REVIEW ARTICLE

Metaverse Journey Exploring Requirements, Architectural Frameworks, Standards, Challenges and Vision

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Abstract

The Metaverse represents a virtual realm that is progressively supplanting the digital world, offering a unified, immersive, and enduring 3D virtual space. Its potential for transforming various aspects of human life is immense, spanning work, leisure, and everyday activities. It delves into the essential elements of the metaverse, including its prerequisites, structure, standards, challenges, and potential solutions. Bitcoin and the rise of NFTs also attract attention to the blockchain ecosystem. This increased focus on blockchain prompted discussions about the metaverse. Mark Zuckerberg, the CEO of Facebook, announced the company's transformation into a metaverse-focused entity and its renaming as Meta. The paper offers a comprehensive exploration of the metaverse, encompassing its historical background, architectural foundations, and standardization efforts. Ultimately, it provides valuable insights, perspectives, and potential remedies for addressing these obstacles. It further examines the hurdles encountered during the metaverse's development and implementation.

Keywords: metaverse, artificial intelligence, virtual reality (VR), big data, blockchain, augmented reality (AR), 5G/6G connectivity, mixed reality (MR).

1 Introduction

Background: Yes, in Neal Stephenson's 1993 novel Snow Crash, the word "metaverse" first appeared. The term is used, in the narrative, to explain personas designed by computer programmers. Subsequently, the term was used by the founder of Second Life, Philip Rosendale at the launch of the virtual world in 2003. Later, the metaverse was thrust into the mainstream following the release of the film adaptation of the novel, Ready Player One [1], which was directed by Stephen Spielberg. Ready Player One features a not-so-distant future where humanity is escaping a ravaged physical world by burying itself in a metaverse

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called OASIS. This story function as a famous version of the metaverse, inspiring mainstream audience and expose a glimpse of a virtual worlds. It touches on the idea of escaping the limitations of the physical world and entering into a digitally constructed reality with boundless potential and risks. Just like other sci-fi movies from the future, fans dream of making science fiction a reality. The Web3 movement is being sparked by the construction of your OASIS metaverse across various blockchain ecosystems (these teams are implementing and deploying blockchain technology use cases). When reading about the blockchain used in the metaverse, the interpretation of both terms hugely differs depending on when and how they are used [16].

Definition: Derived from the prefix "meta" and "verse," the Metaverse refers to an advanced computer-generated ambient or virtual environment that exists beyond the physical world and own a unique value system and allow for interrelated economy. The Metaverse is a digital universe in which users communicate, generate, and participate in digital content, encouraging a sense of connection and immersion. At the same time, the Metaverse has its own economic system, which functions in parallel with the physical world enabling the management, trade, and accumulation of digital assets, currency, and resources. In 2021, Facebook's CEO Mark Zuckerberg made a big announcement - the company is pivoting to build a metaverse. As part of this transformation, the company was renamed as Meta [2].

The Metaverse is poised to become a significant technological breakthrough in the near future. It includes Programming-engineered digital worlds with self-regulating economies, and integrated value systems. The Metaverse provides users with experiential cyber-virtual experiences in real-world contexts, by bridging a massive unified Internet with a unified 3D virtual and physical network. Specifically, developing augmented reality, virtual reality and Metaverse-improving applications that help users explore these experiences and participate in a social network [3]. In addition, the Metaverse was also the Internet of the next generation, commonly known as the 3D Internet, where users can adopt the digital native lifestyle and realize new lifestyles in the virtual world. There are numerous practical applications of the Metaverse in different fields, such as education, healthcare, tourism, and many others. To illustrate, applying the Metaverse to the healthcare industry can lend itself to extraordinary potential in improving patient outcomes by providing new and cost-effectiveness treatment methods. The Metaverse helps healthcare providers reach geographically dispersed patients ensuring remote monitoring and telemedicine [13]. Such versatility of the Metaverse positions a number of opportunities for healthcare disruption by allowing new forms of care delivery, collaboration and information exchange. Revolutionizing various high-tech areas including Internet of Things (IoT), 5G/6G, digital twins, artificial intelligence, augmented reality, extended reality, virtual reality, as well as mixed reality, the Metaverse enables all of these without compromising on security and privacy. These diverse technological integrations play a pivotal role in the evolution and sustainability of the Metaverse. The global pandemic has generated interest in the Metaverse and has changed the way that people work, socialize, and find entertainment. This has accelerated the adoption of virtual platforms to reconfigure traditional ways of interaction, and made the Metaverse an essential component as we head toward the future of remote collaboration and daily functions. The Metaverse is one of the components of Web 3.0, where avatars can travel through virtual worlds and exchange economic tools with its resources and rewards [3]. The timeline of the Metaverse is illustrated in Figure 1.

