EMERGING METAVERSE TECHNOLOGIES AND THEIR APPLICATIONS

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Annotation. This article examines emerging metaverse technologies and their growing applications in modern digital environments. The metaverse represents an integration of immersive technologies such as virtual reality (VR), augmented reality (AR), mixed reality (MR), blockchain, artificial intelligence (AI), and advanced web technologies. These technologies collectively enable persistent, interactive, and shared virtual spaces that support social interaction, education, industry, and digital commerce. The paper reviews the conceptual foundations of the metaverse, its core technological components, and real-world application areas. It also discusses key challenges, including interoperability, performance, security, and ethical considerations. The conclusion highlights the transformative potential of metaverse technologies in shaping future digital ecosystems.

Keywords: Metaverse technologies, virtual reality, augmented reality, immersive environments, blockchain, digital interaction, Web3, simulation.

Annotatsiya. Ushbu maqolada rivojlanayotgan metaverse texnologiyalari va ularning zamonaviy raqamli muhitda o'sib borayotgan ilovalari ko'rib chiqiladi. Metaverse virtual haqiqat (VR), kengaytirilgan haqiqat (AR), aralash haqiqat (MR), blockchain, sun'iy intellekt (AI) va ilg'or veb-texnologiyalar kabi immersiv texnologiyalarning integratsiyasini ifodalaydi.shbu maqolada rivojlanayotgan metaverse texnologiyalari va ularning zamonaviy raqamli muhitda o'sib borayotgan ilovalari ko'rib chiqiladi. Metaverse virtual haqiqat (VR), kengaytirilgan haqiqat (AR), aralash haqiqat (MR), blockchain, sun'iy intellekt (AI) va ilg'or veb-texnologiyalar kabi immersiv texnologiyalarning integratsiyasini ifodalaydi. Ushbu texnologiyalar birgalikda ijtimoiy hamkorlik, ta'lim, sanoat va raqamli tijoratni qo'llab-quvvatlaydigan doimiy, interaktiv va umumiy virtual maydonlarni ta'minlaydi. Maqolada metaverse kontseptual asoslari, uning asosiy texnologik komponentlari va real hayotda qo‘llanish sohalari ko‘rib chiqiladi. Shuningdek, u o'zaro ishlash, ishlash, xavfsizlik va axloqiy jihatlar kabi asosiy muammolarni muhokamaaqolada metaverse kontseptual asoslari, uning asosiy texnologik komponentlari va real hayotda qo‘llanish sohalari ko‘rib chiqiladi.

Kalit so'zlar: Metaverse texnologiyalari, virtual haqiqat, kengaytirilgan haqiqat, immersiv muhit, blockchain, raqamli shovqin, Veb3, simulyatsiya.

Аннотация. В этой статье рассматриваются новые технологии метавселенной и их растущее применение в современных цифровых средах.

Метавселенная представляет собой интеграцию иммерсивных технологий, таких как виртуальная реальность (VR), дополненная реальность (AR), смешанная реальность (MR), блокчейн, искусственный интеллект (AI) и передовые веб-технологии. В совокупности эти технологии создают постоянные, интерактивные и общие виртуальные пространства, которые поддерживают социальное взаимодействие, образование, промышленность и цифровую коммерцию. В статье рассматриваются концептуальные основы метавселенной, ее основные технологические компоненты и области применения в реальном мире. Также рассматриваются ключевые проблемы, включая совместимость, производительность, безопасность и этические соображения. В заключении подчеркивается преобразующий потенциал технологий метавселенной в формировании будущих цифровых экосистем.

Ключевые слова: технологии метавселенной, виртуальная реальность, дополненная реальность, иммерсивные среды, блокчейн, цифровое взаимодействие, Web3, симуляция.

INTRODUCTION

Digital technologies have rapidly evolved from two-dimensional interfaces toward immersive and interactive virtual environments. As users increasingly seek realistic experiences, real-time collaboration, and persistent digital spaces, the concept of the metaverse has emerged as a significant technological trend. The metaverse can be defined as a network of interconnected virtual environments where users interact through digital avatars and engage with both virtual and real-world data in real time. Unlike traditional online platforms, metaverse systems are designed to be persistent, shared, and immersive. Advances in graphics processing, network infrastructure, and wearable devices have accelerated the development and adoption of metaverse technologies.

Today, emerging metaverse technologies are influencing various sectors, including education, healthcare, entertainment, manufacturing, and digital commerce, making them a critical area of research and development.

