Advancing Education Through Extended Reality and Internet of Everything Enabled Metaverses: Applications, Challenges, and Open Issues

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***Abstract*—Metaverse has evolved as one of the popular research agenda that let users learn, socialize, and collaborate in a networked 3-D immersive virtual world. Due to the rich multimedia streaming capability and immersive user experience with high-speed communication, the metaverse is an ideal model for education, training, and skill development tasks. To facilitate research in this area, we provide a comprehensive review of the various educational use cases and explore how enabling technologies, such as extended reality and the Internet of Everything will play a major role in educational services in future metaverses. Then, we provide an overview of metaverse-based educational applications focusing on education, training, and skill development and analyze the technologies they are built upon. We identify common research problems and future research directions in the domain. This article also identifies core ethical considerations of metaverse for education and potential pitfalls. We believe this survey can fully demonstrate the versatility of metaverse-driven education, which could serve as a potential guideline for the researchers.**

***Index Terms*—Artificial intelligence (AI), education, extended reality (XR), metaverse.**

NOMENCLATURE

3-D	Three-dimensional.
AI	Artificial intelligence.
AR	Augmented reality.
BCI	Brain–computer interface.
DARPA	Defense Advanced Research Projects Agency.
DAO	Decentralized autonomous organizations.
DIS	Distributed interactive simulation.
HIL	Hardware in the loop.
HJA	Human joystick attacks.
HMD	Head-mounted display.
ICT	Information and communications technology.
IoE	Internet of Everything.
LCAP	Low-code and no-code application platforms.
MAR	Mobile augmented reality.
MR	Mixed reality.
VR	Virtual reality.
XAI	Explainable artificial intelligence.
XR	Extended reality.

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I. INTRODUCTION

IN THE modern world, the popularity of the metaverse is on the rise in different application domains. The term "metaverse" describes a shared virtual environment that, while lacking a universally accepted definition, is commonly recognized as a collective virtual shared space with a strong sense of mutual presence . This space emerges from the convergence of virtually enhanced physical reality, persistent virtual spaces, and the Internet, made accessible through high-speed Internet [1], [2]. It integrates elements of XR—an umbrella term that includes AR, VR, and other immersive technologies—AI, and the IoE, to create a vast, interactive, and networked digital world. Within the metaverse, individuals interact with each other and with a computer-generated environment in real time, fostering social connection and a sense of physical presence [3], [4]. This environment extends beyond isolated virtual worlds, constituting a persistent, dynamic, and user-driven ecosystem. Here, users may explore, create, cooperate, and engage in a broad spectrum of activities such as social interactions, business, entertainment, and education. The metaverse is characterized by its shared and persistent nature, allowing users to interact via immersive technologies with both the environment and other users, transcending the boundaries of particular applications and serving as the foundational concept of the metaverse [5].

Some key application domains where the technology has been proven very effective include health care, defense, industry (manufacturing), real estate, and gaming [4], [6]. Education is also one of the domains where the use of the concept/technology is gaining momentum with the metaverse promising several advantages. For instance, it allows students and teachers from different parts of the world to meet in a virtual environment regardless of their real-world location [7]. Similarly, building virtual landscapes based on the teacher's lesson plans provides a better opportunity, resulting in an improved and more productive learning experience for the students. Due to such opportunities and the advantages, they bring to the education sector, several studies have analyzed the potential of a metaverse in education [8] as described next.

The potential of a metaverse in education was explored by Sung et al. [9], who compared it with traditional educational content delivery based on video presentations. The evaluation is carried out in terms of students' learning attitude, enjoyment, and performance in a knowledge-based test. It helps to revitalize the economy and market through XR technology. Similarly, Kemp and Livingstone [10] analyzed the pros and cons of a multiuser virtual environment in the education sector. Here, the integration of traditional learning with the multiuser virtual environments and a hybrid educational platform was established. It encompasses interactive objects and learning spaces. Therefore, envisioned to support a diverse range of educational services with immersive experiences for the users, the metaverse will most likely make ground-breaking innovations through IoE and XR.