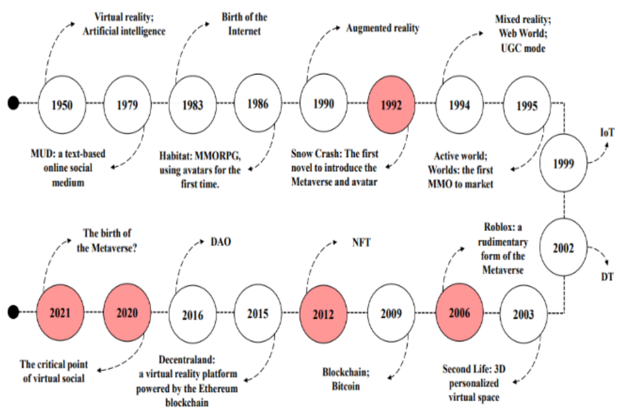

Figure 1. The timeline of the Metaverse.

2 Characteristics

There are a few major characteristics of Metaverse, listed as shown in Figure 2.

Immersiveness: The term "Metaverse" refers to a virtual environment created by a computer that is so authentic that users can get psychologically and emotionally involved in it. This virtual space interacts with our senses, including visual, sound, haptic and

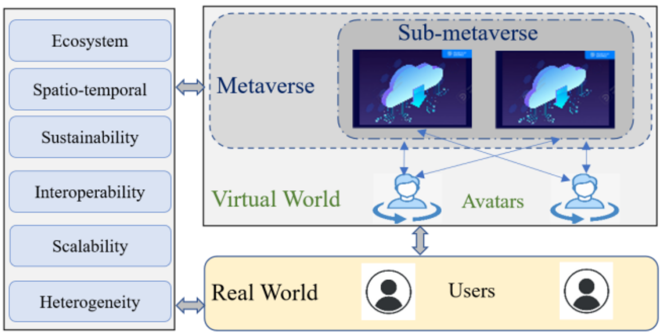

Figure 2. Metaverse characteristics [3].

even thermal and pressure feedback, and lets us negotiate body language through gesture and sign. Since much of our experiences can be in the solely textual and visual realm, these experiences that we perform in the Metaverse gives us a full understanding of who we are and our relationship with the Metaverse.

Economic opportunity: The metaverse is offering new economic opportunities for people and companies alike. It has to do with all sales & marketing on this game, which can be received through the sale of digital goods and services, advertisement, and content generation among others. Hence, individuals and businesses can make various activities in the metaverse, identifying new ways to make handsome bucks and be successful in this virtual space.

Governance: Metaverse governance is all about fairness, equality, and inclusivity when it comes to the development and management of the metaverse ecosystem. This inclusivity and democratic approach allow the metaverse to be a space that is collectively shaped by the contributions of its users, ensuring that the perspectives and interests of all are represented.

Interoperability: This allows for seamless travel across different virtual worlds in the Metaverse while still preserving their immersive experience. Furthermore, the digital items and assets that are created as NFTs can be owned or used across different worlds. This feature allows users to move freely around different virtual worlds and use their digital assets across multiple metaverse platforms.

Sustainability: The Metaverse operates on its own and has its own in-house economy. It has certain values that it upholds and it also has a closed cycle where economic activities take place inside its limits. Put simply, the Metaverse has its own rules and its own economy: and value creation and value exchange in its place.

Scalability: This refers to how well the Metaverse can handle a large number of users at the same time, the complexity of the virtual environments, and the range of interactions between users. It's about ensuring that the Metaverse can efficiently support a high number of people, complex scenes, and various types of interactions between users.

Heterogeneity: Different virtual spaces within the metaverse each have their own features. Different physical devices with Fabrics are also used to access the Metaverse. Types Of Communication And Data In Metaverse Finally, we think and experience the Metaverse very differently.