A metaverse can be described as a digital virtual environment where individuals engage with one another through avatar representations, most commonly within three-dimensional spaces. These environments emphasize social interaction and economic activity, enabling users to communicate, collaborate, and exchange digital assets in real time. The concept of the metaverse was first introduced in the 1992 science fiction novel Snow Crash, where the term was formed by combining the words “meta” and “universe.” In this work, the metaverse is portrayed as an advanced form of the Internet—a unified and immersive virtual world accessed through virtual reality (VR) and augmented reality (AR)

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technologies. In contemporary usage, the term “metaverse” is closely associated with virtual reality systems and, more recently, with Web3 technologies. Since the early 2020s, it has increasingly been adopted as a popular marketing term by technology companies, sometimes overstating the maturity and capabilities of related platforms and innovations. Alongside its rapid development, the metaverse raises significant concerns regarding information privacy, user safety, and the potential for addictive behavior, issues that mirror long-standing challenges within social media and digital gaming ecosystems.



Picture 1. Avatars socialising in the virtual world *Second Life*

Core Technologies of the Metaverse. The metaverse is built upon a combination of several advanced technologies rather than a single system. The most important components include:

- **Virtual Reality (VR)** – creates fully immersive digital environments using head-mounted displays
- **Augmented Reality (AR)** – enhances the physical world by overlaying digital information
- **Mixed Reality (MR)** – blends real and virtual objects into a unified interactive space
- **3D Graphics and Simulation Engines** – enable real-time rendering and physics-based interaction
- **Blockchain Technologies** – support decentralized identity, digital assets, and virtual economies
- **Artificial Intelligence (AI)** – enables intelligent avatars, behavior modeling, and personalization
- **Cloud and Edge Computing** – provide scalability, low latency, and persistent environments

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These technologies work together to deliver immersive experiences and enable continuous interaction across virtual platforms.

Access to the metaverse is made possible through a variety of devices, including general-purpose computers, smartphones, and immersive technologies such as augmented reality (AR), mixed reality (MR), and virtual reality (VR). However, a strong reliance on VR technology has slowed the development and large-scale adoption of metaverse platforms. Constraints related to portable hardware—particularly the challenge of balancing performance, cost, and ergonomic design—have resulted in limited mobility and insufficient graphical quality. Many lightweight wireless VR headsets are unable to achieve the high pixel density required for full visual immersion. In addition, the relatively high cost of consumer VR devices has posed a significant barrier, with headset prices ranging from several hundred to several thousand US dollars in recent years. As a result, current research and development efforts are primarily aimed at improving VR headsets, smart glasses, and sensor technologies, as well as enhancing user immersion through advanced haptic feedback systems.

At present, there is no universally accepted technical standard for implementing metaverse platforms, and most existing solutions are built on proprietary technologies. A key challenge in metaverse development is interoperability, which is closely linked to issues of transparency, data protection, and user privacy. To address these concerns, several initiatives have been launched with the goal of standardizing virtual environment technologies.

One notable example is Universal Scene Description (USD), a 3D graphics interchange framework developed by Pixar and supported by tools such as Blender, Apple's SceneKit, and Autodesk 3ds Max. In 2021, NVIDIA announced the integration of USD into its metaverse development ecosystem. Another important standard is glTF, a format designed for the efficient transmission and loading of three-dimensional models and scenes across different engines and applications. Developed by the Khronos Group—an organization responsible for open, royalty-free standards—glTF 2.0 was officially recognized in August 2022 as an international standard under ISO/IEC 12113:2022. Additionally, OpenXR serves as an open standard for accessing virtual and augmented reality hardware and software experiences. It has been widely adopted by major technology companies, including Microsoft for HoloLens 2, Meta Platforms for Oculus Quest devices, HTC for HTC Vive, Qualcomm for the Snapdragon Spaces XR development platform, and Valve for SteamVR.[Picture

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Picture 2. Some software platforms require a virtual reality headset to explore the metaverse.

CONCLUSION

Emerging metaverse technologies represent a significant step toward immersive and interconnected digital environments. By combining immersive interfaces, intelligent systems, and decentralized infrastructures, the metaverse enables new forms of interaction, learning, and economic activity. Although technical and ethical challenges remain, continued innovation and standardization efforts are expected to drive widespread adoption. As a result, metaverse technologies are poised to become a foundational element of future digital ecosystems, influencing how people communicate, learn, and collaborate in virtual spaces.

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