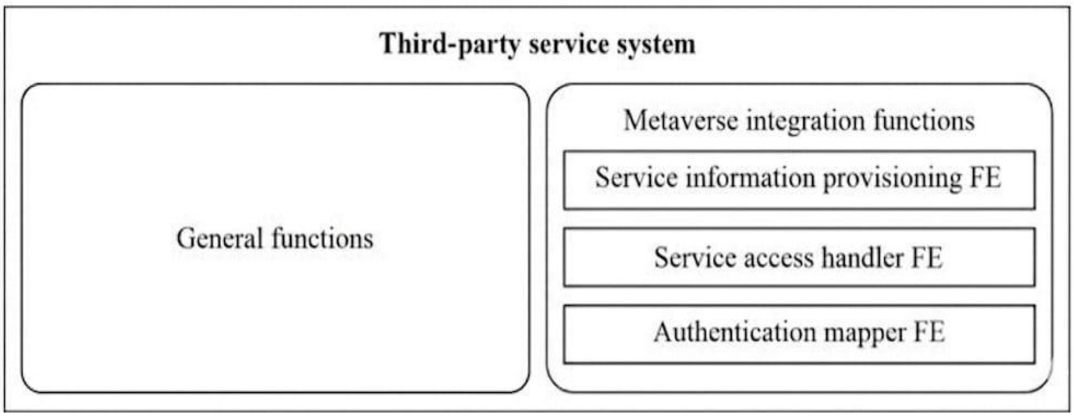

Figure 9: Functions and functional entities of third-party service system

[Source: ITU-T Y.4239]

3.3.1 General functions

The general functions are the functions required to offer standalone services which the third-party service system is supposed to offer. General functions are required to have one or more functionalities for integrating third-party services with metaverse.

3.3.2 Metaverse integration functions

Metaverse Integration Functions support service integration between third-party service systems and metaverse system. These functions provide capabilities to expose, manage, register and update metadata of services offered by third-party service systems, enabling service discovery by metaverse system through the integration enabler. They also serve as a single-entry point for receiving service-related and authentication-related requests from the integration enabler, dispatching them to the appropriate internal components and facilitating communication with general functions and supporting mappers. In addition, the functions support secure authentication by adapting and converting authentication credentials or tokens received from the integration enabler into formats compatible with the internal authentication mechanisms of the third-party service system. Through service information provisioning, request handling and authentication mapping, metaverse Integration Functions enable secure, consistent and seamless integration of external services with metaverse environment.

3.4. Functions of Integration Enabler

The integration enabler comprises of two main components: services integration functions and digital twin integration functions. Figure 10 below shows the functions and their functional entities of the integration enabler.

The services integration functions are responsible for facilitating the integration of the virtual world with external third-party services. The digital twin integration functions are designed to support the integration of one or multiple digital twin systems, allowing for the creation of a unified virtual world.

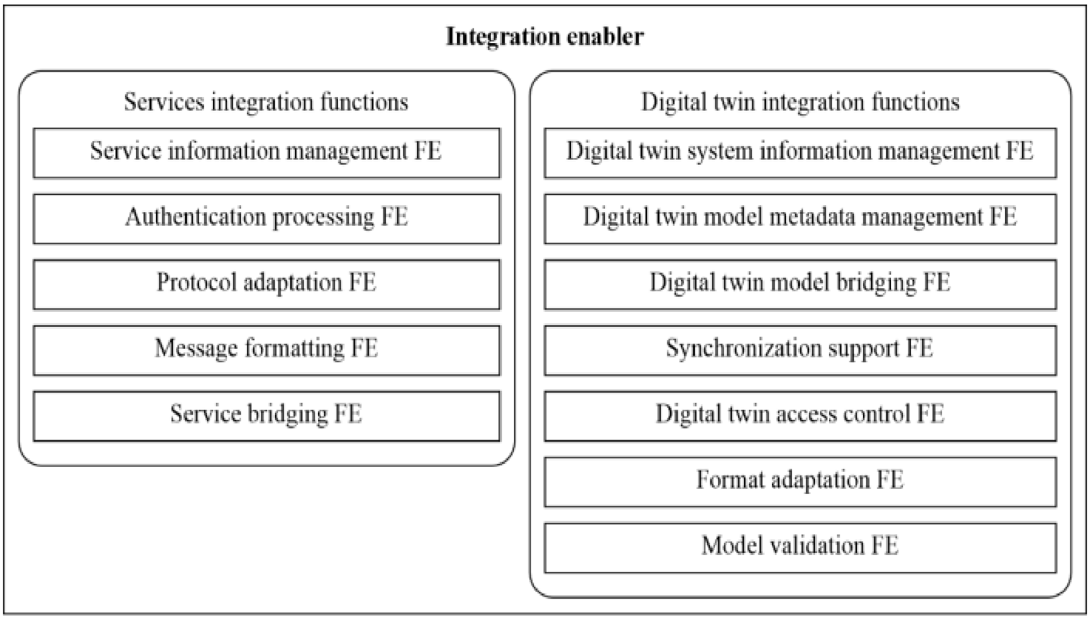

Figure 10: Functions and functional entities of integration enabler

[Source: ITU-T Y.4239]

3.4.1 Services integration functions

The Services Integration Functions support integration between metaverse system and third-party service systems. These functions provide capabilities to store, manage and deliver metadata of third-party services, enabling service registration, discovery and dynamic service interaction. They handle authentication requests from metaverse system by forwarding them to the appropriate third-party service systems and confirming authentication results before returning them to metaverse environment. In addition, the functions support seamless interoperability between heterogeneous systems through protocol adaptation, including the conversion of communication protocols, encoding schemes and interface structures. They also ensure structural and syntactic compatibility of request and response messages through message formatting and transformation. Furthermore, the functions coordinate service invocation and communication flows by bridging service requests between metaverse system and third-party service systems, thereby enabling secure, interoperable and efficient service integration across different platforms and environments.

3.4.2 Digital Twin integration functions

The Digital Twin Integration Functions support integration between metaverse system and digital twin systems. These functions provide capabilities to register, store and manage metadata related to digital twin systems, including provider information, system identifiers and access endpoints, enabling system-level integration and discovery. They also manage metadata of digital twin models to support discovery and selection of appropriate digital twins within metaverse environment. In addition, the functions facilitate the import and export of digital twin models between metaverse system and digital twin systems, serving as the primary interface for model exchange. They support synchronization between virtual objects and their corresponding physical objects, including synchronization of state, location, behaviour and other attributes. The functions further enforce access control policies for digital twin model operations by verifying authentication and access rights before permitting data exchange. To ensure interoperability and data consistency, they provide format adaptation for converting models between different data formats, schemas and representations, as well as model validation to verify integrity, structural compliance and predefined requirements before models are shared across systems. Through metadata management, model exchange, synchronization, access control and validation, the Digital Twin Integration Functions enable seamless and secure integration of digital twin systems with metaverse environment.

4. Requirements of Telecom/ICT for Metaverse

The realization of metaverse services depends significantly on the capabilities of telecom networks, ICT infrastructure and IoT systems to support large-scale connectivity, interoperability, low-latency communication, high data processing and seamless interaction between users, devices and digital environments. The increasing integration of AI, XR, cloud computing, edge computing and digital twins further expands the requirements for robust and intelligent communication systems capable of supporting persistent and immersive experiences.

4.1. Communication and Network Requirements

Metaverse requires advanced telecom and ICT infrastructure capable of supporting persistent, immersive and real-time interaction across interconnected virtual environments. The integration of virtual worlds, digital twins, XR technologies, AI-enabled services and IoT systems introduces significant communication and networking requirements. Metaverse services are expected to support large-scale simultaneous user participation, high-resolution immersive content, real-time synchronization and continuous interaction between physical and virtual entities.

Low latency, high bandwidth and reliable connectivity are fundamental requirements for immersive metaverse experiences. Interactive applications such as virtual meetings, industrial simulations, remote collaboration, gaming and digital twin synchronization require real-time communication and rapid data processing to ensure continuity and consistency of user experiences. Variations in latency, packet loss or network instability may negatively affect synchronization, immersion and user interaction within virtual environments.

Metaverse also requires scalable communication infrastructure capable of supporting heterogeneous devices, distributed computing environments and multi-platform interoperability. Cloud computing, edge computing and distributed network architectures may support real-time processing, rendering and service delivery while reducing latency and improving service efficiency. Interoperability between communication systems and platforms is necessary to ensure seamless interaction between users, services, applications and digital assets across multiple virtual environments.

Multimedia communication requirements in metaverse include support for immersive audio, high-definition video, holographic communication, 3D rendering and multimodal interaction. Human-avatar communication and interaction with them require support for language modalities, AI-based communication technologies and synchronized multimedia processing. Communication systems may also support integration of XR devices, haptic technologies and sensor-based interaction to enable realistic and immersive experiences.

Security, privacy and reliability are important considerations for telecom and ICT systems supporting metaverse. Communication infrastructure may incorporate secure transmission mechanisms, identity management and access control to protect user interactions and sensitive information. Network resilience, fault tolerance and service continuity mechanisms may further support uninterrupted metaverse operations and reduce service disruptions.

4.2. Interoperability and Service Integration Requirements

Metaverse consists of interconnected platforms, services, devices and applications operating across multiple domains and environments. Interoperability is therefore a critical requirement for enabling seamless communication, interaction and transfer of digital assets, identities and services across metaverse platforms. The absence of interoperable systems may result in fragmented user experiences, limited portability of services and reduced scalability of metaverse ecosystems.

Interoperability requirements include support for standardized interfaces, reference points, communication protocols and information exchange mechanisms. Cross-platform interaction may involve synchronization of user identities, avatars, virtual assets, digital twins and service data between different metaverse environments.

Service integration requirements also include mechanisms for integration of third-party systems, external applications and enterprise platforms into metaverse ecosystems. Registration, discovery, authentication and authorization mechanisms may support secure interaction between metaverse platforms and external systems. API interoperability, service orchestration and data collaboration mechanisms may further support coordinated execution of services and exchange of information across distributed environments.

Digital assets and user identities may exist simultaneously across multiple metaverse platforms, creating requirements for consistent identity management and authorization frameworks. Interoperability of identities and access control mechanisms may help maintain continuity of user presence and interactions across virtual environments. Harmonized frameworks may also support portability of virtual assets, data and services while ensuring security and integrity of information.

Metaverse additionally requires interoperability between communication networks, cloud infrastructure, edge computing systems, XR devices and IoT environments. Coordination between these systems may improve scalability, service continuity and operational efficiency. Standardized interoperability frameworks may further support innovation, reduce duplication and enable broader participation of stakeholders across the metaverse ecosystem.

5. Performance evaluation metrics in metaverse

Evaluation metrics play a crucial role in metaverse as they turn broad ideas into measurable factors that help teams decide which use cases are actually worth building. By tracking factors such as user engagement, task completion, comfort, latency, retention and learning outcomes, developers can compare different experiences, identify friction points and refine the design for specific goals such as training, education, retail, healthcare or collaboration. Metrics also help distinguish novelty from real value, showing whether a metaverse application improves performance, saves time or creates a better user experience rather than simply looking impressive. In that way, evaluation metrics act as the bridge between experimentation and practical use case development, guiding teams toward experiences that are effective, scalable and meaningful. Following are three metrics suggested in the whitepaper[7] on XR by XTIC, IIT Madras:

5.1. Measuring Progress

The Inclusive metaverse Index is a measure for countries to capture value and drive progress within the developing metaverse ecosystem. The index is composed of two pillars – Access and Engagement:

i. Access: Access refers to the fundamental availability of underlying and key technologies and their affordability.

ii. Engagement: Engagement comprises the relevance of the emerging metaverse ecosystem for current and potential users, as well as the readiness of countries to engage with it in a safe and secure manner.

5.2. Metaverse Index Framework Structure

The index is composed of three pillars of metrics:

1. **Ethical metaverse Index**
   i. Interoperability: Measures the compatibility of metaverse platforms ensuring seamless experience for users and fostering collaboration between virtual worlds.
   ii. Privacy: Measures the protection of users' privacy within metaverse, including data handling practices, user consent mechanisms and adherence to privacy regulations.
   iii. Content Moderation: Evaluates the effectiveness of content moderation mechanisms to ensure a safe and responsible virtual environment, preventing harmful or inappropriate content.

[7] https://xtic.org/whitepaper-xr-in-india/

2. Responsible metaverse Index

i. Global Connectivity: Measures how well metaverse facilitates global connectivity, allowing users from different regions to interact seamlessly and promoting cross-cultural experiences.

ii. Innovation and Creativity: Measures the degree of innovation and creativity within the metaverse ecosystem, assessing the development of new technologies, applications and user-generated content.

iii. Diversity and Inclusion: Measures the inclusivity of metaverse, looking at how well it accommodates a diverse range of users in terms of gender, age, ethnicity and abilities.

iv. Sustainability: Measures the environmental impact of the metaverse ecosystem, considering factors such as energy consumption, carbon footprint and the use of eco-friendly technologies.

3. Transparent metaverse Index

i. Trustability: Measures how well the metaverse fosters trust among users. When users have clear information about how their data is collected, used and protected, they are more likely to trust the metaverse platform and its operators.

ii. Platform Governance: Measures how well the users know the governance structures and decision-making processes and how policies are developed and enforced.

