UNIVERSITY OF ENGINEERING AND TECHNOLOGY
VIETNAM NATIONAL UNIVERSITY

REPORT

Metaverse: Definition, Architecture and Applications

Course: INT3121 20
Student Name: Nguyen Huong Thao
Student ID: 21020668

Hanoi, 2023

Table of Contents

1. Introduction

1.1. Background

The outbreak of the COVID-19 pandemic in 2020 has forced humanity around the world to live in social isolation. A series of activities in the physical world are transferred to activities in the virtual world. Specifically, activities such as online learning, remote working, online meetings, online shopping, etc. have become an inevitable part of everyone's life at this time. Therefore, people's need for a virtual world that transcends the boundaries of the physical world is increasing. This has aroused the desire for an advanced virtual world where people can operate as effectively as the real world. Thanks to the breakthroughs of VR (virtual reality), AR (augmented reality), AI (artificial intelligence), blockchain, etc., the metaverse, a 3D digital space with virtual and real boundaries collapsed, has attracted increasing attention. The Metaverse has been recognized as the next generation of the Internet, and it is about to change the way we interact with the world dramatically.

1.2. The origin and concept of Metaverse

The concept of the Metaverse first appeared in the science fiction novel Snow Crash by writer Neil Stephenson published in 1992. In the content of the novel, the term is described as another world that can rewrite the system. values, social norms, and the absence of economic and cultural rigidity. The characters in this novel can freely access 3-dimensional (3D) space, which reflects the real world through digital agents and interact with each other. This virtual reality existing beyond reality is called the metaverse. The word “metaverse” is combined by the prefix "meta" (i.e. transcendent) and the suffix "verse" (taken in "universe", i.e. the entire world or universe). At that time, the term was not popular because the metaverse we envisioned could not yet become a reality.

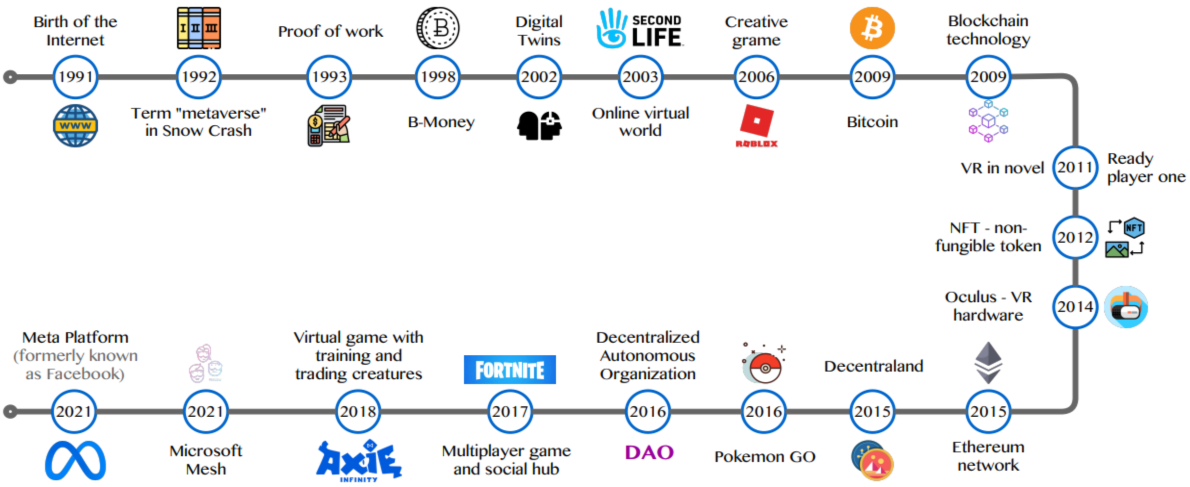

Figure 1. Development timeline of the metaverse since 1991

The term "metaverse" appeared shortly after the birth of the internet (in 1991) and was considered overblown based on existing technology. It was not until 2021 that it became popular after the event that Facebook officially changed the company's name to Meta on October 28, aiming to separate itself from the crisis-ridden social media business and transform itself into a forward-looking creator of a new digital world, called the metaverse.

2. The architecture of the metaverse

2.1. The layers of a metaverse platform

At present, the metaverse is described as a shared virtual 3D environment, or even multiple interconnected cross-platform worlds, offering users a fully immersive experience with interactive and collaborative activities. In addition to virtual places and structures within the virtual world, various entities like objects, user identities, and digital goods can be traded between different virtual worlds and even have an impact on the real world. Recent years have seen an unprecedented growth of the metaverse, largely driven by advancements in hardware (such as big data storage infrastructure, wireless communication networks, built-in sensors, and graphic processing units - GPUs) and software optimization (such as resource allocation in communications, language processing, and computer vision), which contribute to building a more robust and creative virtual world.

Unlike traditional metaverse models that suffer from limited immersive experiences due to insufficient data, the new paradigm not only generates a vast amount of user and behavioral data for businesses (where users freely create creative content) but also provides a rich foundation for integrating artificial intelligence (AI) into various domains, including natural language processing, computer vision, and neural interfaces. Additionally, a modern metaverse platform should adhere to specific characteristics such as virtual world capability, persistency, scalability, always-on synchronicity, financial allowance, decentralization, security, and interoperability.

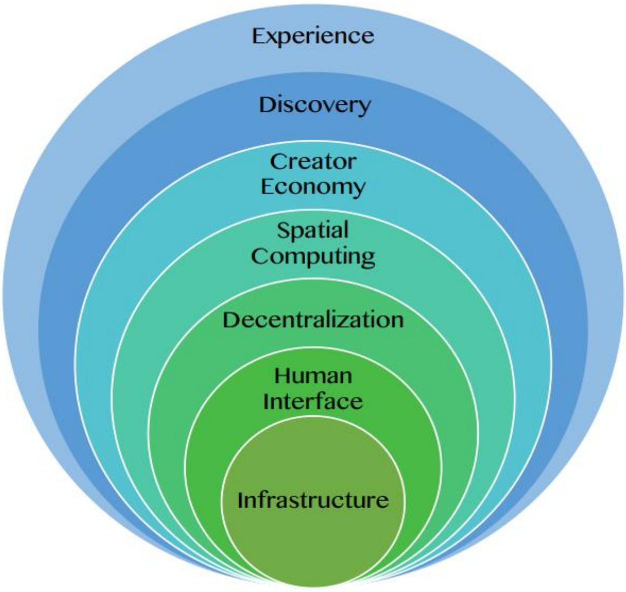

Figure 2. Seven layers of metaverse platform

A comprehensive metaverse platform comprises several layers, as illustrated in Figure 2:

- Infrastructure: This layer allows users to connect to the digital world by their devices with the support of 5G, 6G, WiFi, cloud services, data centers, central processing units, and GPUs. Web 3.0 is the best choice for Metaverse.
- Human interface: Physical-to-digital and digital-to-physical translators, which encompasse mobile devices, smartwatches, smart glasses, wearable devices, head-mounted displays, gestures, voice commands, and electrode bundles.
- Decentralization: Includes edge computing, AI agents, blockchain technology, and microservices. Blockchain technology plays a critical role in this layer as it supports decentralized infrastructure and is responsible for queries.
- Spatial computing: This layer supports a hybrid form of computation that reduces the boundaries between the physical and the digital world. It

encompasses 3D engines, virtual reality (VR), augmented reality (AR), extended reality (XR), geospatial mapping, and multitasking.