Security, privacy and accessibility: In the metaverse data is protected, so users don't have to worry about unauthorized access. This helps in providing a safety or security feeling for users in the metaverse space. Everybody no matter their physical or cognitive ability can be a part of the metaverse. This implies that one must use different devices and methods of interacting with the metaverse easily, and the metaverse must be usability-optimized for people with disabilities

Spatio-temporal and Innovation: In the real world, we have limits: there is only so much space and only so much time. That does not exist in the Metaverse though. In the Metaverse, spatiotemporal literally steps in because there is neither space nor time. It builds a second virtual universe in which time and space are warped, reshaped with limitless potential. It cultivates and advances metaverse and innovation. This means that metaverse has opened its doors to the developer community to an extent, which will allow new ideas to flow and innovative new methods to be used. It stimulates creativity, and experimentation with new ways of doing things.

3 Metaverse Architecture

Industry and academic specialists haven't agreed on a metaverse structure yet. Based on [3] and [4], we propose that both physical and digital environments be incorporated into the Metaverse Structure. The different components of the Metaverse can be accommodated by the proposed architecture, which are:

1. **Infrastructure:** The infrastructure of the Metaverse encompasses a variety of essential technologies that are integral to its functioning. These include Micro-Electro-Mechanical Systems (MEMS) for motion tracking and environmental sensing, Graphics Processing Units (GPUs)

for realistic rendering, communication and networking technologies like Wi-Fi and 5G/6G for seamless connectivity, storage systems for data management, cloud-edge computing for efficient processing, blockchain for secure transactions and asset ownership, and Micro-services architecture for flexible application development. These technologies in combination create the essential base needed for seamless operations, rich experiences, and effective data management in the Metaverse.

2. **Interactivity:** This central element serves as a link that connects the virtual and tangible realms, bridging the two. This allows these two territories to do more than interact: to come together. These components cover a gamut of technologies and features, from geo-spatial mapping respectively relating the location in which the virtual components such as AR layers sit with the corresponding location in the real world, immersive user experiences leading to the heightened sense of presence which reflects to the real-world actions of users in the AR system, to digital twins wherein the objects or entities in the real-world are represented in a virtual space, to 3D modeling for convincing stimulation of the virtual environment itself, to computer vision for the recognition and interpretation of visual data, to sensing technology to capture real-world information, to interpret it, to the AR/MR/VR/XR technologies responsible for the overall immersive experience. All these aspects combined make the Metaverse a space where the virtual and real worlds are interconnected.

3. **Ecosystem:** The functioning of the entire Metaverse relies on this aspect. It encompasses a wide range of activities such as creating personalized avatars, generating and sharing content, facilitating data interoperability, supporting the virtual economy where virtual goods and services are exchanged, enabling social interactions and connections between users, hosting e-sports competitions, providing immersive gaming experiences, facilitating virtual shopping experiences, promoting tourism within virtual environments, and accommodating various other activities that contribute to the diverse and interactive nature of the Metaverse.

This tripartite framework ensures interoperability, scalability, and sustainability while addressing the heterogeneous needs of Metaverse applications."

4 Metaverse Standards

The business and standards communities are working together for the development of standards that will bring the concepts of the Metaverse to life. Currently, the focus of existing Metaverse standards, is primarily on ensuring smooth and uninterrupted connectivity among the physical and the virtual world. The best practices strive to define methodologies and standards that will support interoperability and interoperation between these two environments, thus building a seamless and integrated Metaverse. The summary of metaverse standards are presented in Table 1.

Table 1. Summary of metaverse standards.

Standard	Description
IEEE 7016	Provides an overview of the techno-social aspects of Metaverses and a methodology for assessing their ethical viability.
IEEE 2888	Establishes standardized interfaces for both physical and virtual environments, outlining data formats and APIs.
ISO/IEC 23005	Offers recommendations for the creation, advancement, and implementation of Metaverses.
IEEE P1589	It supports AR learning experiences that enable the development of experience repositories and online marketplaces.
IEEE P2048	Offers terminology, definitions, and taxonomies for the Metaverse, ensuring its sustainable development.

ISO/IEC 23005: Information technology — Media context and control — Part 1: Representation of media content Its aim is to enable the sharing and usability of immersive media across various devices and platforms. The specification defines formats and protocols that can be used for the encoding, decoding, and rendering of immersive media so that users can experience consistent, high-quality immersive content across different systems. ISO/IEC 23005 is a Multifunctional standard, applicable across a variety of Metaverse business services. It brings elements of audiovisual content, sensorial effects, and virtual objects properties into interactions across both the real and digital worlds. It would facilitate smooth communication on this world and as well as help cover an immersive experience in the Metaverse with their respective ecosystem.