6. Trust, Safety, Security and Privacy in metaverse

As metaverse expands across sectors such as manufacturing, smart cities, healthcare, education and entertainment, concerns relating to trust, safety and security become increasingly significant. The persistent and immersive nature of metaverse, combined with various technologies introduces new challenges associated with user confidence, privacy protection, identity management, cyber threats, harmful behaviour and misuse of digital assets. Ensuring a secure and trustworthy metaverse requires mechanisms for data protection, access control, interoperability, content moderation, identity verification and secure interaction among users, avatars and connected systems.

6.1. Trust

Trust forms one of the foundational requirements for the sustainable development and adoption of metaverse. Metaverse is envisioned as an interconnected ecosystem of virtual worlds where users, avatars, devices and services continuously interact, exchange data and perform social and economic activities. In such an environment, users are expected to rely on digital identities, virtual assets, immersive interactions and AI-enabled systems. The absence of trust may directly affect user participation, confidence, adoption and continuity of services in metaverse ecosystem.

Metaverse introduces challenges associated with authenticity of identities, credibility of digital interactions, transparency of algorithms, reliability of services and trustworthiness of data. Since users may simultaneously participate across multiple metaverse platforms, trust becomes dependent not only on individual platforms but also on interoperability between systems and the consistency of user experiences across virtual environments. The integration of technologies such as AI, blockchain, IoT, digital twins and XR further increases the complexity of establishing trustworthy interactions and services.

The concept of trust in metaverse extends beyond technical reliability and includes user confidence, inclusivity, transparency, fairness and responsible governance. Users may experience risks related to misinformation, manipulation, unauthorized behavioural tracking, identity impersonation and misuse of virtual assets. In immersive environments, these risks may have stronger psychological, economic and social impacts compared to conventional digital platforms due to the persistent and interactive nature of metaverse.

To establish trust, metaverse systems may incorporate trusted data management mechanisms, transparent governance policies, reliable authentication mechanisms and secure interoperability frameworks. User-centric approaches, including user control over identities, personal data and interactions, are important for maintaining confidence. Trusted execution environments, verifiable digital identities, consent management and accountability mechanisms may also support trustworthy operations. In addition, interoperability standards and harmonized frameworks can improve consistency and reduce fragmentation across platforms.

The development of trustworthy metaverse ecosystems also requires consideration of accessibility, inclusion and equitable participation. Metaverse may affect both participants and non-participants, particularly where digital twins, AI profiling or behavioural data are used. Therefore, trust frameworks may consider broader societal impacts, ethical implications and the protection of user rights in both virtual and physical contexts.

6.2. Safety

Safety in metaverse involves the protection of users from physical, psychological, behavioural and social harms that may arise from immersive and persistent virtual environments. Unlike traditional online platforms, metaverse combines immersive interaction, digital embodiment and real-time communication, increasing the intensity and impact of harmful experiences. The integration of avatars, haptic technologies, XR devices and AI-generated interactions may expose users to new forms of abuse, manipulation and exploitation.

The immersive nature of metaverse may amplify emotional and psychological impacts arising from harassment, bullying, discrimination, misinformation and violent or inappropriate virtual interactions. Users may experience discomfort, emotional distress or behavioural manipulation due to prolonged exposure to immersive virtual environments. Vulnerable groups, including children and persons with limited digital literacy, may face increased risks associated with harmful content, unsafe interactions and unauthorized data collection.

Safety considerations also extend to physical risks associated with XR devices and immersive interfaces. Users interacting in virtual environments may experience sensory overload, fatigue, disorientation or physical injury due to prolonged use or interaction with surrounding physical objects while immersed in virtual spaces. Furthermore, digital humans and AI-generated content may influence user behaviour, perceptions and decision-making processes in ways that are not always transparent or understandable to users.

To improve safety, metaverse platforms may implement content moderation mechanisms, behavioural monitoring systems, age verification processes and user reporting capabilities. User safety controls, including privacy settings, personal boundaries and interaction restrictions, may help users manage their experiences and reduce exposure to harmful interactions. Mechanisms for identity verification, parental controls and user awareness may also support safer participation, particularly for children and vulnerable users.

Safety-by-design approaches may be incorporated during the development of metaverse platforms and services. This includes consideration of human rights, accessibility, inclusion and user wellbeing during system design and deployment. Transparent governance policies, ethical AI practices and responsible management of immersive technologies may further contribute to safer virtual environments and reduce the likelihood of harmful behaviour or misuse of metaverse services.

6.3. Security

Security in metaverse is essential for protecting digital identities, virtual assets, communications, services, devices and data across interconnected virtual environments. Metaverse integrates multiple enabling technologies, including AI, IoT, blockchain, cloud computing, XR and digital twins, creating a highly distributed and interoperable ecosystem with complex security requirements. The increasing interaction between virtual and physical systems also expands the attack surface and introduces new cybersecurity risks.

Threats in metaverse may include identity theft, unauthorized access, data breaches, impersonation, surveillance, malware attacks, manipulation of digital assets and attacks targeting immersive devices and IoT systems. Since users may maintain multiple identities and interact across different platforms, weaknesses in authentication and authorization mechanisms may compromise user accounts, virtual property and personal information. Similarly, vulnerabilities in cross-platform interoperability and third-party integrations may expose systems to unauthorized access or malicious activities.

Digital twins and IoT-enabled metaverse environments may further increase security concerns due to continuous collection, processing and sharing of real-world data. Unauthorized access to digital twin systems or manipulation of synchronized virtual and physical objects may affect not only virtual environments but also physical infrastructure and services. Security of data processing, storage and transmission therefore becomes critical in ensuring the integrity and reliability of metaverse operations.

Security mechanisms may include strong authentication and authorization frameworks, encryption, identity management, consent and identity behavior management, access control, secure interoperability mechanisms and trusted execution environments. Monitoring and incident response mechanisms may support early detection of malicious activities and unauthorized access. Secure API interactions, protection of digital assets and management of permissions across platforms may also contribute to strengthening metaverse security.

The implementation of security-by-design principles during platform development may help reduce vulnerabilities and improve resilience. Security considerations may include protection of personally identifiable information, secure management of biometric and behavioural data and safeguarding of user communications and transactions. Interoperable security frameworks and harmonized standards may further support secure interaction between metaverse platforms, devices and third-party systems.

6.4. Digital Identity

Digital identity is a foundational element of metaverse, enabling users, avatars, digital humans, IoT devices and autonomous agents to be uniquely identified, authenticated and authorized across virtual environments. The emergence of AI-driven digital humans and autonomous agents further necessitates mechanisms for agent identity, provenance verification and accountability, enabling users to distinguish between human-controlled and AI-controlled entities. In metaverse, a user may simultaneously maintain multiple identities across different platforms, including persistent avatars, professional personas and device identities. The management, portability and integrity of these identities is critical for enabling seamless, secure and trustworthy participation.

Unlike conventional digital platforms, metaverse demands richer and more complex identity frameworks. A user's identity in metaverse may include not only credentials and authentication tokens but also behavioural attributes, avatar representations, virtual asset ownership records and interaction histories. The convergence of these elements requires robust identity architectures that can operate consistently across heterogeneous platforms and virtual environments.

Key requirements for digital identity in metaverse include:

i. **Verifiability:** Identity claims should be verifiable through trusted mechanisms, such as decentralized identifiers (DIDs), blockchain-based credentials or trusted third-party attestation, to prevent impersonation and identity fraud.

ii. **Authenticity and provenance:** Identity frameworks should support mechanisms to verify the authenticity and provenance of avatars, digital humans and user-generated content, helping mitigate risks associated with deepfakes, synthetic identities and impersonation attacks.

iii. **Portability:** Users should be able to carry their identities, credentials, avatars and virtual assets across different metaverse platforms without loss of continuity or the need to re-establish identity from scratch.

iv. **Self-sovereignty:** User-centric identity models, including self-sovereign identity (SSI) frameworks, allow users to retain ownership and control over their identity data, selectively disclosing information as required.

v. **Interoperability:** Identity frameworks should support cross-platform interoperability, enabling consistent authentication and authorization across diverse metaverse environments, consistent with standards such as ITU-T Y.4812 and ITU-T H.770.1.

vi. **Unlinkability and pseudonymity:** Where appropriate, identity mechanisms should allow users to interact under pseudonymous identities without exposing their real-world identities, while still enabling accountability where necessary.

The identity of IoT devices and digital twins within metaverse environments also requires dedicated management. Each physical device or digital entity may have multiple associated identities across different platforms, creating challenges for consistent identification, authentication and authorization. Secure identity lifecycle management — including identity creation, renewal, revocation and cross-platform synchronization — is essential for maintaining the integrity of metaverse operations.

Identity governance frameworks may include policies for identity verification, age authentication (particularly for child safety), access control based on identity attributes and mechanisms for identity recovery in case of loss or compromise. The development of harmonized, interoperable identity standards across metaverse platforms will be essential for reducing fragmentation, improving user confidence and enabling secure cross-platform participation. Identity governance frameworks should also support auditability, compliance with applicable regulatory requirements and cross-jurisdictional trust frameworks to facilitate secure participation in global metaverse ecosystems.

6.5. Privacy

Privacy is a fundamental requirement for user confidence and the sustainable growth of metaverse. Unlike traditional digital platforms, metaverse relies on persistent and immersive interactions involving avatars, virtual environments, IoT devices and digital twins. As a result, metaverse platforms may process a broad range of personal information, including identity data, behavioural information, location data, biometric identifiers and interaction records. The scale, persistence and interconnected nature of these environments increase concerns regarding unauthorized access, excessive data collection and loss of user control over personal information.

The integration of multiple virtual worlds, platforms and third-party services further complicates privacy management. Persistent digital identities and cross-platform interactions may enable tracking, profiling and aggregation of user activities across different environments. Such practices can reveal detailed information about user preferences, behaviours and social relationships, potentially affecting privacy expectations and individual autonomy.

Immersive technologies such as VR, AR and wearable devices introduce additional privacy considerations through the collection of sensitive information including movement patterns, eye-tracking data, facial expressions and other behavioural indicators. Similarly, digital twin-based environments may continuously exchange information between physical and virtual entities, creating additional challenges related to data protection and information governance.

Effective privacy protection requires transparency in data processing practices, meaningful user consent, granular privacy controls and mechanisms that allow users to manage how their information is collected, used and shared. Particular attention is required for children and other vulnerable groups whose personal information may require enhanced safeguards.

The protection of personally identifiable information (PII) should be supported through privacy-preserving measures such as data minimization, purpose limitation, secure storage, controlled access and accountability mechanisms. Privacy can be further strengthened through privacy-by-design and privacy-by-default principles, ensuring that privacy considerations are integrated throughout the design, development and operation of metaverse platforms and services. Such measures contribute to the development of a trusted, secure and sustainable metaverse ecosystem.

7. Challenges

Despite its transformative potential, metaverse faces several technical, regulatory, social and operational challenges that may affect its widespread adoption, trustworthiness and long-term sustainability. Addressing these challenges is essential to ensure that metaverse remains secure, inclusive, interoperable and beneficial for all stakeholders. The challenges discussed in this section are primarily based on the findings and analysis presented in ITU-T FGMV-45[8] and ITU-T FGMV-01[9].

7.1. Societal Challenges

i. **Interoperability:** The lack of interoperability and uniformity between the various metaverse platforms is a significant challenge – a unifying framework and protocol are needed to facilitate user movement between metaverses and devices.

ii. **Regulation**: While metaverse is a space that brings users together, it can also make them vulnerable if proper legislation and regulations are not established. Competition. For metaverse to flourish it needs to be built on a foundation that enables market competition of ideas and avoids dominance by a few companies.

iii. **Disinformation/ Misinformation**: Metaverse ushers in a new set of challenges related to distributing false or malicious information. Unless regulated, metaverse could become a dangerous tool of persuasion, promoting the spread of hate, harassment and polarization.

iv. **Accessibility:** Accessibility remains a key challenge in metaverse, as older persons, individuals with visual, hearing, motor or dexterity impairments and those facing language, cultural or connectivity barriers may encounter difficulties in accessing and navigating virtual environments. Without inclusive design and support for assistive technologies, metaverse may increase digital exclusion and create new forms of digital divide for vulnerable groups.

v. **Sustainability**: Even though metaverse is virtual, it impacts the environment. Metaverse draws far more electricity than previous online technologies; it will also increase data centre activity and corresponding carbon emissions. It is also important to note that continuous technology development can create an influx of e-waste.

vi. **Child online protection and other social challenges**: There is concern that metaverse will exacerbate the problems associated with social media. For instance, virtual environments create loneliness and participants can be exposed to harmful content. Metaverse also poses a potential risk for children, including cyberbullying and a lack of privacy.

vii. **Sexual assault:** Incidents of sexual assault have already been reported on metaverse platforms. There is a serious need for tech companies involved in developing metaverse applications to address issues of sexual assault by introducing forms of moderation and systems to restrict this behaviour.

[8] https://www.itu.int/en/ITU-T/focusgroups/mv/Documents/List%20of%20FG-MV%20deliverables/FGMV-45.pdf
[9] https://www.itu.int/dms_pub/itu-t/opb/fg/T-FG-MV-2023-PDF-E.pdf

viii. **Intellectual property:** Metaverse has the potential to create new forms of intellectual property such as virtual goods, digital assets, non-fungible tokens (NFTs) and experiences. It is important to ensure that these new forms of intellectual property are protected and that their owners can profit from them.