- Creator economy: Involves design tools, asset markets, e-commerce, and workflow tools. Creators design, create and develop their application for end-users.
- Discovery: This layer is driven by creator, it encompasses advertising networks, virtual stores, social curation, ratings, avatars, and chatbots.
- Experience: This is the closest layer to users in the physical world, which ivolves various activities such as games, social interactions, e-sports, shopping, festivals, events, learning, and working.

It is not difficult to discover the presence of AI within layers, with machine learning (ML) algorithms and deep learning (DL) architectures, as well as their significance in many diverse aspects. Numerous ML algorithms, employing both supervised and unsupervised learning, for example, have been deployed in voice recognition and language processing tasks for classification and regression models. This facilitates system agents in comprehending user commands. By analyzing sensor-based signals from devices like mobile phones, smartwatches, and wearables, intricate patterns of human actions can be learned. This data is particularly valuable for applications such as physical activity recognition, allowing systems to interpret user activities and interactions in virtual environments.

Deep learning (DL) has emerged as a potential AI tool for addressing the challenge of understanding complex patterns within extensive and chaotic datasets. With notable success in computer vision, DL is now making inroads into diverse domains like wireless communications, human-computer interaction, gaming, and finance.

2.2. The general architecture of the metaverse

The metaverse is comprised of avatars controlled by users, digital assets, virtual environments, and other computer-generated components. Users, embodying digital avatars, can interact socially and collaborate with others by using intelligent devices. The metaverse seamlessly integrates the physical, human, and digital realms, offering a comprehensive space for human interaction. In the metaverse's digital realm, users engage in various activities, establishing both psychological and social connections.

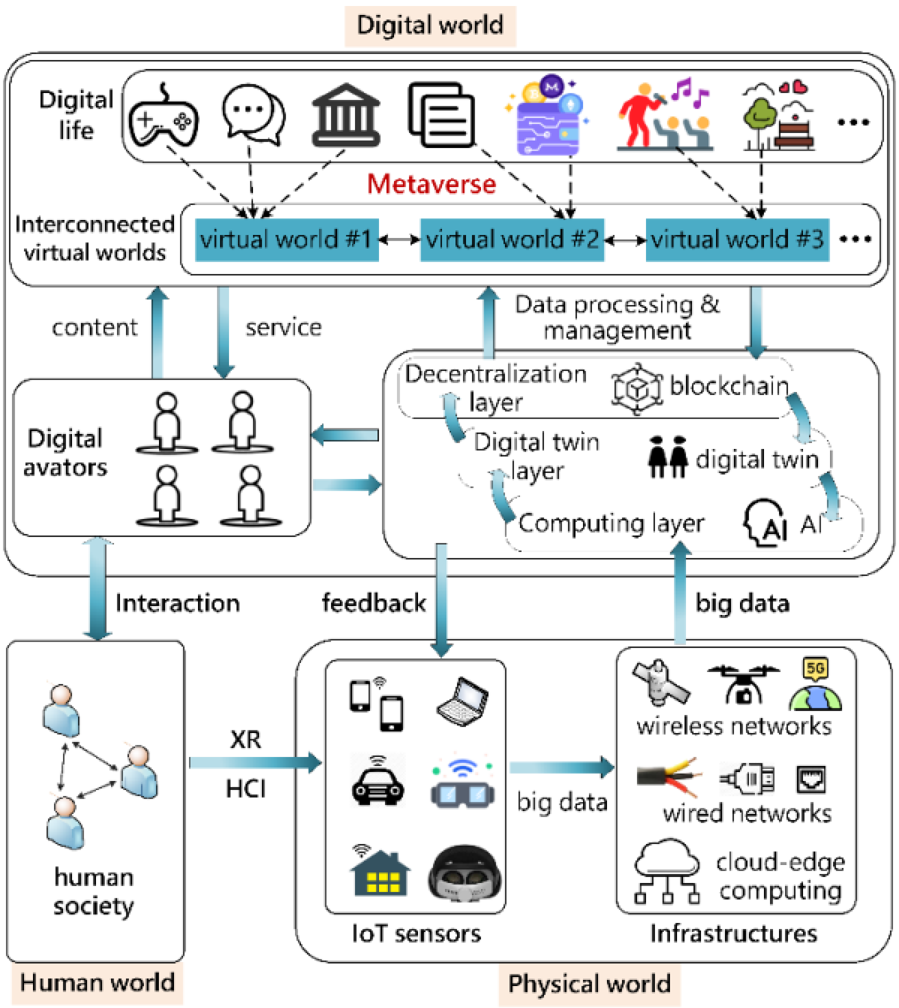

Figure 3. The metaverse architecture

Avatars and digital representations enable users to express themselves and communicate within a simulated environment mirroring the physical world. Figure 3 illustrates the complex network forming the metaverse's virtual universe. The physical dimension includes connected smart devices, objects, and sensors like smart homes, wearables, and IoT devices, serving as the bridge between the digital and physical worlds. These devices facilitate data collection, processing, and transmission to the metaverse's network, enabling real-time responses to real-world events. The metaverse's network and computational systems facilitate high-speed data transfer and processing, keeping pace with evolving technology and user demands. The physical space is instrumental in creating an immersive experience, allowing users to interact with the digital world naturally. Smart objects range from virtual reality headsets to smartphones, serving as interfaces for engaging with the virtual world. The network and computing infrastructure provide essential support for seamless metaverse functioning, ensuring fast data transmission, low latency, and real-time interactions.

The metaverse's digital realm comprises a network of interconnected sub-metaverses, each offering unique experiences such as social dating, gaming, virtual museums, and online concerts. The subsequent sections will explore the interconnectivity between the three realms, the metaverse's building blocks, and the intricate mechanisms governing information processing and circulation within it.