Despite the great potential and proven effectiveness in student engagement in learning, the supporting technologies for metaverse also bring several challenges to the education sector. For example, as demonstrated by MacCallum and Parsons [11], generating virtual content and new ideas for engaging students in the learning process is very challenging and requires a degree of experience. Some studies also report the little impact of technology on the student's performance in knowledge-based tests [9].

A. *Enabling Technologies for Metaverse*

Metaverse is based on the crossroads of key modern technologies, namely, XR and IoE. In the next subsections, we discuss these elements of a metaverse in detail by highlighting their roles and the advantages they bring to a metaverse.

1) Extended Reality: XR drags and stretches the human experiences by blending the real and virtual digital worlds in multidimensional directions. As shown in Fig. 1, XR is an umbrella that integrates VR, AR, and MR technology for provisioning sustainable digital world realization.

1) *VR:* In general, VR creates a whole new environment and provides a completely immersive experience for the users. It uses computer technology to create a simulated experience, which may be similar to or completely different from the real world. Standard VR systems use either headsets or multiprojected environments to generate realistic sounds and visuals.
2) *AR:* AR, on the other hand, keeps the real-world objects as it is and superimposes layers of digital objects to the real world. AR systems integrate three different features: a) the combination of the real and virtual worlds; b) a real-time interaction; and c) accurate 3-D registration of virtual and real objects. The following are the most vital components used for providing rich AR experiences for end users.

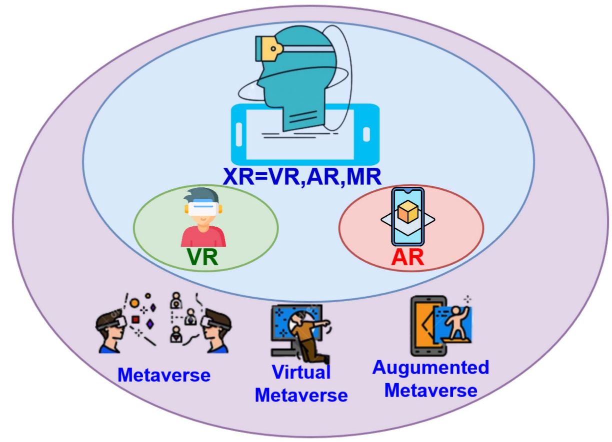

Fig. 1. Realizing digital world under the umbrella of XR.

3) *MR:* MR is the merging of real and virtual worlds to produce new environments and visualizations. Here, the physical and digital objects coexist and interact in real time [12]. Unlike AR, users can interact with virtual objects. To provide different user experiences from fully immersive to light information layering of environments, MR developers have provided robust tools to bring up virtual experiences to life.

VR and AR are the key components of realizing the vision of a 3-D immersive metaverse experience. MR relies on the interaction between physical and virtual world objects. These technologies help in truly owning a digital space allowing for innovation and creativity without any central authority [13]. As XR is at present a core part of the metaverse, the holograms are supposed to be the next big counterpart that could assist the metaverse. XR imparts natural technological progression, and it allows people to be independent of being anywhere in the world. Thanks to the recent advancement in technology, AR applications can also be run on mobile devices ensuring interaction with virtual- and real-world objects. This paves the way for MAR in the metaverse [14].

2) Internet of Everything: The IoE infrastructure is built on top of smart things, data, processes, and people. However, Internet of Things (IoT) systems are built around smart things alone. The IoE plays a key role in delivering rich metaverse applications. The following technologies contribute toward the successful incorporation of IoE infrastructure.

1) *Web3:* Web3, the next evolutionary stage of the World Wide Web, propels the advancement of the Internet into its next version [15]. It enables individuals to have ownership over specific components of the Internet, in contrast to traditional Internet where ownership is limited to the domain name alone. The applications and services of Web3 are mainly powered by distributed ledger technology. Web3 makes us a legitimate owner of our content by providing complete authority over the content and forces every organization to operate in a decentralized manner. DAOs operate without traditional CEOs or presidents. Instead, shareholders hold tokens and collectively govern the organization through voting mechanisms to

Fig. 2. Major supporting technologies the metaverse layers.

enact changes and decisions. Web3 and the metaverse complement each other [5]. Web3 provides connectivity services in a metaverse, while the metaverse provides the basis for the decentralized implementation of Web3 services.