7.2. Technical challenges

i. **Security and Privacy:** Security and privacy remain key challenges in metaverse due to the continuous collection and exchange of personal and behavioural data across interconnected virtual environments. Persistent digital identities, virtual assets and third-party integrations increase the risks of cyberattacks, unauthorized access, identity theft, data breaches and privacy violations. These challenges highlight the need for strong security measures, privacy safeguards and appropriate consent mechanisms.

ii. **Digital identity:** Digital identity is the user's proof of identity in metaverse, the identity proof of the ownership of digital assets and the key to maintaining the sustainable and healthy development of metaverse. Without digital identity, the infrastructure of metaverse would be vulnerable. In the event of a cyberattack, weak digital identities such as user names and passwords will be stolen or used for other fraudulent activities. Digital identities in metaverse face the following challenges:

- **Personal identification (PII):** Digital identity information and sensitive data, such as names, email addresses and phone numbers need to be handled. These data may be obtained illegally and abused. Attackers can obtain these sensitive data through various means such as network sniffing and man-in-the-middle attacks, for malicious activities such as identity theft and fraud.

- **Malicious software and attacks:** As more users and metaverses join, the network must be able to handle large-scale data exchanges and transactions while maintaining low latency and high throughput.

- **Identity visualization and interoperability:** In metaverse, each user maps multiple identities in metaverse platforms. Identification and interoperability between multiple identities and their behaviors can pose challenges. How an identity is visualized and behave in particular metaverse is supposed to be controlled by its owner, exploiting it is a challenge.

iii. **Network connection**: Metaverse integrates VR, AR, AI, blockchain and other technologies and an efficient and reliable network is a key challenge for metaverse. In metaverse, every detail requires a lot of computation and data transmission and if the network is not reliable it can lead to data loss, inaccurate computation results and poor user experience. A trusted network connection faces the following challenges:

- **Interoperability:** Different metaverses have different data formats, interaction methods and economic models. There is a lack of common standards and protocols to ensure that data and assets can be shared across metaverses.
- **Scalability:** As more users and metaverses join, the network must be able to handle large-scale data exchanges and transactions while maintaining low latency and high throughput.

iv. **AI technology:** In the development of metaverse, AI technology can be applied to a wide variety of scenarios such as content generation, character modelling, speech recognition and sentiment analysis. As one of the key technologies for the realization of metaverse, metaverse must support the trusted AI operation in the data, modelling, analysis, prediction and decision-making process. If the AI modelling or operation process is not trusted, it will lead to the entire metaverse not being trusted, with serious consequences. The trust challenges for AI include:

- **Lack of transparency:** The decision-making process of AI is often not transparent, which makes it difficult for people to understand and trust the decisions made by AI and puts AI at risk of abuse.
- **Data supply:** The foundation of AI computing is data and AI computing in metaverse requires access to a large amount of data. As a virtual space, information and property in metaverse are easily to be stolen and attacked in the process of AI computing.

v. **Blockchain technology**: Blockchain is one of the key foundational technologies of metaverse and its security, reliability, decentralization and interoperability provide a secure, trustworthy and transparent environment for metaverse. However, blockchain technology faces a number of technical security challenges.

- **Growing data volume challenge:** With the development of blockchain, the volume of blockchain data stored by nodes is getting larger and larger and the burden of its storage and computation is getting heavier and heavier, which will bring great difficulties to the operation of metaverse clients.
- **Low blockchain application efficiency:** Blockchain transactions require multiple confirmations, each of which creates a delay. Such efficiency does not meet the real-time requirements of metaverse.

vi. **Trusted digital asset:** A digital asset is a digital representation of value recorded on a cryptographically secured distributed ledger or similar technology and it is supposed to be capable of being exchanged and traded in a digital world like metaverse without an intermediary. As in the trustworthy metaverse, the digital assets should be trustworthy enough to do the relevant exchanges and trades in the digital world as metaverse. The following are the essential aspects that should be taken into consideration for the trusted digital assets:

- **Decentralization:** With numerous nodes distributed in the digital world, each node has highly autonomous characteristics, the nodes can freely connect to each other and form new connection units. Each node can become a periodic centre, but does not have mandatory central control functions. The influence between nodes will form a nonlinear causal relationship through the network. Thus, in order to be trusted of the digital asset, “decentralization” should be one of the essential properties of a trusted digital asset.
- **Encryption:** Encryption is the process of converting data into a message that no one can understand without the correct key through cryptographic arithmetic; for the trusted digital asset, it should be encrypted all the time in the digital world.
- **Traceable**: All the traces of the digital asset should be recorded, so that they can be traced back if necessary.
- **Immutable:** Based on the traceability, all the recorded traces should be immutable, i.e., they cannot be falsified.
- **Privacy:** All the private information, especially the assets, should be well protected.
- **Security:** The physical security, network security, data encryption, identity authentication and so on, should be ensured, so that exchanges are protected from attack and illegal access.
- **Trusted exchange/payment:** All the exchanges or payments should be trustworthy enough whether in peer-to-peer, real-time or offline scenarios.

8. Initiatives on metaverse

8.1. Telecommunication Engineering Centre, DoT

TEC is the nodal agency for contributing in ITU's Telecommunication Standardization Sector (ITU-T).

The IoT Division of TEC is having a National Working Group-20 (NWG-20) corresponding to ITU-T Study Group 20 (SG-20), which deals with Internet of things (IoT), Digital Twins and Smart Sustainable Cities and Communities (SSC&C). Following are the achievements of TEC at international level in the domain of metaverse:

i. During the World Telecommunication Standardization Assembly (WTSA-24) held in New Delhi in October 2024, TEC significantly contributed in development of a new Resolution 105 on 'Promoting and strengthening metaverse standardization'. The resolution establishes a formal framework for the ITU-T to lead efforts in creating a trusted, inclusive and interoperable metaverse environment.
ii. TEC has been actively contributing to Metaverse-related activities at the international level in ITU-T SG-20.
iii. Five new work items on Metaverse and its related aspects, proposed by TEC in collaboration with IIT Madras, have been approved in ITU-T SG-20 in the year 2025.

8.2. XTIC, IIT Madras

The eXperiential Technology Innovation Centre (XTIC) at IIT Madras has positioned itself as a major Indian hub for immersive technologies, including VR/AR/MR, haptics and broader metaverse-related systems. Its work spans ecosystem building, policy and standards, academic partnerships, open-source technology development, training infrastructure and sector-specific applications.

In the context of metaverse, XTIC's contribution is notable because it is not limited to building individual applications. Instead, it is shaping an enabling framework that combines research, industrial collaboration, education, standards and national capability building.

Metaverse India Policy and Standards (MIPS)

XTIC established the Metaverse India Policy and Standards (MIPS) Committee to bring together standards agencies and stakeholders around the goal of building a pervasive, open and inclusive metaverse. The MIPS forum is designed to coordinate needs and resources for standards and policy development rather than issuing standards directly on its own.

This initiative is especially important because metaverse ecosystems raise issues of interoperability, identity, safety and governance. XTIC states that MIPS, in collaboration with Telecommunication Engineering Centre, Department of Telecommunications, has initiated standards-related work focused on application areas such as yoga and meditation, renewable energy, tourism and identity management.

XTIC also notes that work items related to IoT and metaverse were approved at the ITU-T SG-20 meeting in January 2025, showing that its standards-oriented work is linked to international forums rather than being purely local or experimental.

XR Policy Committee

Beyond technical standards, XTIC is also driving an XR Policy Committee intended to help build a broader policy framework for immersive technologies. This reflects the recognition that metaverse deployment needs legal, ethical, industrial and societal guidance in addition to engineering innovation.

The policy effort includes commentary on foreign metaverse policies and Indian XR startup and innovation ecosystem issues, indicating that XTIC is attempting to compare international models while adapting policy thinking to Indian conditions.

XR Corridor

The XR Corridor is presented by XTIC as a national initiative to position India as a global leader in extended reality technologies under the broader vision of Viksit Bharat 2047. It aims to connect academia, startups, industry, government and international collaborators to strengthen innovation, workforce development, entrepreneurship and infrastructure in immersive technologies.

The XR Corridor is organized around strategic pillars such as research and innovation, industry collaboration, academic ecosystem expansion, infrastructure development, policy and standards and global partnerships. This makes it a broad national capacity-building initiative rather than a single lab or product line.

CAVE Consortium

XTIC’s Consortium for VR/AR/MR Engineering, known as CAVE, is described as India’s first industrial consortium for XR innovation. CAVE has more than 300 members and is intended to accelerate collaborative innovation, product testing, market development and commercialization.

CAVE is also positioned as a bridge between academia, startups, content creators, developers, consultants and corporations. This is relevant to metaverse use cases because immersive platforms require coordination across hardware, software, content, standards and deployment partners.

Academic Associate Programme (AAP)

XTIC has launched an AAP for XR partnerships with academic institutions to accelerate VR and AR innovation, talent development, startup growth and course expansion. This initiative supports the spread of immersive-technology capacity beyond IIT Madras itself by enabling training, curriculum and resource sharing across universities and institutions.

From a metaverse perspective, the AAP is important because large-scale adoption depends on trained faculty, skilled students and locally available institutional capability rather than only centralized research excellence.

Open Source XR and Indigenous Technology Development

XTIC’s XR Corridor framework includes an Open Source XR initiative focused on indigenous XR engines, frameworks and hardware designs. Separate reporting on XTIC also mentions efforts in open-source VR and AR hardware such as headsets, haptic tools, touch sensing technology, emote biosensors and software, as well as testing and standardization protocols.

This emphasis on indigenous and open technologies suggests that XTIC views metaverse not just as an application layer, but as a strategic technology stack where domestic capability matters for cost, independence and long-term innovation.

XR Experience Centers and Sectoral Centers

XTIC is building XR Experience Centers and related demo and training facilities to widen access to immersive technologies and their applications. XTIC also reports that IIT Madras developed an XR Centre for the Steel Authority of India Limited (SAIL), with AR, VR, MR and haptic technologies aimed at industrial R&D and training in the steel sector. Similarly, an XR center for Indian Oil Corporation IOCL focusing on Fire Safety Training in its headquarters in Bandra, Mumbai and few other centers.

These centers show XTIC’s applied orientation: instead of limiting work to theoretical research, it is creating spaces where industries, students and institutions can experience, test and adopt immersive tools.

Metaverse use cases associated with XTIC’s work

XTIC has already undertaken work in the following domains:

i. Education and Immersive Learning
ii. Healthcare and Wellbeing
iii. Industrial Training and Manufacturing
iv. Tourism and Cultural Heritage

v. Yoga, Meditation and Wellbeing Experiences
vi. Identity Management and Governance
vii. Renewable Energy and Sustainability
viii. AVGC-XR, Gaming and Storytelling
ix. Defense, Space and Advanced Simulation

The detailed explanation of the above use cases is available in Appendix 2.

Strategic Significance of XTIC's metaverse work

XTIC's initiatives suggest a view of metaverse as a national capability domain rather than simply a consumer platform trend. Its work combines four layers: foundational technology, standards and policy, institutional ecosystem development and sector-specific deployment.

This approach is significant because many metaverse efforts globally have concentrated heavily on platforms, content or hardware in isolation. XTIC is instead attempting to align policy, talent, research, industry consortia and applied centers in a more system-wide model.

A second important feature is the emphasis on openness, inclusion and indigenous development. The repeated focus on open standards, global coordination, open-source XR and India-specific capacity building suggests XTIC is trying to reduce dependency on external platforms and help shape a more locally grounded innovation ecosystem.

9. Standardization Landscape

9.1. ITU Initiatives on Metaverse

The ITU Focus Group on Metaverse (FG-MV) was established under the Telecommunication Standardization Advisory Group (TSAG) on 16 December 2022 to study the technical requirements of metaverse and identify key enabling technologies, including multimedia, network optimization, digital currencies, IoT, digital twins and environmental sustainability. The Focus Group also served as a collaborative platform for stakeholders to contribute to metaverse pre-standardization activities and supported the identification of relevant use cases. FG-MV concluded its work in June 2024 and published 52 deliverables on metaverse and the list of these deliverables is available in Appendix 3.