IEEE 2888: It is a collection of rules that define how various elements in the digital world (cyberspace) and the real world can coexist [5]. It provides an outline of both how information is structured and how computer programs can interface with devices that perform physical actions (actuators) and retrieve information from the external world (sensors). Complementing this are standards that also provide a means for interaction between elements that are both in the virtual and real worlds. These rules encompass collecting input from sensors, driving output to devices, referred to as actuators, and enabling coherency between the digital and physical domains. Topics range from advancing Mixed Reality work to create virtual reality training systems to assessing training systems, plus incorporating holographic visuals that join the digital to the physical worlds. Overall, these standards help ensure that different technologies can communicate and interact effectively.

IEEE P1589: is a proposal for improving augmented reality (AR) learning experiences. It explains how different aspects of AR learning, such as activities, the learning environment, and other elements, can be described using a standard format. This format helps exchange information and data between different AR systems. Sensors and computer vision simplify the creation of educational experiences that seamlessly integrate physical-world engagements with online platforms, thus enhancing accessibility and usability. This standard also establishes a connection between the Activity Model and the Environment Model, allowing them to work together to represent a complete AR learning experience. The aim of IEEE P1589 is to make it easier for developers, trainers, and educators to design, create, deploy, use, maintain, and share AR learning experiences [6]. By leveraging this standard, they can enhance the effectiveness and engagement of AR learning for learners.

IEEE P2048: Due to the recent emergence of the Metaverse industry, there is a combination of excitement, confusion, and misunderstandings surrounding it. One of the challenges is that there is no agreement on the basic terms, definitions, and classifications, which can cause confusion for those interested in adopting it early on and hinder progress. IEEE P2048 aims to provide clear and standardized terminology, categories, and levels for the Metaverse [7]. The aim is to encourage sustainable development in activities related to the Metaverse and ensure a balanced and thriving growth of the Metaverse market. This standard include defining and classifying different devices used in VR and AR, establishing quality metrics for immersive videos, determining file formats for immersive videos, addressing person identity and environment safety considerations, developing immersive user interfaces, creating maps for virtual objects in the real world, enabling interoperability between virtual objects and reality, establishing quality metrics for immersive audio, defining file formats for immersive audio, exploring in-vehicle augmented reality applications, and establishing content ratings and descriptors. The main purpose of IEEE P2048 is to encourage the growth and adoption of VR and AR technologies.

IEEE P7016: This standard offers a holistic view of the technical and social elements of Metaverse systems. It also intends to establish a framework for ethically evaluating their design and operation. The IEEE P7016 standard is a useful tool for people involved in creating, running, or using metaverse systems. It offers guidance on how to make sure these systems are built and operated in a way that respects ethics [8]. It serves as a set of guidelines for Metaverse developers, helping them prioritize the creation of systems that align with ethical principles. This is important because it helps safeguard the rights and interests of the users of metaverse systems.

IEEE P2114: It is a set of rules that provides a structure for creating augmented reality (AR) applications. It outlines guidelines for designing, developing, and launching AR applications. These guidelines help developers understand how to build AR applications effectively.

IEEE P2396: It is a set of guidelines that establish ways to measure how good an augmented reality (AR) experience is. These guidelines define specific metrics to evaluate the quality of AR experiences. The metrics focus on factors such as how realistic the AR experience feels, how easy it is to use, and how deeply it immerses the user in the virtual world. By using these metrics, developers can assess and improve the overall quality of AR experiences.

OpenXR: It is a widely accepted and open standard specifically designed for creating augmented reality and virtual reality applications. This standard provides developers with a comprehensive set of application programming interfaces (APIs). These APIs enable tasks such as rendering 3D objects, tracking user input, and facilitating interaction with virtual objects. OpenXR is one among numerous standards being developed to address the evolving field of extended reality technologies.

W3C XR API: It is a set of helpful tools that allow developers to make augmented reality and virtual reality applications. This API provides a variety of features such as rendering 3D objects, tracking user input, and interacting with virtual objects. These tools make it easier for developers to build immersive and interactive AR and VR experiences.

WebXR: This standard outlines a collection of APIs that enable the access and interaction with AR and VR content directly within web browsers.

MPEG-H Part 23: This standard establishes a specification for the representation of 3D audio and video content specifically designed for AR and VR applications.