2) *5G/6G Services:* Within the realm of metaverse and XR applications, the immediacy of interaction and the richness of the immersive experience are heavily reliant on the underlying network's capability to deliver low-latency and high-throughput communication [16]. The last mile latency normally encountered in other communication services is significantly reduced to a larger extent with the advancements in 5G/6G services. Here, 5G/6G technologies emerge as the cornerstone, with their ultrareliable low-latency communication features making them indispensable for the kind of instantaneous feedback that is required for realistic virtual environments. It also helps to boost the user experiences by providing multiaccess edge computing, and universal, as well as standard edge offloading services. With metaverse being the next generation of the Internet, most companies have already sensed the transformation and the demand for adopting 5G and 6G communication services [17]. Moreover, the adaptability and scalability of wireless networks to diverse educational settings make them particularly suited to the evolving landscape of metaverse-enabled learning. While optical fiber offers a high-speed connection, it is the wireless communication that brings the promise of an untethered and ubiquitous metaverse experience into fruition, a consideration that is of particular importance when envisioning the widespread deployment of these transformative educational technologies.

B. Layers of the Metaverse

According to Tsai [18], the metaverse is made up of seven different layers each representing a different phase of the process. The core layers of the metaverse consist of various components and supporting technologies that seamlessly integrate to deliver a captivating and immersive user experience, as depicted in Fig. 2. These layers form the foundational framework upon which the metaverse is built, enabling a diverse range of interactions and functionalities.

1) *Experience:* Beyond the workplace and home for most people, the metaverse provides the experience of "third place," with venues for immersive social life, community interaction, shopping, e-sports, and other various activities through creativity. This aspect/layer of the metaverse is one of the main causes of the buzz and the investment attracted it [19]. The experience layer of metaverse dematerializes the physical space and objects by incorporating a social immersive experience.
2) *Discovery:* Instead of focusing on what the people need in the network, this layer visualizes what people are doing at present. The metaverse provides both inbound and outbound discoveries. Some common ways of inbound discoveries include search engines, community-driven content sharing, and real-time prescience [19]. The outbound discoveries in the metaverse occur through notifications, emails, social media posts, and advertisements. Real-time presence and community-driven content sharing are more economical means of marketing and discovery.
3) *Creator economy:* There is a huge business potential in the virtual world resulting from the metaverse, and further, the content creators are expecting to witness significant growth in the economy. More companies are expected to invest in the metaverse to build a sustainable economy. In this regard, the content creators, who are already enjoying great success in different social media outlets, are going to play a major role [19]. Creators are already playing their part with the help of integrated full-suite tooling, networking, and discovery for monetization of the economy and crafting the experience of the users.
4) *Spatial computing:* The machines and devices involved in providing the metaverse experience need not be tied together to a fixed location. Furthermore, spatial computing imparts this feature, which is synonymous with XR, and it intends to make a very big leap in the economic transformation of the metaverse. It also helps to bind the community through shared services and thereby incorporates the feature of digital togetherness.
5) *Decentralization:* In the process of decentralization, decision-making authorization control transfers from a centralized entity to a distributed authorized network. It is capable of providing a scalable ecosystem for metaverse without the need to focus on the integration of the back-end capabilities of interoperable systems.
6) *Human interface:* This layer of the metaverse is concerned with the hardware devices and technology that allow humans to interact with the machines. A better human interface mechanism will allow users to experience the true potential of the metaverse. Thanks to the recent advancements in technology, several connected handheld devices, 3-D-printed wearables, and biosensors are available to bring humans closer to machines. This