Several Recommendations on metaverse and on metaverse applications have been published and under work in ITU-T, which have been listed below:

i. **ITU-T Y.4812 - Interoperability of the identity of Internet of things devices across metaverse platforms:** Recommendation ITU-T Y.4812 describes identity interoperability for IoT devices across metaverse platforms and provides relevant technical features and reference framework. With regard to the IoT (Recommendation ITU-T Y.4000), each IoT device may have a single or multiple unique identities in multiple IoT systems. Similarly, each IoT device also may have a single or multiple identities in multiple metaverses. The identity of an IoT device usually includes a unique identifier and a corresponding identity object (Recommendation ITU-T Y.4811). Although it may take advantage of one IoT device having one unique identity in multiple metaverses, there are challenges; how those metaverses identify, authenticate and authorize the IoT devices when they are roaming across metaverse platforms and how the trustworthy shared storages interact with each other to support identity interoperability across storages.

ii. **ITU-T Y.4238 - Requirements for integrating virtual and physical worlds through digital twins in the metaverse:** Metaverse is a vast virtual environment composed of numerous distinct virtual worlds, each designed for specific purposes and characterized by unique features. Among these virtual worlds, there are certain virtual worlds that incorporate digital twins, virtual representations of physical entities that act as interfaces between the physical and virtual domains. These digital twins enable bidirectional interactions, allowing information from physical objects to be transmitted to their virtual counterparts, thereby achieving synchronization. Conversely, actions performed on virtual objects can influence or control the corresponding physical objects. Recommendation ITU-T Y.4238 explores service scenarios and defines the requirements for integrating virtual and physical worlds through digital twins in metaverse.

iii. **ITU-T Y.4239 - Reference model for integrating virtual and physical worlds through digital twins in the metaverse:** Metaverse is a vast virtual space made up of many distinct virtual worlds, each with its own purpose and characteristics. Among them, there is a type of virtual world that incorporates digital twins acting as an interface bridging the virtual and physical worlds, enabling two-way interaction between virtual objects and their physical counterparts. This allows information from physical objects to synchronize with their virtual versions. Conversely, controlling virtual objects can affect the physical ones. By analyzing service scenarios, key requirements can be identified, which serve as the basis for developing an integration reference model. Recommendation ITU-T Y.4239 defines a reference model for integrating virtual and physical worlds through digital twins in metaverse.

iv. **ITU-T Y.4240 - Interoperability for integrating virtual and physical worlds through digital twins in the metaverse:** Recommendation ITU-T Y.4240 defines three foundational interfaces and their specific reference points that enable the interoperability required to integrate virtual and physical worlds through digital twins in metaverse. It provides an overview of interoperability for integrating virtual and physical worlds through digital twins in metaverse, outlines the interfaces and their related reference points and describes operational procedures through these reference points.

v. **ITU-T H.770.1 - Service scenarios and high-level requirements for metaverse cross-platform interoperability:** Recommendation ITU-T H.770.1 specifies service scenarios and high-level requirements for metaverse cross-platform interoperability. With the increasing number of metaverse platforms being developed, there is a need to create open and seamless interoperable environments between metaverse platforms that foster innovation and collaboration. This Recommendation aims to identify the various intended service scenarios and high-level requirements of four types of metaverse cross-platform interoperability: avatar interoperability, asset interoperability, content interoperability and identity interoperability.

vi. **ITU-T Y.4515 (ex Y.IoT-MV) - Functional framework of an Internet of things (IoT) platform for metaverse applications** [Under Publication]: This recommendation provides a functional framework for IoT platforms supporting metaverse applications, including integration of heterogeneous IoT devices, standardized interfaces, interoperability, device management and reliable data exchange. It specifies functional capabilities, associated entities and the overall functional framework.

vii. **ITU-T Y.4246 (ex Y.ACC-IoTMV) - Accessibility requirements for metaverse services supporting Internet of things** [Under Publication]: This recommendation specifies accessibility requirements for IoT-supported metaverse services, including alternative representations of visual and audio information, assistive technology support and personalization features. It aims to ensure effective access, navigation, communication, understanding and interaction for persons with disabilities.

viii. **ITU-T Y.MetaExpSys - Requirements of Metaverse Experience System for Tourist Places** [Under Study]: This recommendation outlines requirements for a metaverse-enabled experience system for tourist places, supporting immersive virtual tours, interactive information overlays, real-time navigation and virtual access. It aims to improve visitor engagement, accessibility, operational efficiency and sustainable tourism development.

ix. **ITU-T Y.MetaSklSys - Requirements of Metaverse-powered skills Training System, for renewable energy plant installations and monitoring** [Under Study]: This recommendation specifies requirements for a metaverse-powered skills training system supporting renewable energy plant installation and monitoring through immersive simulations and real-time monitoring. It aims to improve operational efficiency, safety, reliability and energy production optimization.

x. **ITU-T Y.metaID - Framework and requirements for identity visualization in and across metaverse** [Under Study]: This recommendation provides a framework and requirements for identity visualization in and across metaverse environments, including identity representation, visual indicators of verified identities, cross-metaverse consistency and identity visibility controls. It aims to enhance trust in digital interactions.

xi. **ITU-T Y.Fwrk-mwell - Requirements and capability framework for IoT enabled well-being methods measurement through metaverse** [Under Study]: This recommendation outlines requirements and a capability framework for IoT-enabled measurement of well-being methods through metaverse, supporting standardized guidelines, real-time feedback, safe practice environments and certification processes. It aims to ensure instructional quality and user trust.

xii. **ITU-T Y.meta-ED - Requirements and functional architecture for IoT enabled multilingual and immersive education system** [Under Study]: This recommendation outlines functional requirements and an architectural framework for IoT-enabled multilingual and immersive education systems. It supports learner-centric educational experiences while addressing interoperability, privacy, security, accessibility and multilingual content delivery.

xiii. **ITU-T Y.Meta-PEH - Requirements and framework of metaverse for IoT-based power equipment hoisting** [Under Study]: This recommendation proposes a metaverse-based framework for IoT-enabled power equipment hoisting, integrating IoT sensing, 3D simulation, modeling and metaverse technologies. It aims to improve operational safety, efficiency and planning accuracy.

xiv. **ITU-T Y.PM-FUSG - Technical framework and use cases of the power metaverse for future urban smart grids** [Under Study]: This recommendation outlines requirements and a technical framework for the power metaverse supporting future urban smart grids. It includes use cases illustrating service scenarios and practical applications for metaverse-enabled smart grid management.

xv. **ITU-T Y.CIP - Requirements of metaverse-based emergency response in chemical industrial parks** [Under Study]: This recommendation specifies requirements for metaverse-based emergency response systems in chemical industrial parks, supporting immersive training, emergency drills, interactive visualization and real-time monitoring. It aims to strengthen emergency preparedness, improve response capabilities and mitigate operational risks.

9.2. European Union (EU) Initiatives on Metaverse

EU Strategic Vision: Web 4.0 & Virtual Worlds (Metaverse)[10]: In 2023, the Commission adopted a new strategy on Web 4.0 and virtual worlds to steer the next technological transition.

i. Communication (COM (2023) 442 final) An EU initiative on Web 4.0 and virtual worlds: a head start in the next technological transition outlines the vision, high-level objectives and actions.

ii. Commission aims for a Web 4.0 and virtual worlds that reflect EU values and principles and fundamental rights, where people can be safe, confident and empowered, where people's rights as users, consumers, workers or creators are respected and where European businesses can develop world-leading applications, scale up and grow.

iii. Communication describes virtual worlds as "persistent, immersive environments, based on technologies including 3D and extended reality (XR), which make it possible to blend physical and digital worlds in real-time, for a variety of purposes such as designing, making simulations, collaborating, learning, socializing, carrying out transactions or providing entertainment" and Web 4.0 as "the expected fourth generation of the World Wide Web.

[10] Web 4.0 and virtual worlds (RP 2025): https://interoperable-europe.ec.europa.eu/collection/rolling-plan-ict-standardisation/web-40-and-virtual-worlds-rp-2025

Using advanced artificial and ambient intelligence, the internet of things, trusted blockchain transactions, virtual worlds and XR capabilities, digital and real objects and environments are fully integrated and communicate with each other, enabling truly intuitive, immersive experiences, seamlessly blending the physical and digital worlds."

iv. The strategy aims to ensure:
   - Open, secure, trustworthy and fair virtual worlds aligned with EU values and laws.
   - Empowering citizens with skills and awareness for engagement in virtual worlds.
   - Support for business innovation and scaling of EU companies in metaverse-relevant sectors.
   - Global governance engagement to steer international standards and avoid dominance by a few global tech players.
   - This strategy ties to broader programs such as Digital Europe, Horizon Europe, Creative Europe and feeds into the EU Digital Decade strategic objectives.

The following existing EU rules also apply to many aspects of metaverse:

i. Digital Services Act (DSA) and Digital Markets Act (DMA) apply to platforms and intermediary services that metaverse platforms would also fall under.
ii. GDPR applies to user data handling, privacy, consent, etc.
iii. Proposed EU Digital Identity frameworks support age verification and trust in digital environments.

This means the policy approach so far blends tailored strategy with application of broad digital regulation frameworks.

ETSI ISG ARF (Augmented Reality Framework) defines a framework for the interoperability of AR components, systems and services that specifies relevant components and interfaces required for AR and XR solutions as the basis for metaverse applications. The design as a modular architecture allows components from different providers to interoperate through defined interfaces. Transparent and reliable interworking between different AR components fosters the successful roll-out and wide adoption of AR/XR applications and services.

Collection of use cases: GR ARF 002 "Augmented Reality Framework (ARF) Industrial use cases for AR applications and services"

Specification of the framework: GS ARF 003 "Augmented Reality Framework (ARF) AR framework architecture"

Specifications for interoperability requirements:

i. GS ARF004-1 "Augmented Reality Framework (ARF); Interoperability Requirements for AR components, systems and services; Part 1: Overview"

ii. GS ARF004-2 “Augmented Reality Framework (ARF) Interoperability Requirements for AR components, systems and services Part 2: World Storage and AR Authoring functions”
iii. GS ARF004-3 “Augmented Reality Framework (ARF); Interoperability Requirements for AR components, systems and services; Part 3: World Capture, World Analysis and Scene Management”
iv. GS ARF 004-4 “Augmented Reality Framework (ARF); Interoperability Requirements for AR components, systems and services; Part 4: World Analysis, World Storage and Scene Management functions”
v. GS ARF004-5 “Augmented Reality Framework (ARF); Interoperability Requirements for AR components, systems and services; Part 5: External Communications”

OpenAPI specification: GS ARF 005 “Augmented Reality Framework (ARF); Open APIs for the Creation and Management of the World Representation”

ETSI ISG CIM (crosscutting Context Information Management) has consistently demonstrated a strong interest in Digital Twins, which is evidenced by the implementation of the document ‘Feasibility of NGSI-LD for Digital Twins’ (GR CIM 017 v1.1.1). The group is investing time and resources to identify how to align the NGSI-LD API (GS CIM 009 v1.8.1) for use in VR/AR applications (ETSI ISG CIM GR 0052 “VR and AR for Smart Learning: Guidelines for using NGSI-LD to train personnel in Smart Industries”).

10. Conclusion

The transition towards metaverse represents a paradigm shift in how digital and physical realities interact. As this technical report has outlined, metaverse is not a singular technology but a complex, converging ecosystem driven by Extended Reality, Artificial Intelligence, Cloud Computing, Blockchain and other emerging technologies. At the heart of this transformation is the seamless integration of physical and virtual domains, anchored by IoT and digital twins.

Realizing the vision of a persistent, interactive and immersive metaverse hinges on the establishment of robust architectural frameworks. The reference model for digital twin Integration for metaverse, detailed in this report, highlights the role of the specialized Systems Integration Functions and Digital Twin Integration Functions. These functional entities ensure seamless data acquisition, real-time synchronization and third-party service orchestration. However, these architectures cannot function in isolation; they are entirely dependent on next-generation telecom and ICT infrastructure. High-bandwidth, ultra-low-latency cellular connectivity (5G and beyond) and distributed edge computing are non-negotiable pre-requisites for delivering the multimodal, multilingual and real-time experiences that users and industrial applications will demand.

While the transformative potential of metaverse is evident across diverse applications, from immersive digital exhibitions and real estate to complex industrial IoT deployments, widespread adoption is contingent upon overcoming substantial societal and technical hurdles. The complexities of seamless interoperability, persistent network reliability and the precise synchronization of physical and virtual objects demand rigorous solutions. Furthermore, as the divide between physical and digital identities dissolves, instituting trust, safety, security and privacy as foundational principles is of paramount importance. Ultimately, the success of metaverse relies on deploying resilient cybersecurity protocols, robust digital identity management and stringent data governance to ensure unwavering user confidence.

Ultimately, the successful deployment of a scalable metaverse relies on global standardization. The fragmented development of closed ecosystems will stifle innovation and limit interoperability. The initiatives spearheaded by organizations such as the ITU and other global SDOs are critical steps toward harmonizing technical specifications for metaverse. By establishing standardized interfaces, unified communication protocols and universal interoperability frameworks, these bodies are laying the groundwork for a cohesive metaverse ecosystem.

In parallel with technological advancements and standardization efforts, governments and regulatory authorities have a pivotal role in fostering a secure, trusted and innovation-friendly metaverse ecosystem. The rapid convergence of virtual and physical worlds necessitates the development of comprehensive legal and regulatory frameworks addressing critical issues such as digital identity, privacy and data protection, cybersecurity, consumer protection, intellectual property rights, virtual asset governance, content moderation and cross-border data flows. Regulatory approaches should strike an appropriate balance between innovation and oversight, enabling businesses to experiment and invest while safeguarding the rights and interests of citizens.

Moving forward, the realization of metaverse requires unprecedented collaboration. Government, telecom operators, ICT providers, standards organizations, platform providers, content creators, digital asset providers and industry innovators must work in tandem to build intelligent and scalable infrastructure. By prioritizing open standards, secure architectures and inclusive design, the global community can ensure that metaverse evolves into a sustainable, accessible and transformative digital environment that benefits both industry and society at large.

Appendix 1: Use cases in the field of metaverse

A1.1 Use Case 1: Industrial metaverse for Smart Manufacturing and Workforce Training

Description

Manufacturing sector is integrating AR/VR-powered industrial metaverse solutions with digital twins and IIoT to accelerate workforce training, enhance maintenance efficiency and scale operational impact. These immersive environments enable step-by-step visual guides for repairs, rapid defect detection and remote collaboration across geographically dispersed plants.

Example – Ericsson, Volvo Group & Bharti Airtel Partnership[11]

M/s Ericsson, Volvo Group and Bharti Airtel partnered to explore XR, digital twins and AI in manufacturing using 5G Advanced at Volvo Group's factory and R&D centre in Bengaluru. The focus is on industrial metaverse applications enabling human-machine collaboration by merging physical and digital environments.