- Human world (society): Metaverse focuses on user experience and demands. Using advanced wearable devices (e.g. VR/AR helmets), individuals can connect with their digital avatars and direct their actions in the virtual world. After integrating into the virtual world as an avatar, people can participate in activities such as playing, working, and making friends with avatars or other virtual entities thanks to human-computer interaction (HCI) and extended reality (XR) technologies.
- Physical world: The physical world supports the metaverse by supplying important infrastructures like sensing/control, communication, computation, and storage. By using these support systems, the metaverse can efficiently handle and store multi-sensory data, facilitating seamless information and experience exchange between the virtual and physical realms through the integration of technology and human interaction. The sensing and control system, which consists of smart devices, detectors, and regulators, allows for the collection of extensive data from the external environment and human anatomy in addition to precise technological manipulation. A network architecture that consists of several wired and wireless networks, such as satellite, cellphone, and unmanned aerial vehicle networks, facilitates interconnectivity. Utilizing the synergies of cloud, edge, and end computing technologies, the computing and data storage architecture also offers significant computing and storage capabilities. The metaverse can operate to its fullest capacity thanks to this support system, giving users a deep and engaging experience.
- Digital world: The digital world consists of interconnected virtual worlds referred to as sub-metaverses. Each sub-metaverse provides users with a kind of virutal experience such as gaming, socializing, studying, etc. In these digital spaces, users can take part in these

virtual experiences within these sub-metaverses due to the uses of advanced technologies such as artificial intelligence (AI), extended reality (XR), and human-computer interaction (HCI). These sub-metaverses are seamlessly connected, forming a cohesive and interconnected digital world, allowing users to move between different virtual spaces effortlessly.

3. Roles of AI in the Metaverse

By integrating AI with other technologies like AR/VR, blockchain, and networking, the metaverse can establish secure, scalable, and realistic virtual environments on a dependable and always-available platform. The significance of AI in ensuring reliability and enhancing the performance of the infrastructure is evident in the seven-layer metaverse platform. In the context of 5G and future 6G systems, advanced machine learning (ML) algorithms, incorporating supervised learning and reinforcement learning, have been implemented for various challenging tasks, including efficient spectrum monitoring, automatic resource allocation, channel estimation, traffic offloading, attack prevention, and network fault detection.

With sensor-based wearable devices and other human-machine interaction tools, both simple human movements and intricate actions can be analyzed and recognized based on learned ML and deep learning (DL) models. Consequently, users' real-world movements are translated into virtual worlds, enabling users to have complete control over their avatars and interact seamlessly with other elements in the metaverse. Furthermore, these avatars can engage in a variety of real-world modalities, such as facial expressions, emotions, body movements, and physical interactions, in addition to speech recognition and sentiment analysis, all powered by AI for accuracy and processing speed.

While XR/VR devices represent the outward appearance of the metaverse with immersive tools like head-mounted displays, AI plays a crucial role behind the scenes in constructing a creative and visually appealing world, delivering a seamless virtual-reality experience to users. AI facilitates content creation processes; for instance, technologies like GANverse3D introduced by NVIDIA allow developers to capture images of objects and create virtual replicas. Various DL-based methods have been proposed for rendering 3D objects, including human body parts, achieving impressive accuracy with real-time processing accelerated by both software (e.g., PyTorch3D library from Facebook AI and TensorRT from NVIDIA) and hardware (e.g., GPUs).

AI research supercluster (RSC), which is considered one of the world's fastest AI supercomputers, designed to accelerate AI research and contribute to building the metaverse, was recently introduced by Meta. The RSC assists AI researchers and scientists in developing improved DL models from extensive data, encompassing text, speech, image, and video, for various services and applications. Consequently, the achievements and outcomes from the RSC serve as foundational elements for constructing the metaverse platform, where AI-driven products play a substantial role.

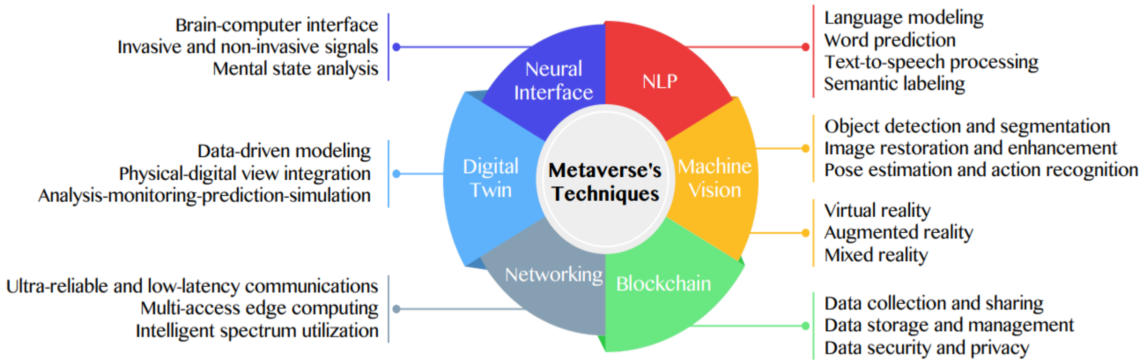

Figure 4. Primary technical aspects in the metaverse

3.1. Natural Language Processing

Natural Language Processing (NLP), also known as computational linguistics, encompasses computational models and learning processes to automatically analyze and understand human languages, including speech and text. NLP covers various topics like speech-to-text, text-to-speech, conversation design, voice branding, and handling multi-language and multicultural aspects in voice. In the context of the metaverse, NLP plays a crucial role in intelligent virtual assistants (chatbots), enabling them to understand complex human conversations across different dialects and tones. AI-powered chatbots can provide nuanced responses and learn from interactions to enhance response quality in virtual environments like the metaverse.

Language modeling, a key task in NLP, involves predicting words or linguistic units based on the syntactic and semantic relations of preceding words. Various neural network architectures, including recurrent neural networks (RNNs), long short-term memory networks (LSTMs), and convolutional neural networks (CNNs), have been explored for language modeling. Attention mechanisms and advanced structures like gated connections and bi-directional structures have been employed to improve efficiency. Character-aware and word-aware models contribute to tasks such as part-of-speech tagging, named-entity recognition, and semantic role labeling in the metaverse.

Deep Learning (DL) has been utilized to overcome the limitations of conventional machine learning (ML) algorithms in NLP. CNNs with advanced architectures have been applied to tasks like sentiment prediction and question type classification. Sentiment analysis may involve feature extraction of aspects and sentiment polarities to enhance the reliability and flexibility of virtual assistants in the metaverse. Natural language generation, an advanced chatbot functionality, uses models like single RNN/LSTM and mixture LSTM-CNN to generate text for tasks ranging from image captioning to virtual question answering.

NLP tasks in the metaverse require a combination of text-based and speech-based interactive experiences. Techniques such as supervised learning, unsupervised learning, and reinforcement learning with deep models have been adopted for specific NLP tasks, including text parsing, semantic labeling, context retrieval, language interpretation, and dialogue generation. Overall, the integration of NLP techniques enhances the immersive and interactive capabilities between human users and virtual assistants in the metaverse.