5 Core Components and Essential Requirements

Multiple emerging technologies converge to drive the development of the Metaverse. In the selected literature, key technological requirements have been identified. These requirements, include reliable connectivity for seamless interaction, interoperability between systems and platforms, scalability to handle large user populations and data, robust security measures, immersive and realistic experiences, standardized protocols for compatibility, integration of artificial intelligence for intelligent virtual characters and personalized experiences, and user-friendly interfaces for intuitive navigation. By addressing these requirements, the Metaverse can be developed with a solid foundation, enabling a connected virtual world that offers immersive, interactive, and secure experiences for users.

5.1 Networking and Communication

Several pivotal technologies play a crucial role in enabling seamless real-time communication between reality and virtuality, promoting interconnectedness among various sub-Metaverses. These cutting-edge technologies include Software Defined Networks, the Internet of Things, Resource Allocation Frameworks, 4G/5G and 6G networks. Leveraging the progress made in 5G/6G, the Metaverse stands to benefit from improved connectivity, empowering a multitude of devices with reliable and instantaneous communication coupled with enhanced mobility. SDN, on the other hand, enables the agile and scalable administration of expansive networks by decoupling control and data planes, paving the way for flexible management solutions. The SDN abstracts the physical devices and resources which can be logically managed through standard interfaces, as is OpenFlow, allowing dynamic allocation of computational power, storage and bandwidth resources in an SDN-based Metaverse. The time-critical requirements of sub-Metaverses are met through the use of IoT sensors that serve as an extension of human senses in the Metaverse [9]. They perform an important role capturing and passing the data which ensures a seamless and engaging experience for users in various virtual environments.

5.2 Ubiquitous Computing

The goal is on-demand capability to compute resources, in the sense that it can be anywhere and it can provide at any time [10]. This allows users to interact naturally with their environment by surrounding them with smart objects. Reality in the Metaverse: Owners of avatar can take their avatars to different services and perform actions, through connected network and intelligence objects that empowered these services in such a way that the consumers of the service do not need hardware, such as phone or laptop but only fitness sensor in an object. It aims to create an environment in which computing resources are readily available and effortlessly woven into daily life.

5.3 Digital Twin

Digital twin is an accurate and intentional representation of the physical world [11]. AI then processes streams of real-time data, along with physical models, and historical data to elevate virtual user experiences. The linked up twin continues to receive data from physical entities and leverages these data to learn and adjust in its mirrored space. The 3D Metaverse could create accurate, realistic 3D models of items using 3D simulated artificial intelligence (AI). This feature can be invaluable for creating and visualizing large-scale Metaverses. These techniques, which employ both mathematical and experimental modeling, allow the generation of virtual physical systems inside the Metaverse. Mathematical models are the simplification of the functional representation, whereas experimental modeling requires performing a larger number of experiments. This two-way link between the physical and digital worlds makes it possible to conduct predictive maintenance, monitor accidents, and minimize hazards while increasing productivity.

5.4 Interactive experience within Metaverse

With data as embedded technologies and miniaturization — sensors and extended reality advances, XR devices will come to be the primary way people access and experience the Metaverse. XR stands for eXtended reality, which is a combination of augmented reality, virtual reality and mixed reality technologies offering immersive experiences, improved interactive and real-time engagement with avatars, other users and the environment. The realization of this is done by means of holographic displays, human-computer interaction, and the building of large models in 3D [12]. VR takes you to immersive virtual worlds, and AR brings holograms and real-time images in the real world. This mixed reality (MR) combines these technologies, acting as a link between the two. Consequently, people will interact with avatars on a variety of devices other than smartphones and PCs. Also, low-latency edge computing systems and AI-driven real-time rendering could be used to mitigate users' motion sickness caused by an XR helmet or headset [3].

5.5 Artificial Intelligence

It merges AI, communication, ubiquitous computing, interactivity, security and privacy into virtual environments that are safe, scalable, and realistic, as well as always on [3]. AI is thus an essential factor in improving the reliability and performance of the Metaverse infrastructure. Deep learning, machine learning, and reinforcement learning are applied to solve energy consumption and efficiency, issues of resources allocation and optimality, scalability, and securing issues in communication and networking systems. By using various IoT sensors, actuators, and human-machine interface devices, AI analyzes and recognizes human behaviors and users can control their avatars and communicate with Metaverse items.