Impact

i. Reduced downtime & errors: Step-by-step visual guides minimize rework and enhance productivity while pre-delivery checks detect issues early.
ii. Accelerated training: Digital simulations slash training time for equipment disassembly, reassembly and quality checks.
iii. Real-time process optimization: 5G Advanced network supports real-time simulations and design prototyping without disrupting factory operations.

Key Beneficiaries

i. Manufacturing workers: Gain hands-on practice with complex equipment in a safe virtual environment.
ii. Factory operators: Remote experts can guide on-site technicians through AR overlays.
iii. India's Industry 4.0 vision: Supports government's push for smart infrastructure and digital twin adoption.

Key Technologies

i. Digital twins and IIoT integration
ii. 5G/5G Advanced connectivity for low-latency XR
iii. AR/VR training simulations with visual repair guides
iv. Cloud-based collaboration and analytics platforms

[11] https://www.volvogroup.com/en/news-and-media/news/2025/mar/ericsson--volvo-group--and-airtel-announce-research-collaboratio.html

A1.2 Use Case 2: Virtual Cultural Tourism & Heritage Preservation

Description

Metaverse is leveraged to bring its rich cultural and spiritual heritage to a global audience, enabling immersive virtual exploration of temples, monuments and historical landmarks. These virtual platforms combine 3D scanning, AI and spatial audio to recreate authentic experiences, including seasonal variations, festival celebrations and historical narration.

Example – KiyaAI's Bharatmeta[12]

KiyaAI partnered with the Ayodhya Development Authority to launch Bharatmeta, India's first indigenous metaverse platform, featuring immersive 3D experiences of the Ram Janmabhoomi temple, Hanuman Garhi and Sarayu River ghats. The platform also integrates India's digital payment systems and open commerce. Bharatmeta has already delivered metaverse experiences for Mata Vaishno Devi temple and Kashi Vishwanath temple.

Impact

i. Global accessibility: Users worldwide can virtually explore India's sacred and heritage sites, overcoming physical, financial or mobility barriers.
ii. Cultural preservation: Digital archiving protects historical sites from natural decay, vandalism or conflict.
iii. Tourism boost: Virtual experiences spark interest in real-world travel, increasing footfall at destinations.

Key Beneficiaries

i. Domestic & international tourists: Experience India's heritage from anywhere, at any time.
ii. Pilgrims & elderly devotees: Access sacred sites without arduous travel.
iii. Heritage conservationists: Digital documentation aids structural monitoring and restoration planning.

Key Technologies

i. Photorealistic 3D modeling and 360° rendering
ii. AI-powered guided tours and historical narration
iii. Spatial audio for immersive atmosphere
iv. Blockchain-based metaverse platform
v. Cross-device compatibility (VR headsets and AR devices)

[12] https://www.kiya.ai/bharatmeta-taking-india-forward-as-the-leading-force-in-the-area-of-metaverse/

A1.3 Use Case 3: Gaming & social interactions in metaverse

Description

Metaverse integrates gaming and social interaction into unified, persistent environments. Instead of fragmented ecosystems where games and social platforms are separate, users can participate in User-Generated Content (UGC) worlds, maintain persistent avatars across experiences and engage in multiplayer activities with low latency. This convergence transforms gaming into a social hub, where entertainment, community and commerce coexist seamlessly.

Figure 11: Gaming & Social Interactions in metaverse

Impact

i. Unified ecosystem: Achieved by merging gaming and social platforms into persistent worlds, reducing fragmentation.
ii. Stronger community engagement: Persistent avatars allow users to build long-term identities and relationships across games.
iii. Enhanced multiplayer experiences: Low-latency telecom infrastructure ensures smooth and real-time interactions.
iv. Massive market potential: With over 500M gamers globally, metaverse expands reach and monetization opportunities.

Key Beneficiaries

i. Gamers: Gain richer, more social experiences with persistent avatars and UGC-driven worlds.

ii. Game developers: Access new revenue streams by integrating social features and persistent economies.
iii. Telecom Service Providers: Benefit from demand for low-latency, high-bandwidth infrastructure supporting multiplayer gaming.
iv. Communities: Build stronger digital social networks through shared gaming experiences.

Key Technologies

i. UGC platforms: Allow players to create and share worlds, expanding creativity and engagement.
ii. Persistent avatars: Enable continuity of identity across games and social spaces.
iii. Low-latency telecom infrastructure: Supports real-time multiplayer interactions without lag.
iv. Cross-platform engines: Ensure interoperability between gaming and social applications.
v. Cloud-based multiplayer servers: Scale to support millions of concurrent players globally.

A1.4 Use Case 4: Avatar-led e-Commerce in metaverse

Description

Metaverse enables e-commerce platforms to integrate lifelike avatars that act as brand representatives and virtual try-on assistants. Customers can interact with avatars to explore products, visualize clothing or accessories on themselves and receive personalized recommendations. These avatars replicate human-like engagement, reducing the gap between online and in-store shopping experiences. Telecom infrastructure supports this by delivering high-bandwidth 3D content in real time, ensuring smooth and immersive interactions.

Figure 12: Avatar-led e-Commerce

Impact

i. Higher customer engagement: Achieved through interactive avatar try-ons that replicate the experience of physically testing products.
ii. Reduced product returns: Customers make more informed decisions by visualizing items on avatars, lowering mismatch risks.
iii. New revenue streams: AI-driven brand avatars upsell and cross-sell products, boosting sales.
iv. Market expansion: With a Total Addressable Market (TAM) exceeding $200B, avatar-led commerce scales e-commerce globally.

Key Beneficiaries

i. Consumers: Benefit from personalized, immersive shopping experiences that reduce uncertainty and improve satisfaction.
ii. E-commerce platforms: Gain higher engagement, lower return rates and stronger brand loyalty.
iii. Retail brands: Showcase products in innovative ways, reaching global audiences with avatar-led interactions.
iv. Telecom Service Providers: Provide the high-bandwidth infrastructure needed for real-time 3D commerce experiences.

Key Technologies

i. 3D avatar rendering engines: Enable lifelike virtual try-ons for clothing, accessories and products.
ii. AI-powered brand representatives: Deliver personalized recommendations and interactive sales support.
iii. High-bandwidth telecom infrastructure: Ensures smooth delivery of real-time 3D content to users.
iv. AR integration: Allows customers to project products onto their own environment for contextual visualization.
v. Cloud-based commerce platforms: Scale avatar-led interactions globally, supporting millions of concurrent users.

A1.5 Use Case 5: Metaverse enabled Entertainment

Description

Metaverse transforms live entertainment by creating immersive, multi-sensory concert experiences that transcend physical boundaries. Fans can attend virtual performances from anywhere in the world, interact with artists and collect digital keepsakes. MR performances blend physical and virtual stages, amplifying the emotional connection between music and audience. These experiences democratize access to cultural events, making them inclusive for global audiences and individuals with disabilities.

Example – Music Festival: Coachellaverse[13]

Coachella expanded beyond its physical grounds with the Coachellaverse, a multi-sensory AR music experience. Fans worldwide engage in immersive virtual spaces, collect digital keepsakes and enjoy MR performances. This bridges the gap between the festival and remote audiences, offering an improved experience compared to traditional concerts.

Impact

i. Global reach: Virtual concerts allow fans worldwide to participate, achieved through immersive platforms accessible across devices.

ii. Increased revenue for artists and organizers: Digital tickets, virtual merchandise and keepsakes create new monetization streams.

iii. Enhanced inclusivity: Fans with disabilities or mobility limitations can attend without barriers, enabled by accessible virtual environments.

iv. Stronger emotional connection: Multi-sensory immersion and interactive features deepen audience engagement compared to traditional concerts.

Key Beneficiaries

i. Fans: Gain access to concerts regardless of geography or physical limitations, with richer interactive experiences.

ii. Artists: Reach larger audiences, experiment with creative MR performances and diversify revenue streams.

iii. Event organizers: Expand brand presence globally and reduce dependency on physical infrastructure.

iv. Communities: Benefit from cultural democratization, where iconic events are accessible to all.

Key Technologies

i. Immersive Virtual Spaces: Provide interactive environments where fans can explore, socialize and attend performances.

ii. AR and MR: Blend physical and digital stages, enhancing live performances.

iii. Virtual Keepsakes/NFTs: Enable fans to collect unique digital memorabilia, supporting new revenue models.

[13] https://time.com/6168688/coachella-enters-the-metaverse/

iv. Multi-sensory streaming platforms: Deliver audio-visual experiences with enhanced immersion, supporting global scalability.

v. Accessibility features: Ensure inclusive participation for fans with disabilities, such as customizable avatars and adaptive interfaces.

A1.6 Use Case 6: Metaverse enabled Real Estate

Description

Metaverse transforms property exploration by enabling immersive and interactive virtual tours. Buyers can remotely walk through homes, examine layouts and visualize spaces in 3D without visiting physical visits. Beyond property showcases, metaverse platforms support virtual interior design, allowing buyers to experiment with furniture placement, décor and customization before purchase. This creates a more informed, engaging and convenient buying experience.

Example – Sotheby's International Realty

Sotheby's International Realty[14] has embraced technology to redefine how buyers explore homes with the help of 3D and VR tours, interactive features and AI-powered recommendations to redefine luxury property exploration. Buyers can virtually tour properties, test interior design options and receive personalized suggestions, significantly improving decision-making and reducing the need for repeated physical visits.

Impact

i. Improved buyer experience: Achieved through immersive tours that replicate the feeling of being inside the property.
ii. Reduced need for physical visits: Virtual showcases save time and effort for both buyers and agents.
iii. Enhanced decision-making: Interior design visualization helps buyers see how spaces can be customized before committing.
iv. Expanded market reach: Properties can be showcased globally, attracting international buyers without geographical constraints.

Key Beneficiaries

i. Property buyers: Gain convenience, confidence and personalization in exploring and customizing homes remotely.
ii. Real estate agents: Showcase properties more effectively, reduce logistical challenges and reach wider audiences.

[14] https://www.sothebysrealty.com/extraordinary-living-blog/sothebys-international-realty-global-website-integrates-new-technologies

iii. Developers and sellers: Attract global buyers and differentiate offerings with immersive experiences.
iv. Interior designers: Use virtual tools to collaborate with clients on layouts and décor before physical implementation.

Key Technologies

i. 3D and VR tours: Provide immersive property walkthroughs, replicating real-world exploration.
ii. Interactive features: Allow buyers to engage with property details, floor plans and customization options.
iii. AI-powered recommendations: Suggest properties and design options tailored to buyer preferences.
iv. Virtual interior design platforms: Enable visualization of furniture and décor, supporting informed decisions.
v. Cloud-based property databases: Ensure scalability and accessibility for global audiences.

A1.7 Use Case 7: Immersive Communication for Digital Humans[15]

Description

Metaverse enables the creation of lifelike digital humans that serve as customer service representatives, educators, or companions in immersive communication environments. These digital humans can be generated through human-driven or computer-driven methods, using 3D engine modelling and rendered into real-world backgrounds. They replicate facial expressions, body gestures and voice interactions, creating natural and engaging communication experiences.

Example – Telecom Operators & Customer Service

Telecommunication companies are deploying digital humans for customer service. These avatars are generated via local or cloud servers, rendered in virtual spaces and transmitted to users' devices through efficient codecs. Customers interact with them online or offline to resolve queries, handle business processes and receive personalized support.

[15] https://www.itu.int/en/ITU-T/focusgroups/mv/Documents/List%20of%20FG-MV%20deliverables/FGMV-39.pdf

Figure 13: One type of digital human for customer service

Impact

i. Improved customer experience: Achieved through natural, human-like interactions that reduce frustration compared to traditional chatbots.
ii. Operational efficiency: Digital humans handle routine queries, freeing human agents for complex cases.
iii. Scalability: Virtual agents can serve millions simultaneously, supported by cloud infrastructure.
iv. Brand differentiation: Companies enhance their image by offering cutting-edge, personalized customer service.

Key Beneficiaries

i. Customers: Gain faster, more intuitive support through lifelike avatars available 24/7.
ii. Telecom Service Providers: Reduce costs, improve efficiency and expand service capacity.
iii. Businesses across sectors: Adopt digital humans for sales, training or healthcare support, benefiting from scalable communication.
iv. Employees: Freed from repetitive tasks, they can focus on higher-value, complex problem-solving.

Key Technologies

i. 3D engine virtual space modelling: Builds realistic avatars with facial and body expressions.
ii. Voice synthesis models: Generate natural speech, enabling fluid conversations.
iii. Action-driven models & training data: Support realistic gestures and emotional responses.
iv. Efficient codecs: Ensure smooth transmission of digital humans to mobile and PC devices, even offline.
v. Cloud/local servers: Provide scalable infrastructure for rendering and deploying digital humans.

A1.8 Use Case 8: Interactive sports viewing in metaverse

Metaverse can enable users to watch the sports competition with immersive experiences. It includes multi-view angle and multiple degree of freedom from the viewer's position with a mobile phone or VR equipment. Using only a mobile phone or a VR headset, users can choose their own camera angles (e.g., goal-side, player-tracking or referee perspective) and feel a near on-site presence. Users will have a near on-site immersive watching experience in the competition process and enjoy the charm of the competitive sports. Immersive video coding can provide efficient data compression, data reconstruction, data rendering with input data including multi-view angle videos, depth map and camera parameters to ensure immersive experiences.