3.2. Machine Vision

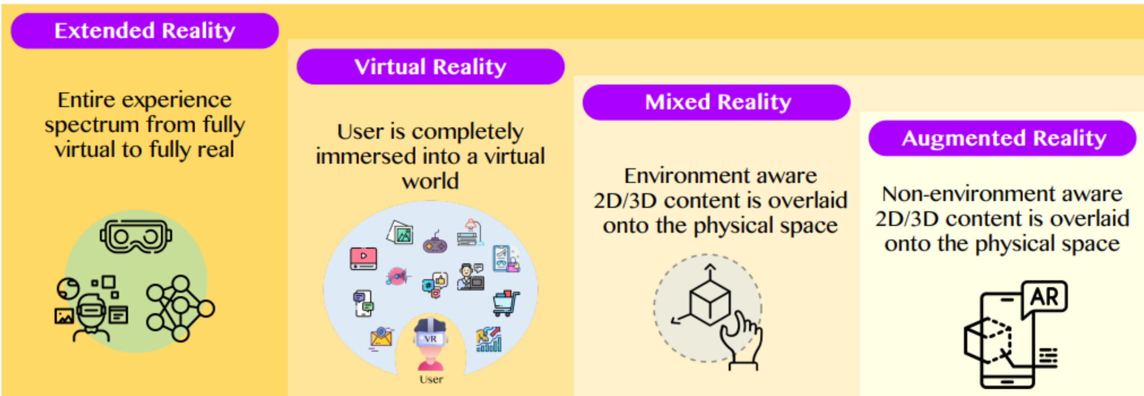

Figure 5. The differences between AR, MR, VR, and XR

Machine vision, including computer vision and extended reality (XR), plays a crucial role in building the foundation of the metaverse. It involves capturing and processing visual data from the environment to provide users with high-level information through devices like headsets and smart glasses. XR encompasses virtual reality (VR), augmented reality (AR), and mixed reality

(MR), allowing users to interact with virtual worlds using avatars. AI, particularly deep learning (DL), is integrated into XR devices to enhance user experiences, such as predicting eye fixations and improving human-machine interaction.

The focus on XR is due to its potential in bridging the physical and digital worlds, offering natural interactions. MR, a blend of physical and digital realities, stands out for its hybrid experiences, combining holographic devices for physical object manipulation and immersive devices for virtual interactions. The challenge is to minimize gaps between these devices. Computer vision, empowered by AI and DL, contributes to the metaverse by enhancing user experiences through tasks like semantic segmentation and object detection.

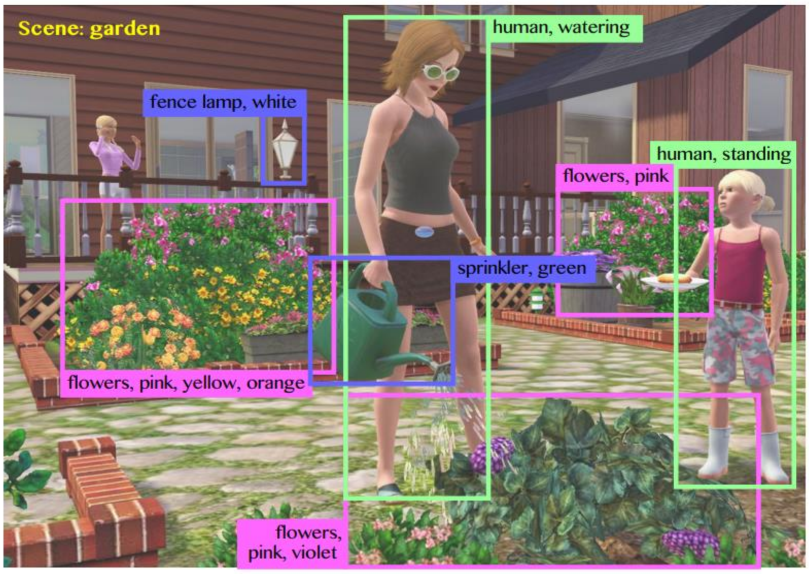

Figure 6. Computer vision in the metaverse with scene understanding, object detection, and human action/activity recognition

Semantic segmentation categorizes pixels into predefined classes, and DL-based approaches have improved its performance. Object detection, dealing with real and virtual objects, benefits from CNN architectures. Challenges in the 3D environment, such as occlusion and illumination, are addressed using advanced image processing and depth sensing algorithms. Image quality issues in the virtual world are tackled through image restoration and enhancement, leveraging AI algorithms for real-time processing.

In XR environments, human pose estimation and action recognition are critical for avatar control. Models using CNN architectures improve accuracy by considering depth information and structural connections. The last decade has seen a revolution in visual-based action recognition with DL, significantly improving accuracy and dealing with various realistic actions. Hand gesture recognition, gait identification, and eye tracking are also considered to enhance interactive experiences in XR environments. Overall, AI and computer vision technologies are instrumental in creating a seamless and immersive metaverse experience.

3.3. Blockchain

Blockchain is a digital ledger that records transactions and tracks assets using cryptography, providing shared and transparent information. In the metaverse, where vast amounts of data are generated and transmitted by VR devices, blockchain, combined with AI, offers a promising solution for security and privacy issues. It can securely record and track digital assets via transparent transactions with smart contracts.

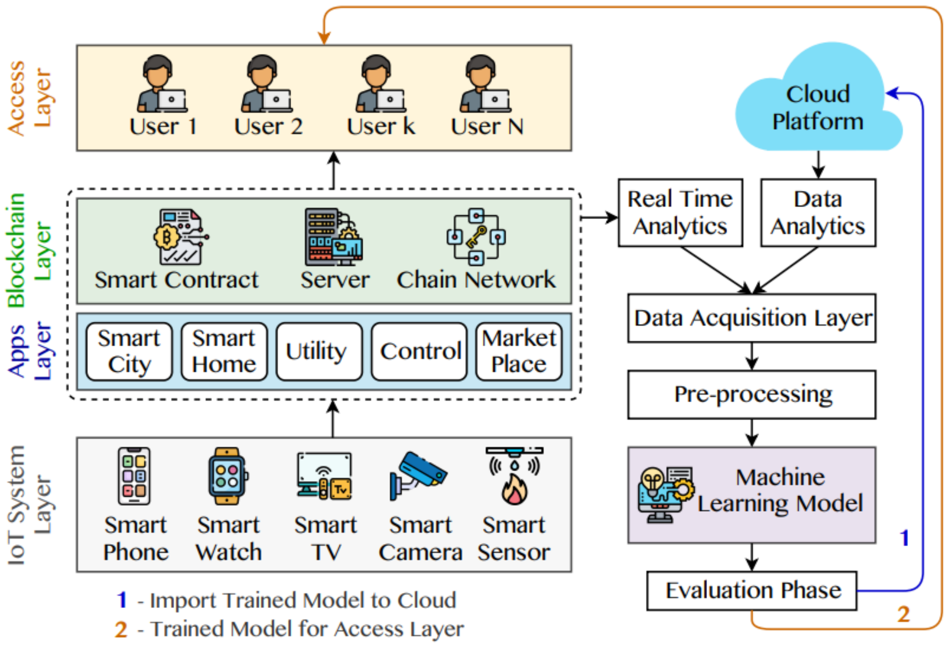

Figure 7. A blockchain-based IoT framework with ML to enhance security and privacy