TABLE I
COMPARISON OF OUR REVIEW ARTICLE WITH RELATED METAVERSE SURVEY PAPERS

Authors	Year	Application	XR	IoE	Education	No. of References	Main Topics
Falchuk et al. [26]	2018	Privacy in social metaverse	✗	✗	✗	21	Focuses on immersive social platforms with the privacy aspects incorporated, thereby provisions promising platforms with enhanced and persistent physical and virtual space interactions.
Nevelsteen et al. [27]	2018	Technologies for virtual world	✓	✗	✗	73	Focuses on the technology classification to build up a virtual world in comparison with other recent supporting technologies.
Lee et al. [28]	2021	Computational Arts	✓	✗	✗	223	Focus on artworks by blending virtual and physical objects, to facilitate immersive arts, user-centric creation, and robotic arts through the expanded horizon of the metaverse.
Shen et al. [29]	2021	User purchase promotion	✓	✗	✗	156	Exploit virtual commerce considering various influential factors of customer behavior along with the synergy of design artifacts.
Kye et al. [24]	2021	Education	✓	✗	✓	22	Exploit metaverse for educational services with immersive virtualization for establishing new means of social communication.
Lee et al. [20]	2021	Development status	✓	✗	✗	711	Targets six user-centric features of Metaverse such as Accountability, Trust, Privacy & Security, Creation of content, Avatar, and Virtual Economy cellular.
Wang et al. [4]	2021	Development status	✓	✗	✗	36	Focus on Metaverse development status from five different perspectives.
Park and Kim [8]	2022	Social value enhancement	✓	✗	✗	357	Targets on realizing the possible components of metaverse for creating a social value by considering the implementation, application, and user interactions.
Chen and Zhang [30]	2022	Healthcare	✓	✗	✗	50	Explores the strategies in health informatics with the laws in the application of health metaverse from the perspectives of socialization, intelligence, knowledge, and digitalization.
Yang et al. [161]	2022	Blockchain and AI fusion	✓	✓	✗	97	Briefly survey Blockchain, AI, and their integration with metaverse components.
Wang et al. [2]	2022	Security, and privacy	✓	✗	✗	188	Focuses on the security and privacy preservation schemes, and investigated the countermeasures for the metaverse.
Our survey	2024	Education, training and skill development	✓	✓	✓	190	Provide survey about the usage of metaverse for education, training, and skill development application with the support of XR and IoE. Further, challenges, solutions, and opportunities in the metaverse domain are provided.

allows for building more immersive applications for the metaverse.

7) *Infrastructure:* The infrastructure layer of the metaverse provides the technological infrastructure needed to build a fully functional and interoperable metaverse. The infrastructure of the metaverse is composed of different technologies, such as computational and communication resources, machine intelligence, blockchain technology, gaming, and display technologies. However, improvement in the communication speed, with reduced latency, is in demand for delivering rich content without any network contention and latency. 5G and 6G services could be supported with high speed and better utilization of the bandwidth.

C. Related Surveys

The literature reports several interesting works and surveys on the emerging concept of metaverse [20] (Table I provides a summary of the existing surveys on metaverse). The literature also reports extensive work on key enabling technologies such as XR and IoEs and their joint applications, where XR and IoEs are used for providing immersive experiences for a diversified range of applications in different domains [21], [22], [23]. There are some works [17], [24], [25] that see XR and IoE as converging subjects for the metaverse applications. Nonetheless, the metaverse is regarded as a distinct field, despite its shared applications and concerns [3]. In this survey, we focus on the convergence of XR and IoE technologies for education-focused metaverse applications. The synthesis of research directions in this article is handled in a smooth progression, starting from the fundamentals of the metaverse, followed by its technical building platforms, through to its role in provisioning immersive educational services. Accordingly, the reader will gradually become familiar with state-of-the-art and supporting techniques such as IoE and XR, while gaining an insight into the challenges and opportunities in the broad areas of educational services and skill development through metaverse frameworks.