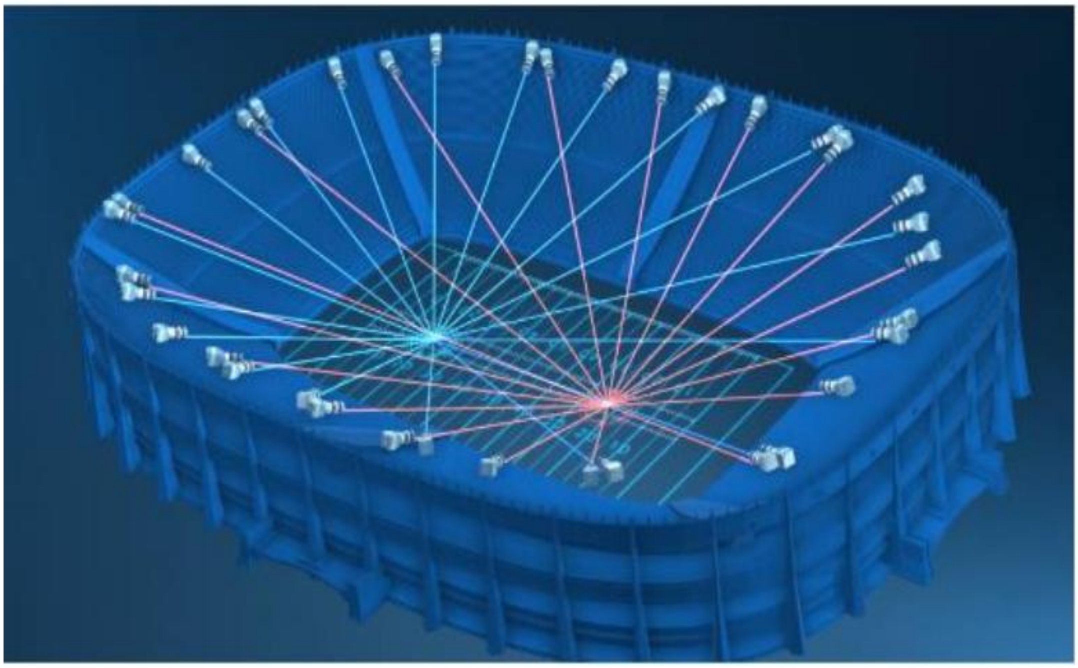

Figure 14: True view platform volumetric capture at a stadium.

Example – Viacom18's Metaverse Sports Broadcast for IPL (Illustrative based on JioCinema's 2023-24 multi-camera innovations)[16]

During the Indian Premier League (IPL) 2023-24 season, Viacom18 (JioCinema) experimented with metaverse-style features: multiple camera angles (helmet-cam, stump-cam, drone-cam), 4K 360° replays and an interactive "Virtual Dugout" where fans could join digital watch-parties with celebrities. Using a mobile-first approach, millions of users switched angles in real time. The platform employed advanced video coding and edge computing to deliver low-latency, high-quality streams. A similar model is being tested for FIFA World Cup broadcasts via FIFA+ and for the Olympic Broadcasting Services' "Intentional Camera" project.

Impact

i. Enhanced fan engagement: Viewers become active participants – choosing angles, replays and stats, that has increased watch time and emotional connection.
ii. Accessible "near-live" experience: Fans who cannot attend stadiums (due to cost, distance, or capacity) get a richer experience than traditional TV.
iii. New revenue streams: Broadcasters can offer premium metaverse tiers (e.g., player-cam, VR locker-room access) and interactive ads.
iv. Lower infrastructure cost for niche sports: Smaller leagues can use metaverse streaming to reach global audiences without building huge physical venues.

Key Beneficiaries

i. Sports fans (especially younger, tech-savvy audiences): Enjoy customizable, immersive viewing from any device.
ii. Broadcasters and OTT platforms: Differentiate their service, increase user retention and unlock new advertising formats.
iii. Sports leagues and teams: Build deeper fan relationships and sell virtual tickets / merchandise inside metaverse.
iv. Technology providers (video coding, edge cloud, XR hardware): Gain large-scale deployment opportunities.

Key Technologies

i. Immersive video coding (multi-view video + depth maps + camera parameters
ii. 6DoF (Six Degrees of Freedom) rendering and view synthesis for free-viewpoint video
iii. Low-latency streaming (edge computing, WebRTC, 5G)
iv. VR headsets and mobile AR/VR frameworks (WebXR, OpenXR)
v. Real-time 3D overlays (player tracking data, live statistics, virtual ads)

[16] https://www.sportsvideo.org/2024/04/25/viacom18-premiers-new-virtual-jiocinema-sportsplex-for-start-of-their-ipl-coverage/

A1.9 Use Case 9: Metaverse Art Gallery

Description

A metaverse art gallery is a virtual 3D space where users from around the world can experience paintings, sculptures, installations and digital art. Visitors navigate through themed halls, zoom in on fine details, walk around sculptures for 360° views and access audio guides or written descriptions. AR features let users "place" a digital artwork in their own physical space (e.g., on a living room wall) to preview, scale and fit. The gallery also hosts live virtual events: artist talks, curator tours and interactive workshops, making high-culture accessible to global audiences regardless of location or mobility.

Figure 15: Metaverse Arts Exhibition Hall

Example – WoWExp's "Art Metaverse" Pilot with various Indian Art Fair

M/s WoWExp conducted local art events for traditional and NFT artists in Delhi and Mumbai. Building on that, they launched "Sangam Art Metaverse" – a virtual gallery featuring 50+ contemporary Indian artists. Users enter via VR headset or web browser, walk through galleries recreating real-world venues (e.g., NGMA, Jehangir Art Gallery) and interact with digital twins of physical paintings. A special AR mode allows collectors to project a purchased artwork onto their wall before buying. The platform hosted a live panel discussion with three renowned artists, attracting 2,000+ attendees from various countries.

Impact

i. Democratized art access: Anyone with an internet connection can view world-class art without travel or ticket costs.
ii. Enhanced artist reach: Emerging and regional artists gain global visibility, selling NFTs or physical prints via integrated links.
iii. Immersive education: Audio guides and 3D exploration deepen appreciation, making art history engaging for students.
iv. New revenue models: Galleries can sell virtual tickets, host paid workshops or offer AR previews for art sales.

Key Beneficiaries

i. Art enthusiasts and students: Explore diverse art styles interactively, from anywhere.
ii. Traditional and NFT artists: Showcase work to a global audience without physical gallery constraints.
iii. Art galleries and museums: Extend physical exhibitions into metaverse, increasing footfall and digital engagement.
iv. Collectors and buyers: Use AR to visualize art in their own space before purchasing.

Key Technologies

i. VR and web-based metaverse platform
ii. 3D rendering for artworks and gallery spaces
iii. AR for virtual “try-before-you-buy” art placement
iv. Audio guides and descriptive text overlays
v. Live event streaming and interactive chat for artist talks and workshops

A1.10 Use Case 10: Education through metaverse

Description

Metaverse has the potential to transform education into a highly immersive and personalized experience. Books can become interactive gateways to simulations, 3D visualizations and virtual learning environments that adapt to each learner's progress, preferences and prior knowledge. Learning can seamlessly resume from where a student left off, with context preserved across devices and experiences.

Concepts such as "Metaversities"[17] are emerging, creating digital twins of universities that make world-class education accessible from anywhere in the world and make it inclusive. As immersive technologies and AI evolve, education may shift away from rote memorization toward problem-solving, creativity and the effective use of intelligent tools.

[17] https://www.metaversity.com/

Learners can interact directly with educational content by asking questions, collaborating with peers and receiving guidance from educators or AI tutors within the learning environment. The entire learning journey can be captured, enabling automatic generation of notes, highlights, summaries and personalized insights that improve knowledge retention and lifelong learning.

Example – University of Oxford & Oxford Medical Simulation (OMS)[18]

Metaverse enables immersive, interactive environments where medical students can practice clinical procedures, decision-making and communication in risk-free simulations. These environments replicate real-world medical scenarios, allowing repeated practice that builds competence and confidence without endangering patients. Learners can access modules globally, using VR headsets or desktop-based simulations, making advanced training scalable and flexible.

University of Oxford, England has adopted OMS to provide immersive VR simulations where students treat acutely unwell patients in realistic, repeatable scenarios. OMS integrates headset-based and on-screen modules, covering a wide range of emergencies and procedures, while also developing communication skills through AI-driven virtual patients and voice interaction.

Impact

i. Enhanced competence and confidence: Achieved through repeated exposure to realistic scenarios that mirror actual emergencies.

ii. Improved patient safety: Students practice on virtual patients, reducing risks during early clinical training.

iii. Expanded access to advanced education: Remote learners can engage in high-quality training without needing physical labs or hospitals.

iv. Flexible learning modalities: Both headset-based and on-screen simulations allow institutions to adapt training to resources and learner needs.

Key Beneficiaries

i. Medical students and trainees: Gain hands-on experience in a safe, repeatable environment, improving readiness for real-world practice.

ii. Universities and teaching hospitals: Reduce costs and logistical challenges of physical training labs while maintaining high-quality education.

iii. Healthcare systems: Benefit from professionals entering the workforce with stronger skills and decision-making abilities.

iv. Patients: Ultimately receive safer, more effective care from better-trained doctors.

[18] https://oxfordmedicalsimulation.com/platform/

Key Technologies

i. VR simulation platforms: Provide immersive, high-fidelity environments for practicing medical scenarios.

ii. AI-driven virtual patients and caregivers: Enable realistic interactions, supporting both clinical reasoning and communication skill development.

iii. Voice interaction and natural language processing: Allow learners to practice handling difficult conversations with patients and colleagues.

iv. Scenario libraries: Offer diverse emergency and procedural cases, ensuring comprehensive training coverage.

v. Cloud-based learning management and analytics: Track learner progress, provide feedback and scale training across institutions.

A1.11 Use Case 11: Metaverse for Solar Energy Education & Vocational Training

Description

SpitVR is a metaverse / VR product designed to educate solar energy enthusiasts through immersive simulation environments. Learners experience step-by-step virtual training on solar energy fundamentals, panel design, manufacturing processes and safe installation practices. The platform covers beginner to advanced knowledge that is sufficient to prepare a solar engineer or technician for real-world tasks. It is tailored for students pursuing Trade Certificates, Diplomas or Bachelor's degrees at ITIs, engineering colleges and polytechnic institutes, regardless of their current semester.

Example – WoWExp's spitVR Pilot at ITI Bengaluru (Illustrative, based on skill development partnerships)

M/s WoWExp developed spitVR as a VR-based informational product comprising modules on photovoltaic cell operation, rooftop load calculation, panel assembly and safety protocols. In a pilot with ITI Bengaluru's electrical trade program, 80 students used low-cost VR headsets to practice installing panels on virtual rooftops under varying sun angles and weather conditions. The simulation tracks errors (e.g., improper earthing, shading losses) and provides instant feedback. After completing the 30-hour program, students reported 40% higher confidence in handling real installations and the institute reported reduced need for physical solar lab equipment.

Impact

i. Accelerated vocational readiness: Students gain hands-on experience without waiting for live projects or expensive lab setups.
ii. Risk-free practical training: Dangerous mistakes (electrical faults, fall hazards) are simulated safely, with corrective guidance.
iii. Scalable and repeatable: Hundreds of students across multiple colleges can access the same high-quality training anytime.

iv. Standardized knowledge: Ensures uniform skill levels across different institutes and states, supporting India's solar workforce goals.

Key Beneficiaries

i. ITI, polytechnic and engineering students: Build job-ready solar skills in an engaging, gamified environment.
ii. Vocational training institutes: Offer advanced practical training without heavy investment in physical solar labs.
iii. Solar energy companies: Hire graduates with verified simulation-based practice, reducing on-boarding time.
iv. Government skill development missions (e.g., Suryamitra, NSDC): Scale up quality training for India's renewable energy targets.

Key Technologies

i. VR simulation platform with physics-based solar models
ii. Low-cost VR headsets and WebXR for desktop fallback
iii. Interactive 3D modules for design, manufacturing and installation
iv. Real-time error tracking and feedback analytics
v. Cloud-based content updates and learner progress dashboards

A1.12 Use Case 12: Digital Twin based metaverse for Smart Urban Planning and Infrastructure

Description

Cities are adopting digital twins of physical urban environments for real-time simulation, monitoring and optimization of urban systems. These virtual city models integrate data from IoT sensors, satellite imagery and municipal records to enable data-driven decisions for traffic management, utility distribution, emergency response and future infrastructure planning.

Example – Mumbai Metropolis Metaverse

At Mumbai Tech Week, Deputy Chief Minister of Maharashtra unveiled the "Mumbai Metropolis Metaverse," a digital twin project showcasing ongoing infrastructure developments and the intended transformation of the Mumbai Metropolitan Region by 2025. M/s NVIDIA also unveiled an AI blueprint to aid Indian smart cities, enabling developers to create SimReady digital cities using satellite and aerial imagery.

Impact

i. Data-driven urban planning: Simulate infrastructure projects before breaking ground, optimizing designs and reducing costly errors.

ii. Real-time city management: Integrate live data from traffic signals, water pipes and power grids for immediate issue detection.
iii. Disaster resilience: Model flood risks and evacuation routes, improving emergency preparedness.
iv. Citizen engagement: Allow residents to visualize proposed developments in 3D, fostering participatory governance.

Key Beneficiaries

i. City planners & municipal corporations: Access powerful simulation tools for smarter planning.
ii. Citizens: Benefit from reduced traffic congestion, better utility management and responsive city services.
iii. Construction companies: Optimize project timelines and resource allocation through virtual pre-construction modeling.