Various methods combining blockchain and AI have been proposed for data security and privacy in different domains. ML and DL algorithms have been investigated for data analytics to detect and classify cyberattacks in blockchain-based networks. In the context of IoT-aided smart cities, a framework integrating blockchain and ML enhances privacy and security. DL has replaced traditional ML in addressing the security and privacy challenges of big data in blockchain networks. Federated learning (FL) is employed to address privacy issues in data sharing among multiple untrusted parties in a blockchain network, with applications in resource trading systems and vehicular edge computing.

Interoperability is crucial in blockchain for collaboration between parties with different data infrastructures. Learning analytics frameworks and the integration of blockchain into FL address interoperability challenges. In the metaverse, where diverse parties contribute digital content with different formats, the collaborative development of blockchain and AI can effectively handle data security, privacy, and interoperability.

3.4. Networking

The metaverse, serving a vast user base with pervasive network access, relies on advanced wireless communication technologies. Over the past decade, innovations in wireless systems, particularly the integration of AI at multiple network layers, have significantly improved performance. Real-time multimedia services in the metaverse demand reliable, high-throughput, and low-latency connections to ensure a satisfactory user experience. The fifth-generation (5G) network requirements include a peak data rate of 10 Gbps and an end-to-end delay under 10 ms, highlighting the importance of ultra-reliable and low-latency communications (uRLLC) for emerging mission-critical applications.

To achieve uRLLC in 5G and beyond (6G) networks, optimization algorithms have been introduced, many of which require high computing resources. Machine learning (ML) and deep learning (DL) have demonstrated significant potential in handling challenging tasks, such as intelligent radio resource allocation. Reinforcement learning (RL) has been used to address resource slicing problems in enhanced mobile broadband (eMBB) and uRLLC, optimizing network states and channel conditions.

Efficient radio resource management, a crucial aspect of enabling uRLLC, has been approached with distributed risk-aware ML methods. DL has been applied to various uRLLC tasks, including spectrum management, channel prediction, traffic estimation, and mobility prediction. Advanced convolutional neural network (CNN) architectures like MCNet and SCGNet have been designed to identify modulation types for enhanced spectrum utilization efficiency. Online channel state information (CSI) prediction methods, combining CNN and long short-term memory (LSTM), aim to overcome the computational cost of traditional CSI estimation approaches.

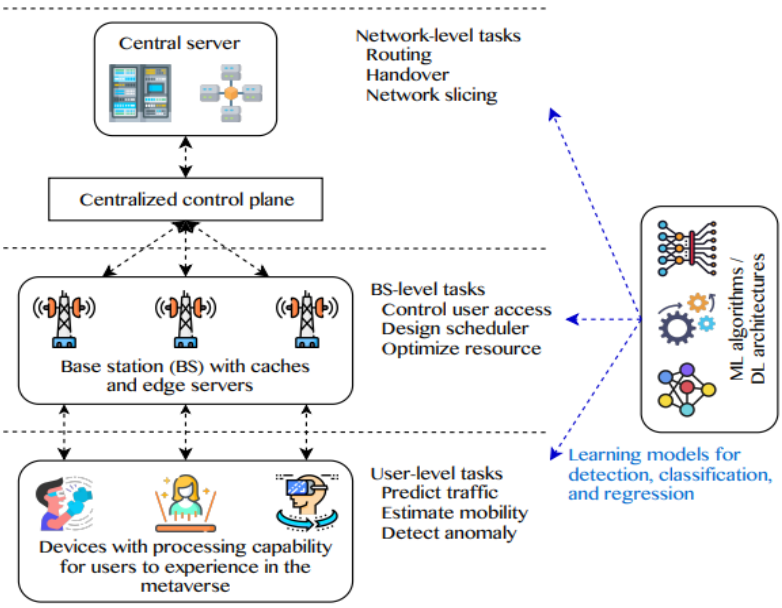

Figure 8. A general architecture in 5G and beyond for metaverse services and applications, in which AI with ML algorithms and DL models contribute in multi-level tasks

3.5. Digital Twins

Digital Twins (DTs) are digital representations of real-world entities that synchronize operational assets, processes, and systems with the physical world. They serve as a fundamental building block for the metaverse, creating exact replicas of reality in terms of structure and functionality. DTs play a crucial role in allowing users to enter and enjoy services in the virtual world. For instance, technicians can maneuver 3D representations of complex systems for technical training and commercial customization.

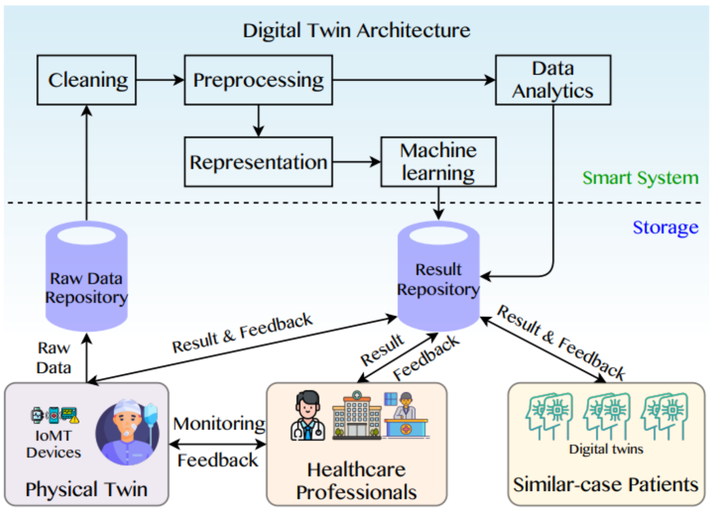

Figure 9. A data-driven DT framework for intelligent healthcare systems using ML to process raw data of IoMT devices

In the metaverse, a general architecture involves AI with machine learning (ML) algorithms and deep learning (DL) models contributing to multi-level tasks, such as predicting traffic, estimating mobility, and optimizing resources. DTs enable application developers and service providers to remotely analyze physical machines and processes using AI. They have been applied in various domains, including industry 4.0 for sensor-fault detection, human-robot welding actions monitoring, intelligent healthcare systems for health diagnosis, and smart urban agriculture for decision support.