5.5.1 Research Gaps, Challenges and Disscussion

In the context of the Metaverse architecture, a potential research gap could be the absence of consensus and agreement among industry and academic specialists regarding the precise structure and components of the Metaverse. In terms of the Metaverse's architecture, industry and academia experts may lack consensus and agreement on the definition and composition of the Metaverse as a potential research gap. This discrepancy may stem from a number of factors, including geopolitical motivations, the global character of the Metaverse, jurisdictional obstacles, and disparate viewpoints held by professionals from disparate disciplines. While the text provides a summary of the features and use cases of it, it starts saying that nobody agrees on the Metaverse architecture. It additionally shows that no big agreement has been settled on the essential design and properties of the Metaverse among specialists working in the field [3]. This section discusses the issues of the Metaverse's core technologies based on the architectural and requirement. These challenges are all manifestations of 'technology', and we analyze their implications for developing and implementing the Metaverse.

5.5.2 AI Models within Metaverse

Artificial Intelligence and machine learning algorithms will also help operators and designers adapt to the Metaverse and maximize efficiency and functionality more efficiently than the traditional methods. However, there are several challenges to address. Current AI models tend to be deep and computationally intensive, limiting their applicability on resource-constrained mobile devices. Therefore, it is crucial to develop lightweight and efficient AI models specifically designed for mobile platforms. Additionally, deep learning (DL) algorithms are highly specialized, necessitating retraining for different but similar problems within the same domain. Bootstrapping, a critical aspect of RL convergence, poses significant challenges due to the time-consuming nature of RL algorithms. Timeliness is essential in the Metaverse, particularly in gaming, interactive experiences, and telemedicine, where delays are unacceptable.

5.6 Metaverse and the Era of Big Data

The Metaverse is renowned for its extensive volume of data. including valuable but sensitive information generated by avatars, XR devices, and IoT devices. However, there are unresolved issues surrounding data capture, analysis, and storage. Accurate and high-quality data collection is vital for meaningful analysis, yet challenges arise from IoT device data input and user-generated content. As the data volume steadily grows, issues emerge regarding expansion speed, backup and storage capability. Moreover, the storage system must handle diverse and interconnected user-generated content data. To address the challenges posed by the scale and complexity of data, centralized storage methods face difficulties and incur significant infrastructure costs. Research and technological advancements are crucial in various areas, including interactive experiences, data interoperability, storage, communication, data sharing, computing power as well as security and privacy [3].

5.7 Global nature and jurisdictional challenges

The metaverse operates in a digital realm beyond physical borders, presenting challenges in jurisdiction and law enforcement. Universal legal frameworks are difficult to define and enforce across different countries and legal systems [14]. Technological advancements in the metaverse often outpace the development of legal frameworks, requiring time for adaptation. Virtual property rights, digital identity, virtual currencies, and digital assets pose unique legal complexities. The legal architecture which is comprehensive for players in the metaverse would have to be developed through cooperation of interested stakeholders. As the metaverse continues to develop, discussions are already underway to account for its legal implications in the future.

Geopolitical Challenges in the Metaverse: Collaboration on addressing the metaverse user experience across these diverse geopolitical spaces will need multiple stakeholders with diverse lenses of understanding. It is necessary to closely work with policymakers, technologist, researchers, and communities to fill the huge cultural gap, which make things more easier by applying the culturally-sensitive strategies to implement metaverse under the light of data-from-decision perspective. In low-income areas, the goal should be to close the digital gap through increased access to tech and digital literacy courses.

Moreover, as technology has developed from the margins to the mainstream, information governance frameworks should be transparent, adaptable, inclusive of culture, and pay attention to the nuances of users' rights, privacy, and freedom of expression amid geopolitical context(s) [15]. So through collaboration and tackling these challenges together "Striving for a metaverse" that is valued and accommodates end user experiences stemming less global but rather geo-centric is where we want to be.

6 Conclusion

In this paper, we provide an in-depth discussion of the Metaverse concerning its core components, its architecture, existing standards, challenges faced, and the state-of-the-art research efforts. The key concepts, unique features of the Metaverse has been discussed along with an explanation of its components. In addition, a comparative analysis of existing virtual environment standards was performed, as well as the collection of a full catalogue of six technological enablers pertinent to the enabling of the Metaverse. All the critical requirement was carefully analyzed with explanation of relevant concepts and solutions. Furthermore, a detailed investigation into the existing challenges and future trends in the scope of the Metaverse was conducted, covering areas including AI-related applications, big data management, security & privacy issues, computation capabilities, multidisciplinary approach and broader aspects including global nature and legal domains.

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Conflicts of Interest

The authors declare no conflicts of interest.

Ethical Approval and Consent to Participate

Not applicable.

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