Key Technologies

i. 3D digital twin platforms
ii. IoT sensor networks for real-time data ingestion
iii. AI for predictive analytics and scenario modeling
iv. Satellite and aerial imagery for base mapping

A1.13 Use Case 13: Digital Twin based metaverse for Smart Agriculture and Precision Farming

Description

The agricultural metaverse creates a digital realm linked to the physical world of farming, where digital twins, virtual simulations and data analytics enable farmers to perform predictive maintenance, immersive training, remote monitoring and group decisions. Farmers can test planting patterns, irrigation schedules and fertilizer use without real-world risk. NITI Aayog has emphasized that metaverse technologies can be used for agricultural forecasting, disease forecasting and deep science applications.

Example – IFFCO's Mixed Reality Campaign for Nano Urea Education

In Punjab and Haryana, IFFCO is equipping farmers with information on how Nano Urea can boost crop productivity. By scanning a QR code on in-store standees, farmers enter a virtual world demonstrating Nano Urea's usage and benefits. Additionally, M/s ANNAM.AI and IIT Ropar have built the world's first real-plant digital twin.

Impact

i. Yield improvement & resource efficiency: Significant gains in crop yield and resource use documented through AI+XR case studies.

ii. Risk reduction: Farmers test interventions virtually before committing resources in the physical field.
iii. Sustainability: Reduced water consumption and optimized fertilizer application lower environmental footprint.
iv. Data-driven decision making: Remote monitoring enables real-time adjustments based on precise field data.

Key Beneficiaries

i. Small and marginal farmers: Gain access to precision agriculture insights without expensive trial-and-error.
ii. Agronomists & extension officers: Use virtual simulations to advise multiple farmers simultaneously.
iii. Agri-cooperatives: Pool data for collective decision-making on irrigation schedules, pest control and crop rotation.

Key Technologies

i. Digital twins of crops and agricultural fields
ii. MR and VR for immersive training
iii. AI and machine learning for predictive analytics
iv. IoT sensors (soil moisture, weather, pest detection)
v. Cloud-based remote monitoring platforms

A1.14 Use Case 14: Metaverse enabled Healthcare

Description

Metaverse has the potential to transform fitness and wellness by making healthy living more immersive, engaging and personalized. Virtual fitness studios can bring together activities such as yoga, strength training, dance and guided workouts in highly interactive and gamified environments. Users can exercise alongside friends, compete with others through personalized avatars and receive coaching from virtual trainers inspired by athletes, fitness experts or healthcare professionals.

Beyond structured workouts, metaverse can encourage everyday physical activity. People may take virtual walks through historical cities, scenic landscapes or fantasy worlds while exercising alone or socially with others. AI-powered fitness companions can provide real-time motivation, track progress and offer personalized recommendations, making fitness a more enjoyable and sustainable habit.

Spatial computing and smart glasses can further enhance wellness by providing contextual information about nutrition and health. By simply looking at food items, users could receive insights into calorie content, nutritional value, allergens and dietary recommendations, helping them make more informed choices throughout the day.

Metaverse also holds significant promise for mental health and emotional well-being. Immersive experiences can be used for relaxation, meditation, stress management, exposure therapy and rehabilitation. Carefully designed virtual environments may help individuals cope with anxiety, trauma and certain phobias by providing safe, controlled and personalized therapeutic experiences. As these technologies mature, metaverse could become a powerful platform for both physical fitness and holistic well-being.

Example – Stanford VR-IT Clinic[19]

Metaverse provides secure, immersive environments where patients can engage in behavioral therapy sessions tailored to their specific needs. Virtual spaces can mimic real-world scenarios or triggers associated with psychiatric conditions, such as anxiety disorders, enabling exposure therapy in a controlled setting. Patients and therapists interact through personalized avatars, reducing stigma and encouraging openness. The sense of "presence" enhances immersion, making therapy more engaging and effective.

Stanford's Virtual Reality and Immersive Technology (VR-IT) Clinic integrates evidence-based psychotherapies, clinical research and medical technologies within private virtual environments. Patients participate in therapy sessions designed to replicate real-world triggers, while AI algorithms track progress, suggest coping strategies and provide resources to empower patients in managing their mental health.

Impact

i. Enhanced therapeutic engagement: Achieved through immersive environments that foster presence and reduce distractions compared to traditional settings.

ii. Reduced stigma: Avatars allow patients to express themselves more freely, lowering barriers to participation.

iii. Personalized treatment: AI-driven tracking tailors coping strategies and resources to individual patient needs.

iv. Scalable access: Virtual clinics extend mental health services to remote or underserved populations.

Key Beneficiaries

i. Patients with psychiatric conditions: Gain safe, stigma-free environments to practice coping strategies and receive therapy.

ii. Therapists and clinicians: Access tools to monitor patient progress in real time and adjust treatment dynamically.

[19] https://med.stanford.edu/psychiatry/patient_care/vrit.html

iii. Healthcare institutions: Expand reach of mental health services without physical infrastructure constraints.

iv. Society at large: Benefits from improved mental health outcomes, reduced stigma and broader access to care.

Key Technologies

i. VR environments: Create immersive therapy spaces replicating real-world triggers for exposure therapy.

ii. Personalized avatars: Support patient identity expression, reduce stigma and encourage openness in therapy.

iii. AI algorithms: Track patient progress, recommend coping strategies and deliver tailored resources.

iv. Clinical research integration: Ensures therapies are evidence-based and continuously refined.

v. Secure virtual platforms: Guarantee privacy and confidentiality, critical for sensitive mental health sessions.

A1.15 Use Case 15: Metaverse enabled Banking & Virtual Financial Services

Description

Financial institutions are adopting metaverse platforms to deliver personalized, secure and scalable virtual banking experiences. These platforms combine immersive design, AI-driven avatars and open banking APIs to allow customers to explore banking products, check balances, view transactions and receive financial advice in engaging virtual environments**.**

Example – Tech Mahindra's "Uni-Verse" for Union Bank of India[20]

M/s Tech Mahindra's Makers Lab introduced "Uni-Verse", a metaverse banking platform for Union Bank of India that generated over 76,000 leads for the bank. The platform offers immersive web and VR-based banking with avatars and interactive elements, using open banking APIs. The solution is AI-driven, personalized, secure and scalable**.**

Impact

i. Enhanced customer engagement: Immersive banking experiences increase customer dwell time and satisfaction.

ii. Lead generation: Demonstrated ability to generate significant qualified leads (76,000+ for Union Bank).

[20] https://www.techmahindra.com/insights/press-releases/tech-mahindra-partners-union-bank-india-launch-indias-first-psu-metaverse-lounge-uni-verse/

iii. Financial inclusion: Virtual banking reduces the need for physical branch visits, particularly beneficial for remote customers.

Key Beneficiaries

i. Bank customers: Enjoy personalized, anytime banking with AI-driven avatars for financial guidance.
ii. Banks & financial institutions: Reduce branch infrastructure costs while increasing customer acquisition.
iii. Unbanked populations: Gain easier access to financial products through simplified virtual interfaces.

Key Technologies

i. AI-driven avatars for personalized banking support
ii. Open banking APIs for real-time account access
iii. Immersive web and VR-based banking interfaces
iv. Secure blockchain for transactions and credentialing

A1.16 Use Case 16: Metaverse for Immersive e-Governance & Citizen Services

Description

Governments are actively exploring metaverse adoption for citizen-centric service delivery, enabling services and applications to be accessed through avatars 24/7 from anywhere. This Meta-governance model built on Web 3.0 principles — can transform citizen interactions with government, from virtual help desks and meta-town halls to immersive public awareness campaigns.

Example – Telangana's SpaceTech Framework Launch on Metaverse[21]

The Government of Telangana launched India's first official government event hosted on metaverse to unveil its SpaceTech Framework policy. The event featured a space-themed metaverse environment and custom avatars of key dignitaries. NITI Aayog has outlined a meta-governance model including "Meta-Mann ki Baat" and interactive governance where citizens ask questions in meta-town halls.

Impact

i. 24/7 accessibility: Government services available anytime, anywhere through avatar-based interfaces.
ii. Rural inclusion: Citizens in remote areas access urban-quality public services without travel.
iii. Enhanced civic engagement: Immersive formats increase participation in public consultations and grievance redressal.

[21] https://telanganatoday.com/telangana-to-launch-spacetech-framework-on-metaverse

Key Beneficiaries

i. Citizens in remote/rural areas: Access certificate downloads, tax payments, welfare schemes through metaverse portals.
ii. Government agencies: Reduce operational costs associated with physical service centers.
iii. Students & researchers: Participate in meta-dialogues with policymakers.

Key Technologies

i. Avatar-based service interfaces (Web 3.0)
ii. Blockchain for secure credentialing and transactions
iii. AR/VR for immersive help desks and training
iv. AI-powered virtual assistants for citizen queries
v. Integration with India's digital infrastructure (UPI, Aadhaar, DigiLocker)

A1.17 Use Case 17: Metaverse for Immersive Virtual Museums & Interactive History

Description

Museums are adopting XR and AI technologies to transform static historical exhibits into immersive, interactive experiences where visitors engage with lifelike 3D avatars of historical figures, explore digitally reconstructed heritage sites and experience history through virtual tours. The approach makes history engaging for younger generations while preserving archival material.

Example 1– Pradhanmantri Sangrahalaya's AI HoloBoxes[22]

Pradhanmantri Sangrahalaya in New Delhi unveiled AI-powered HoloBoxes featuring hyper-realistic 3D avatars of Mahatma Gandhi, Sardar Patel and Dr. A.P.J. Abdul Kalam. Visitors can engage in lifelike conversations, asking questions and receiving responses from historical writings. In Kochi, a VR museum dedicated to freedom fighter V.C. Ahammedunni uses immersive technology to bring his speeches to life. The Madhya Pradesh Tourism Board also launched virtual heritage tours of historic sites.

Impact

i. Enhanced engagement: Visitors connect more deeply with history through interactive, conversational experiences.
ii. Educational value: Students gain memorable understanding of historical figures through immersive encounters.
iii. Accessibility: Rare archival material and distant heritage sites become accessible to global audiences.

Key Beneficiaries

i. Students & young learners: Engaging format improves historical literacy.

[22] https://www.pib.gov.in/PressReleasePage.aspx?PRID=2167179&reg=48&lang=2

ii. Museums & cultural institutions: Increase footfall and preserve collections digitally.
iii. Researchers & historians: Access detailed digital archives for study.

Key Technologies

i. AI-powered holographic avatars with natural processing
ii. Voice interaction for conversational engagement
iii. 3D digital reconstruction of historical figures and events
iv. VR museum platforms with immersive storytelling

Example 2 - Abraham Lincoln Presidential Library and Museum

Abraham Lincoln Presidential Library and Museum[23] is strengthening its reputation for immersive educational experiences by harnessing AR and other spatial computing technologies. These innovations enable visitors to connect with history in engaging and memorable ways, allowing them to virtually step into historical periods, interact with digital representations of people and events, and participate in collaborative learning experiences.

Immersive technologies are transforming the museum experience through features such as indoor navigation, interactive exhibits, artifact visualization and gamified learning journeys. Visitors can engage in virtual encounters, explore historical events through time-travel experiences and gain deeper insights through contextual digital content layered onto physical exhibits.

Beyond physical museums, 360-degree virtual museum[24] experiences are making cultural and educational content accessible to remote audiences around the world. These digital experiences provide learners with the feeling of being present within the museum, regardless of their location.

Looking further ahead, the concept of the "Zero Museum" is emerging—a museum space that contains few or no physical artifacts. Instead, visitors enter a digitally powered environment where artifacts, historical settings and educational experiences are rendered virtually through AR, VR and holographic technologies. Such museums have the potential to democratize access to culture and history while enabling experiences that would be impossible in traditional museum settings.

Impacts

i. Immersive historical engagement**:** Achieved by allowing visitors to virtually step into historical periods, interact with digital representations of people/events and experience time-travel storytelling.
ii. Enhanced visitor experience**:** Indoor navigation, interactive exhibits and gamified learning journeys make museum visits more engaging and memorable.
iii. Global accessibility**:** 360-degree virtual museum experiences extend cultural and educational access to remote audiences worldwide.

[23] https://www.thoughtworks.com/en-in/clients/abraham-lincoln-presidential-library-and-museum
[24] https://www.seattlenftmuseum.com/

iv. Cultural democratization**:** The emerging "Zero Museum" concept enables museums without physical artifacts, offering experiences that would be impossible in traditional settings.

Key Beneficiaries

i. Students and learners: Gain deeper insights into history through interactive, contextual digital content layered onto exhibits.
ii. Museums and cultural institutions: Strengthen reputation, expand reach globally and preserve heritage digitally.
iii. Remote audiences: Access immersive museum experiences regardless of location, overcoming physical barriers.
iv. Historians and researchers: Benefit from digital reconstructions and contextualized artifacts for study and collaboration.

Key Technologies

i. AR and spatial computing: Enable interactive exhibits, artifact visualization and contextual layering of digital content.
ii. 360-degree virtual museum platforms: Provide immersive experiences for remote audiences.
iii. Indoor navigation systems: Guide visitors seamlessly through museum spaces.
iv. Gamification engines: Transform learning into engaging, interactive journeys.
v. VR and holographic technologies: Power the "Zero Museum" concept, rendering artifacts and historical settings virtually.