DL has been recently applied in DT architectures, such as in edge computing-aided Internet of Vehicles (IoV) to improve computational resource utilization and in mobile edge computing systems for investigating ultra-reliable low-latency communication services. In industrial IoT, DTs simulate and capture the operation state of industrial devices, addressing bias issues with federated learning to improve performance. DTs, empowered by AI, would improve system performance, reduce incidents, minimize maintenance costs, and optimize business and production process. This would allow users to view the metaverse as a real-time replication of reality, enhancing the overall experience in the virtual world.

3.6. Neutral Interface

The neutral interface is a technology that significantly enhances the human experience and bridges the gap between reality and the virtual world in the metaverse. The most immersive and popular interface for interacting with the virtual world is currently a VR headset with a controller. However, there is a growing focus on neural interfaces, also known as brain-machine interfaces (BMIs) or brain-computer interfaces (BCIs), that go beyond traditional VR devices. These interfaces aim to blur the boundary between humans and wearable devices.

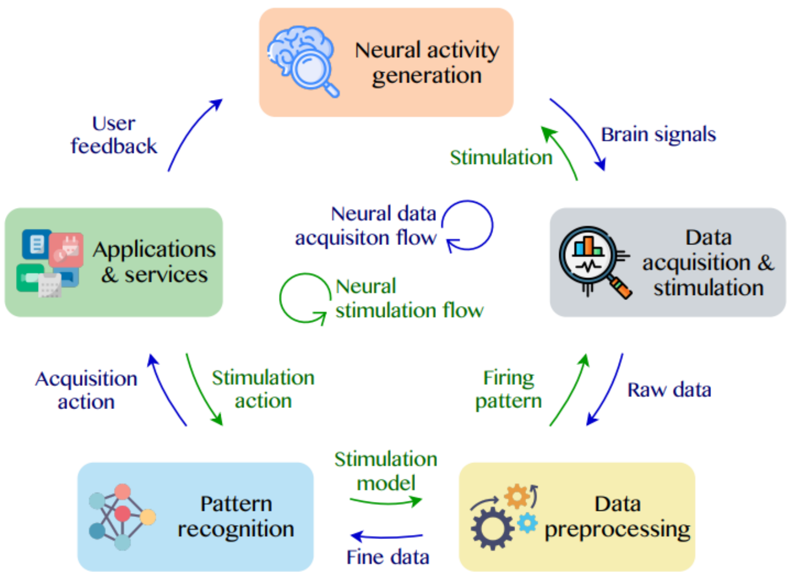

Figure 10. A common BMI cycle with primary components for processing neural signals and responding neural stimulations

BMIs detect neural signals using external electrodes or optical sensors attached to the skull and other parts of the body. Noninvasive devices, which read and control the mind at a basic level, can manipulate thoughts with transcranial electromagnetic pulses. The BMI cycle involves processing neural signals and responding to neural stimulations. Data engineering techniques in the preprocessing stage and AI/ML algorithms in the pattern recognition stage enable accurate analysis of complex neural signals.

The use of electroencephalogram (EEG) signals is common in BCI systems. Studies have explored brain signal classification through offline unsupervised and simulated online supervised approaches, achieving lower computational costs and better performance in tasks such as motor imagery and mental analysis. Other efforts involve learning discriminative spatiotemporal features from EEG signals to build predictive models for deciphering brain activities into communication and control commands.

Various machine learning algorithms, including logistic regression, Naive Bayes, and SVM, have been applied to investigate the performance of event-related potential (ERP) in BCI systems. Different studies explore the feasibility of using visual hemispheres for target locations in aerial images and propose advanced ML frameworks to increase the correct classification rate of EEG signals. Capsule networks (CapsNet) and hybrid DL frameworks with multidirectional CNN and bidirectional LSTM have been employed to improve accuracy in ERP detection and brain-controlled robotic arm systems.

The future outlook for brain-computer interfaces involves consumer-ready mind-control systems that will further enhance immersive interactions between reality and the virtual world in the metaverse.

4. Applications of the Metaverse

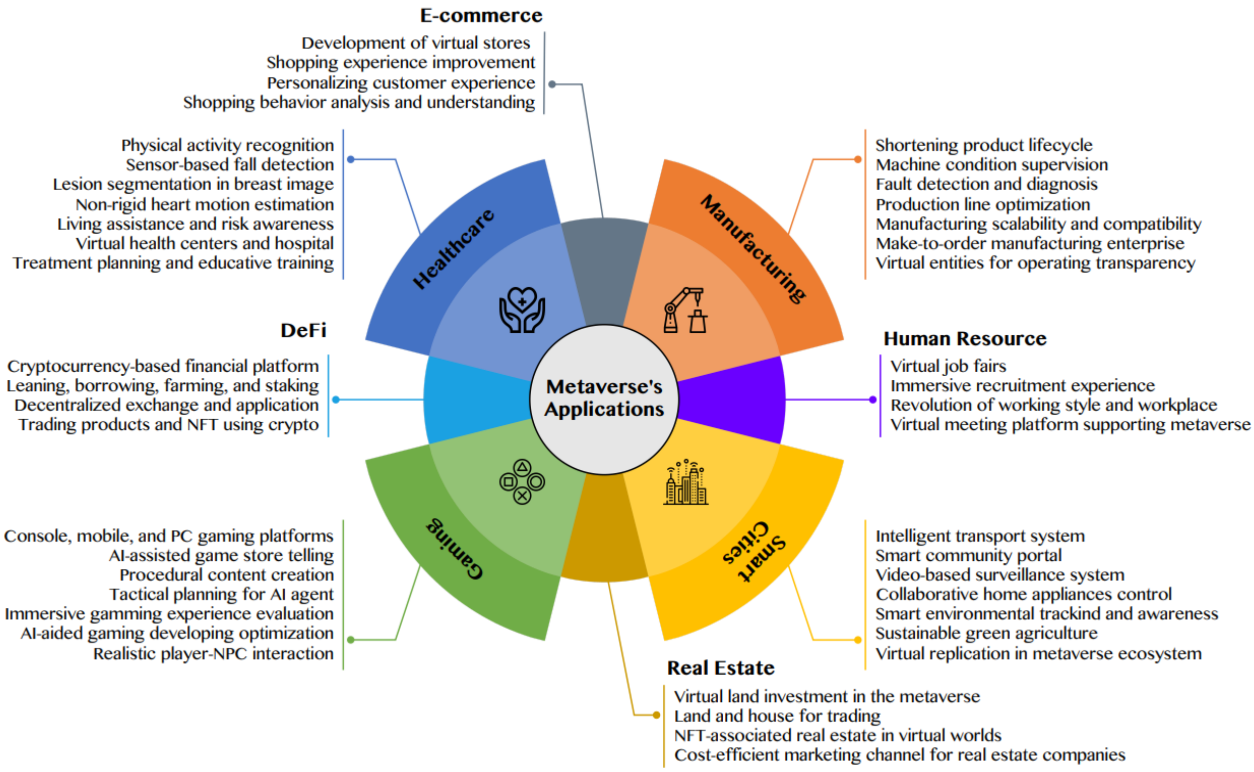

Figure 11. Applications of the Metaverse in some areas with AI technology

4.1. Healthcare

In the healthcare industry, recent advancements involve the integration of revolutionary technologies like virtual reality (VR), big data, and artificial intelligence (AI) in both software and hardware. These innovations aim to enhance the efficiency of medical devices, reduce healthcare costs, improve operational processes, and extend the accessibility of medical care. The metaverse, transitioning from a 2D to a 3D virtual environment, enables immersive learning, understanding, and sharing of patients' health conditions and medical reports.

AI, particularly in VR/extended reality (XR) systems, plays a crucial role across various healthcare sectors. It contributes to more efficient diagnosis, faster and accurate medical decisions, real-time medical imaging and radiology improvements, and the creation of realistic simulated environments for educating interns and medical students. Wearable healthcare devices benefit from AI, which automates the recognition of complex patterns in sensory data. For instance, a method for recognizing physical activities utilized handcrafted and deep features, combining them to enhance activity recognition rates. Another approach employed an encoding algorithm to convert inertial sensory signals into color images, facilitating human activity classification using a lightweight CNN.

Fall detection systems for IoT-based healthcare services utilize hierarchical deep learning frameworks, including CNN architectures, to process sensory data collaboratively at local devices and a cloud server. RNN and LSTM networks have also been applied to early healthy risk attentions, such as fall detection and heart failure. The success of deep learning, particularly CNN architectures, in image processing and computer vision has led to its widespread use in various challenging tasks of medical image analysis. For example, advanced networks like the saliency-guided morphology-aware U-Net (SMU-Net) have been developed for lesion segmentation in breast ultrasound images.

In medical image analysis, cost-efficient unsupervised deep learning approaches have been introduced to accelerate non-rigid motion estimation in heart images. To address the computational challenges of 3D medical image segmentation, 2D neuroevolutionary networks have been explored, renovating optimal evolutionary 3D CNNs to reduce computational costs without sacrificing accuracy. AI serves as the core technology for data analytics in healthcare, enabling the development of applications for medical diagnosis and treatment planning in virtual reality environments. An example of the application of augmented reality in medical education would be an augmented reality T-shirt that allows students to examine the inside of the human body as an anatomy lab.

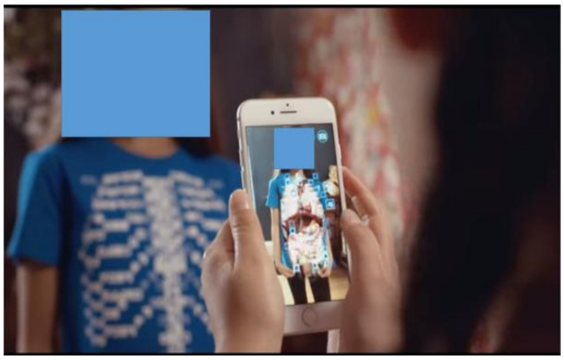

Figure 12. Virtuali-Tee: augmented reality T-Shirt

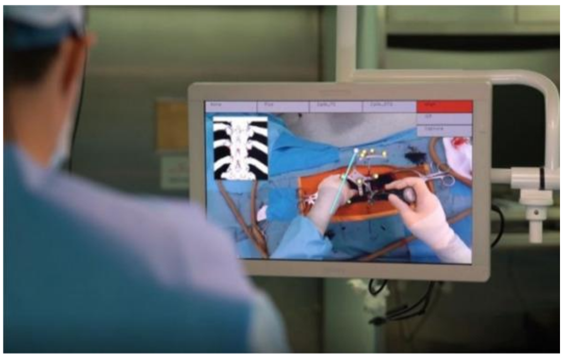

Figure 13. Augmented reality-based spine surgery platform

The metaverse opens up new possibilities for healthcare and medical services, including interactive practice lessons for medical education, collaborative treatment planning, and access to virtual health centers and hospitals through virtual assistants.

4.2. Manufacturing

In manufacturing, a shift towards digital connectivity between machines and systems is occurring to enhance the analysis and understanding of physical entities. Unlike traditional digital transformation aimed at improving the physical world through digital operations, the metaverse introduces a virtual world that is translated onto the physical world, emphasizing reality interaction and persistence. The integration of cutting-edge technologies, such as AI and digital twin (DT), facilitates the modernization of digital operations in the ongoing digital revolution within the manufacturing sector.

AI, featuring machine learning (ML) algorithms and deep learning (DL) architectures, has significantly impacted manufacturing through various industrial applications. One challenge in manufacturing is the frequent reconfiguration and upgrading of production systems due to shortened product lifecycles and increased product variants. ML-based systems often require substantial time and computing resources for new data collection, preprocessing, and model learning. To address these challenges, a symbiotic human-ML framework was employed, utilizing a reinforcement learning strategy that combines the learning capacity of Q-learning models with the domain knowledge of experts. Human exploration was also considered to reduce noise in data and enhance the quality of automatic decision-making systems.

Quality inspection in modern manufacturing systems has gained importance, with intelligent data-driven condition supervision approaches attracting attention. For reliable fault detection and diagnosis, DL techniques with recurrent neural networks (RNN) and convolutional neural networks (CNN) have been applied to achieve high accuracy in real-time monitoring. AI has also been applied to optimize specific sectors in production systems, enhancing production line performance while addressing scalability and compatibility concerns. For example, prediction models have been developed to estimate optimal buffer sizes in production lines, combining artificial neural networks (ANN) with genetic algorithms.

The rise of industrial collaborative robots in manufacturing plants has led to the development of cooperative AI models capable of learning complex patterns from multimodal data for various correlated tasks in the manufacturing process and production line. These AI models should possess explanation and reasoning capabilities. In the metaverse, virtual entities contribute to improving industrial manufacturing efficiency by leveraging AI to accelerate production process design, foster collaborative product development, reduce operational risks through quality control, and enhance transparency for both producers and customers.

4.3. Smart Cities

Smart cities gather valuable information about citizens' needs through various sources, including the Internet of Things (IoT), video cameras, and social media. City governments use feedback from users to make decisions about enhancing, offering, or removing services. The metaverse platform enables smart cities to provide more intelligent interactive services, replicating environmental data such as air quality, weather, energy consumption, traffic status, and parking availability in a virtual world for a user-friendly interface.