A1.18 Use Case 18: Immersive Virtual Workplace for Remote Collaboration

Description

As work-from-home culture becomes a new norm, employees increasingly prefer remote flexibility over daily commutes to physical offices. However, traditional video conferencing tools lack presence, spatial awareness and engaging collaboration features. Metaverse addresses this by offering immersive virtual workplaces where distributed teams can gather using personalized avatars. Participants enter a simulated environment via VR headsets or desktop interfaces, enabling natural interactions such as eye contact, hand gestures and proximity-based audio. Teams can brainstorm on digital whiteboards, share presentations, annotate 3D models and move between breakout rooms – all from home. Customizable venue templates with gamified elements enhance productivity and reduce meeting fatigue.

Example – WoWExp's "WoWMeet" Virtual Reality Meeting Platform

M/s WoWExp built WoWMeet, a VR meeting platform that transports users to a virtual workplace where meetings are held using VR headsets. Distant employees gather in simulated environments with personalized avatars, making virtual meetings interactive and engaging. Features include collaborative whiteboards, presentation sharing and 3D model visualization in an immersive VR environment. Users choose from venue templates with customizable floor plans – from large auditoriums to small huddle rooms – all designed carefully to enhance productivity with a gamified model (e.g., achievement badges for participation, interactive polls and virtual breakout challenges).

Impact

i. Enhanced presence and connection: Avatars and spatial audio replicate the feeling of "being there," reducing isolation and strengthening team bonds.
ii. Higher engagement and productivity: Gamified templates and interactive tools (whiteboards, 3D models) keep participants focused compared to passive video calls.
iii. Preserved remote flexibility: Employees work from home while still accessing a rich collaborative environment, improving work-life balance.
iv. Reduced real estate costs: Companies can downsize physical office space without compromising teamwork and culture.

Key Beneficiaries

i. Remote and hybrid employees: Enjoy more engaging, less fatiguing meetings than traditional video conferencing.
ii. Team leaders and managers: Facilitate brainstorming, design reviews and training sessions more effectively.
iii. IT and facility managers: Lower overhead costs for office maintenance while maintaining collaboration quality.
iv. Global enterprises with distributed teams: Bridge time zones and geographies through persistent virtual workspaces.

Key Technologies

i. VR headsets with optional desktop fallback
ii. Personalized avatars with facial and gesture tracking
iii. Spatial audio for natural conversation dynamics
iv. Real-time collaboration tools (digital whiteboards, presentation sharing, 3D model annotation)
v. Customizable venue templates with gamified engagement features
vi. Cloud-based session hosting and recording

Appendix 2: Metaverse use cases associated with XTIC’s work

1. Education and Immersive Learning

Education appears repeatedly as one of the strongest metaverse-related use cases in XTIC’s ecosystem. XTIC highlights the metaverse’s potential to democratize education by overcoming geographic barriers and enabling more engaging, personalized and immersive learning environments.

The XR Corridor explicitly includes immersive learning environments, virtual labs and remote collaboration tools under its education and research impact area. In addition, XTIC researchers are examining ways to improve learning in metaverse environments through higher student engagement across offline, online and hybrid settings, along with personalization of learning.

2. Healthcare and Wellbeing

Healthcare and wellbeing are major impact areas in XTIC’s published XR plans. The XR Corridor lists medical training simulations, rehabilitation, telemedicine and mental health interventions among its intended application domains.

These use cases are particularly aligned with metaverse strengths because immersive environments can simulate complex clinical settings, support skill training and create new forms of patient or practitioner interaction. XTIC’s broader focus on haptics further strengthens this use case by adding touch and tactile feedback to virtual experiences.

3. Industrial Training and Manufacturing

Industrial training is a clear and current use case in XTIC’s work. The SAIL XR Centre and other industrial training ambitions show how immersive technology can be used for equipment familiarization, safety training, process learning and simulation in manufacturing environments.

XTIC also identifies workforce development for manufacturing and service industries as one of the XR Corridor impact areas, suggesting that it sees the industrial metaverse as a high-value, practical entry point compared with purely consumer-facing visions.

4. Tourism and Cultural Heritage

XTIC’s MIPS work specifically mentions tourism as one of the key applications being considered in standards development. Reporting on XTIC also states that agreements were signed for developing VR tours for 23 national museums, indicating a strong cultural and heritage dimension to its metaverse-related use cases.

In this area, metaverse tools can support virtual tourism, heritage preservation, remote access to cultural sites and immersive storytelling for public education.

5. Yoga, Meditation and Wellbeing Experiences

An unusual but distinctive area in XTIC's standards-related work is the inclusion of yoga and meditation as target metaverse applications. This suggests an attempt to shape culturally relevant and wellness-oriented use cases rather than focusing only on gaming or social virtual worlds.

This use case could support guided immersive wellbeing experiences, digital therapeutics, mindfulness environments or global access to Indian wellness practices in virtual settings.

6. Identity Management and Governance

Identity management is one of the metaverse applications named in XTIC's standards work. This is a foundational use case because metaverse systems require trusted identity, authentication, persistence and secure interaction across platforms.

The XR Corridor also includes judiciary and governance use cases such as immersive evidence presentation, remote hearings and citizen services. Together, these strands indicate that XTIC sees metaverse as relevant not only to entertainment or training, but also to public systems and governance design.

7. Renewable Energy and Sustainability

MIPS identifies renewable energy as a focus area in standards-related work. While this is less detailed than some other sectors, it implies interest in using immersive systems for simulation, visualization, planning, training and possibly digital-twin-style operations in the energy sector.

The XR Corridor also lists mobility and sustainability, including smart cities and sustainable infrastructure planning, as important impact areas. This broadens metaverse discussion from media experiences to infrastructural and societal applications.

8. AVGC-XR, Gaming and Storytelling

XTIC includes AVGC-XR as a formal impact area, covering animation, visual effects, gaming, comics and immersive storytelling. Public reporting on XTIC also mentions gaming and entertainment as sectors where metaverse applications can create new business opportunities.

This remains one of the most visible and commercially recognized use cases of metaverse, but XTIC's framing places it alongside education and industrial development rather than treating it as the sole purpose of immersive technology.

9. Defense, Space and Advanced Simulation

XTIC has identified space-tech and defense-tech as key areas of growth and reporting notes agreements relating to India's manned spaceflight training module and defense applications with the Army Design Bureau. The XR Corridor further highlights simulation and training for space exploration, deep-sea research, defense and aerospace.

These use cases fit metaverse especially well because they rely on high-fidelity simulation, safe rehearsal of rare or dangerous events and collaborative virtual environments for mission preparation.

Appendix 3: List of 52 Deliverables of ITU-T FG-MV

No.	Title of Deliverable
FGMV-01	Technical Report on Exploring the metaverse: opportunities and challenges
FGMV-02	Technical Report on Metaverse: an analysis of definitions
FGMV-03	Technical Report on Guidelines to assess inclusion and accessibility in metaverse standard development
FGMV-04	Technical Specification on Requirements of accessible products and services in the metaverse: Part I – System design perspective
FGMV-05	Technical Specification on Requirements of accessible products and services in the metaverse: Part II – User perspective
FGMV-06	Technical Report on Guidelines for consideration of ethical issues in standards that build confidence and security in the metaverse
FGMV-07	Technical Report on Policy and regulation opportunities and challenges in the metaverse
FGMV-08	Technical Specification on Design criteria and technical requirements for sustainable metaverse ecosystems
FGMV-09	Technical Report on Power metaverse: Use cases relevant to grid side and user side
FGMV-10	Technical Report on Cyber risks, threats and harms in the metaverse
FGMV-11	Technical Report on Embedding safety standards and the user control of Personally Identifiable Information (PII) in the development of the metaverse
FGMV-12	Technical Report on Children's age verification in the metaverse
FGMV-13	Technical Report on Responsible Use of AI for Child Protection in the metaverse
FGMV-14	Technical Report on Regulatory and economic aspects in the metaverse: Data protection
FGMV-15	Technical Specification on Accessibility requirements for metaverse services supporting IoT
FGMV-16	Technical Report on Accessibility in a sustainable metaverse
FGMV-17	Technical Report on Guidelines and requirements on interpreting in the metaverse
FGMV-18	Technical Report on Guidance on how to build a metaverse for all – Part I: Legal Framework
FGMV-19	Technical Specification on Service scenarios and high-level requirements for metaverse cross-platform interoperability

FGMV-20	Technical Specification on Definition of metaverse
FGMV-21	Technical Report on Principles for building concepts and definitions related to metaverse
FGMV-22	Technical Specification on Capabilities and requirements of generative artificial intelligence in metaverse applications and services
FGMV-23	Technical Report on Considering online and offline implications in efforts to build confidence and security in the metaverse
FGMV-24	Technical Report on A framework for confidence in the metaverse
FGMV-25	Technical Report on Near-term and long-term Implications for people in the metaverse
FGMV-26	Technical Specification on Requirements for communication between human-avatar languages in the metaverse
FGMV-27	Technical Report on Guidelines for metaverse application in power system
FGMV-28	Technical Specification on Requirements for the metaverse based on digital twins enabling integration of virtual and physical worlds
FGMV-29	Technical Specification on Reference model for the metaverse based on a digital twin enabling integration of virtual and physical worlds
FGMV-30	Technical Report on Overview of the application requirements of metaverse on emergency management in chemical industrial parks
FGMV-31	Technical Specification on Requirements, functional framework and capability of IoT for metaverse
FGMV-32	Technical Report on Overview of metaverse
FGMV-33	Technical Specification on Glossary for metaverse
FGMV-34	Technical Report on Definitions of CitiVerse
FGMV-35	Technical Report on Building a People-centred CitiVerse
FGMV-36	Technical Report on The future of travel in the metaverse: landscape and use cases
FGMV-37	Technical Report on Landscape and Use cases for the Industrial metaverse
FGMV-38	Technical Specification on Framework and requirements for the construction of human-driven 3D digital human application system for metaverse
FGMV-39	Technical Specification on Use case and requirements for virtual and real fusion coding in metaverse application
FGMV-40	Technical Specification on Multimedia aspect of metaverse architecture
FGMV-41	Technical Specification on The reference framework of industrial metaverse

FGMV-42	Technical Report on Interoperability of identity of things across metaverse platforms
FGMV-43	Technical Specification on High-level interoperability architecture for cross-platform metaverse
FGMV-44	Technical Report on Security for things across metaverses in aspects of data processing and management
FGMV-45	Technical Report on Challenges to achieving trustworthy metaverse
FGMV-46	Technical Report on The essential components of trusted data use in building a trustworthy metaverse
FGMV-47	Technical Report on Economic Value Creation and Competition in metaverse
FGMV-48	Technical Report on Guidance on how to build a metaverse for all: Part II - Survey
FGMV-49	Technical Report on Metaverse Sustainability: Driving energy efficiency and GHG emissions reduction
FGMV-50	Technical Specification on Methodology on assessment of GHG emissions of metaverse
FGMV-51	Technical Report on Standardization roadmap for metaverse
FGMV-52	Technical Report on Metaverse standardization landscape for gap analyses

Appendix 4: Table of Abbreviations

S. No.	Abbreviation	Full Form
1.	AAC	Augmentative and Alternative Communication
2.	AI/ML	Artificial Intelligence / Machine Learning
3.	API	Application Programming Interface
4.	AR	Augmented Reality
5.	ASL	American Sign Language
6.	BCI	Brain-Computer Interface
7.	BSL	British Sign Language
8.	CC	Content Creator
9.	DAP	Digital Asset Provider
10.	DT	Digital Twin
11.	DTAC	Digital Twin Access Control
12.	DTDA	Digital Twin Data Acquisition
13.	DTIA	Digital Twin Information Acquisition
14.	DTIF	Digital Twin Integration Functions
15.	DTS	Digital Twin Synchronization
16.	DTSD	Digital Twin System Discovery
17.	DTSR	Digital Twin System Registration
18.	ECoG	Electrocorticography
19.	EEG	Electroencephalography
20.	eMBB	Enhanced Mobile Broadband
21.	FE	Functional Entity
22.	FG-MV	Focus Group on Metaverse
23.	GF	General Functions
24.	HPC	High-Performance Computing
25.	ICT	Information and Communication Technology
26.	IoT	Internet of Things
27.	ISAC	Integrated Sensing and Communication
28.	L1-MV	One-way Linked Object Metaverse
29.	L2-MV	Two-way Linked Object Metaverse
30.	LLM	Large Language Model
31.	mMTC	Massive Machine-Type Communications
32.	MR	Mixed Reality
33.	NFT	Non-Fungible Token
34.	NLP	Natural Language Processing
35.	NL-MV	No-linked Object Metaverse
36.	PIF	Physical Integration Functions
37.	PII	Personally Identifiable Information
38.	PM	Payment Manager
39.	PP	Platform Provider

40.	SC	Spatial Computing
41.	SDC	System and Data Collaboration
42.	SIF	Systems Integration Functions
43.	SP	Service Provider
44.	SR	Spatial Reality
45.	TPSAA	Third-Party System Authentication and Authorization
46.	TPSD	Third-Party System Discovery
47.	TPSR	Third-Party System Registration
48.	TSI	Third-Party System Interaction
49.	TSIF	Third-Party Service Integration Functions
50.	URLLC	Ultra-Reliable and Low-Latency Communications
51.	VR	Virtual Reality
52.	XR	Extended Reality

Appendix 5: References

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Appendix 6: List of Working Group (WG) meetings

S. No	Date of the virtual meeting of WG
1.	1st Meeting: 30 December 2025
2.	2nd Meeting: 29th January 2026
3.	3rd meeting: 26th February 2026
4.	4th Meeting: 27th April 2026
5.	5th Meeting: 29th May 2026

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