Several smart services, including utility payments and smart home control, can now be executed in the virtual world through platforms like intelligent transportation systems (ITS), smart streetlight management systems, automatic parking systems, smart community portals, and surveillance systems. Although the impact of these technologies on smart cities is currently limited, the metaverse has the potential to accelerate the integration of smart services into citizens' daily lives.

In the realm of smart cities, AI plays a crucial role in achieving automation and intelligence in services. An example involves the integration of EEG-based Brain-Computer Interface (BCI), Virtual Reality (VR), and IoT technologies powered by AI to control home appliances collaboratively. The use of ML algorithms on brain signals allows users to control home appliances over the IoT network.

Efforts to develop a hybrid Intelligent Transportation System (ITS) spanning both physical and virtual worlds have been introduced. An IoT-enabled architecture was proposed to control and manage urban traffic in both realms simultaneously, offering real-time services and reducing operational costs. Addressing air pollution concerns, an efficient forecasting approach was studied using a hybrid deep learning architecture combining 1-D CNNs and bi-directional LSTM networks.

In the context of smart green cities, AI is vital for precision agriculture systems, contributing to yield prediction, quality evaluation, and pest and disease detection. Designing and implementing a metaverse ecosystem for smart cities is a challenging task for metropolitan governments. The metaverse enables the provision and improvement of administrative services, covering various sectors like environment, education, transportation, and culture. AI technology facilitates data analytics in the metaverse, with an emphasis on rules, ethics, and security to ensure a safe experience environment.

4.4. Gaming

Gaming stands as a pivotal application in the metaverse, and machine learning (ML) and deep learning (DL) are reshaping the gaming industry across various platforms, from consoles to mobile and PC platforms. This section delves into the transformative impact of ML and DL on game development, exploring the possibilities of building the next generation of gaming experiences in the metaverse.

Over the past decade, ML has significantly influenced video game development, enabling the creation of more realistic worlds with engaging challenges and unique narratives. Game developers increasingly utilize ML as a powerful tool set to dynamically and intelligently respond to player actions, particularly in terms of non-player character (NPC) behavior strategy and learning, tactical planning, player response modeling, procedural content creation, player-NPC interaction design, general game AI, AI-assisted game storytelling, and AI in commercial games.

A comprehensive survey investigates the application of AI algorithms in intelligent video and computer games, particularly in in-game decision-making and learning. Primary AI algorithms such as decision trees, fuzzy logic, Markov models, rule-based systems, and finite-state machines are deployed for tasks such as modeling game flow, assessing player motivation, evaluating immersive experiences, adapting gameplay, customizing gameplay, and controlling NPC behavior. Learning-based tasks leverage algorithms like Naïve Bayes, artificial neural networks (ANN), support vector machines (SVM), and case-based reasoning systems for tasks like classifying user gameplay, NPC behavior, user behavior recognition, and adapting the game flow based on personal experience.

In real-time strategy (RTS) games like StarCraft, Bayesian models are employed for multi-scale uncertainty modeling and multi-level abstraction levels, addressing micromanagement, tactics, and strategy. AI is also applied in testing tasks during the design and development stages, such as using metamorphic testing mechanisms to optimize move selection in artificial chess games.

The combination of reinforcement learning (RL) and deep networks is utilized in creating AI agents capable of overcoming challenges in real-time fighting games. This framework, employing deep RL, is effective in various competitive games, demonstrating the capability to handle level upgrades and balance policies. RL and supervised learning are also applied to enhance AI agents in RTS games, outperforming traditional search algorithms by employing convolutional neural networks (CNNs) and deep Q-learning networks.

4.5. Applications in other areas

Education: The Metaverse holds significant potential in education, particularly in audio and visual-based learning, offering a unique opportunity for experiential learning. This immersive technology bridges the gap between theoretical knowledge and practical experience, allowing individuals to explore complex concepts, such as radiation, tangibly and understandably. Many research studies highlight the effectiveness of the Metaverse in enhancing the educational experience and improving learning outcomes.

The primary difference between the metaverse and the current application of VR or AR in education lies in the duration of the immersive experience and the integration of AI technology. First, in the metaverse, students tend to have a life that is separate from the real world and runs for a period of time. The current applications of VR and AR in education tend to engage students in experiencing specific situations over a short time period where they can pause or start over. Unlike those applications, the metaverse seeks to deliver an authentic life, implying that the experience inside generally cannot be paused or restarted. In addition, in the metaverse, AI technology plays a crucial role in maintaining the authentic world.

E-commerce: Numerous consumer brands have entered the digital realm within the metaverse, integrating E-commerce to enhance shopping experiences, despite the limited popularity of VR devices among mainstream consumers. Brands are gradually creating innovative digital stores that seamlessly blend offline and online shopping, ensuring a consistent user experience. Virtual shopping enables consumers, represented by avatars, to navigate 3D-rendered spaces, interact with virtual cashiers/sellers powered by VR and AI technologies, and experience real-time representations of static products. Retailers are increasingly focusing on personalizing customer experiences in the metaverse, leveraging AI-based understanding of shopping behavior for both business survival and revenue growth.

5. Conclusion

This essay report has provided basic information about the Metaverse, how it is defined, and works, as well as the potential development of this trillion-dollar industry. The development of technology as well as the impact of the COVID-19 pandemic has made the nearly 30-year-old concept a hot topic recently. With the participation of technology giants, we have a complete basis to believe in the potential of the Metaverse.

However, contrary to the great potential of the metaverse, the challenge of creating a metaverse world as imagination is extremely daunting. Experts believe that there is not yet a good enough technology and application infrastructure to truly realize the dream of building a completely virtual metaverse. The metaverse offers users a rich experience, which will require the transmission of large amounts of data with low latency. This means that a 5G connection is inevitable. Other requirements include high-power semiconductors to run complex algorithms and devices such as VR glasses to allow users to immerse themselves in the digital world. Technical barriers remain, such as VR glasses are bulky and have many errors in image resolution. Many people still feel dizzy and nauseous after using glasses for a long time. Battery life is also a challenge as advanced computing capabilities like gesture navigation eat up power. Content is also crucial to the success of the metaverse, but 3D modeling software is still expensive, making it inaccessible to developers on a large scale. In addition, like social networks, the metaverse requires very high information security, privacy, and user data. In conclusion, the Metaverse has huge implications for society, however, besides the great advantages will be dangers.

REFERENCES

1. [2202.10336] Artificial Intelligence for the Metaverse: A Survey (arxiv.org)
2. (PDF) Unveiling the Metaverse: Exploring Emerging Trends, Multifaceted Perspectives, and Future Challenges (researchgate.net)
3. Educational applications of metaverse: possibilities and limitations - PMC (nih.gov)
4. Definition, roles, and potential research issues of the metaverse in education: An artificial intelligence perspective - ScienceDirect