D. Scope and Contributions of This Article

This article revolves around the applications of the metaverse and its supporting technologies in the education sector. This article emphasizes the importance of the metaverse and its impact on key applications of education, skill development, and training. We also discuss the related concepts and supporting technologies in detail by analyzing the convergence of XR and IoE for metaverse educational use cases. This article also highlights the current limitations and drawbacks of the technology in the sector. We also analyze research trends in the domain by identifying the aspects of the technology that need the attention of the research community.

The primary objective of this article is to provide the reader with a comprehensive survey of the literature on metaverse and associated technologies for education, skill development, and training. The contributions of this article are manifold. On the one side, it provides a complete tutorial on the metaverse by describing the key components and supporting technologies. On the other side, it provides a detailed overview of the existing literature on the topic by highlighting key challenges, potential opportunities, and future research directions. The key contributions of this work can be summarized as follows.

1) This article provides a detailed survey of the state-of-the-art metaverse techniques that leverage XR and IoE paradigms for education, training, and skill development.
2) This article also elaborates on the description of metaverse approaches for adaptive educational services, such as online classrooms, industrial training, aircraft, maritime,

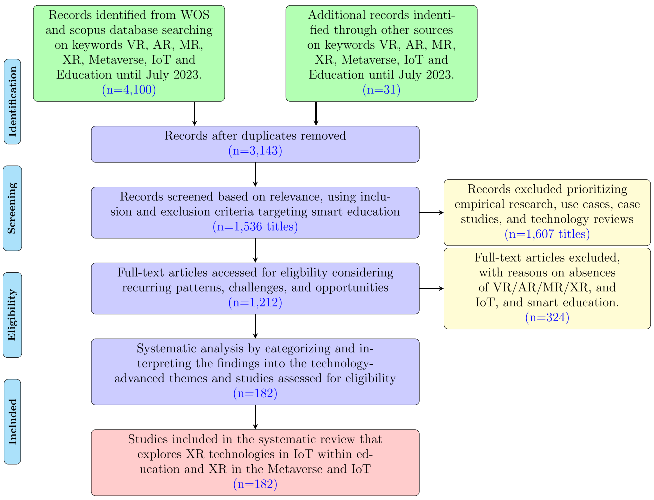

Fig. 3. Our methodology for systematic review: The PRISMA flowchart for literature search and selection.

military, and gaming, and highlights ethical issues, limitations, and potential pitfalls of the technology.
3) This article also identifies key challenges and future research directions and makes recommendations concerning the metaverse for educational services in the context of XR and IoE frameworks.

The rest of this article is organized as follows. Section II outlines our survey describing, including the strategy for including relevant articles. Section III describes the key applications of a metaverse in the education sector. Section IV provides a detailed overview of the technical approaches used for the metaverse. Section V outlines the key research challenges and future directions. Finally, Section VII concludes this article. A summary of acronyms used in this article is provided in the Nomenclature.

II. Methodology

In this section, we outline our approach to conducting a systematic literature review, including our database selection, search criteria, and inclusion parameters, providing a transparent framework for our research process. Fig. 3 depicts the four-phase flowchart of the literature search and selection process for this study.

A. Search Methods

To identify and select relevant studies, we used four databases including Google Scholar, IEEE Xplore Digital Library, Web of Science (WoS), and Scopus. The Google Scholar database was chosen due to its large volume of sources available in a single platform. The IEEE database was chosen due to its status as the world's largest professional technical organization dedicated to technological advancement for the benefit of society. Scopus, a prominent database, was selected for its extensive coverage of abstracts and citations from peer-reviewed literature across a multitude of global publishers. WoS, a comprehensive resource, was included for its wide-ranging access to references and abstracts across all knowledge domains and its array of tools for citation analysis, references, H-index, bibliometric analysis, and access to five distinct database collections. Scopus and WoS were also preferred for their similarities and prominence among other databases, specifically designed to facilitate research citation and bibliometric analysis, making them pivotal references for bibliographic research. To conduct our search, we employed the following set of keywords: "Education," "Virtual Reality," "Augmented Reality," "Extended Reality," "Metaverse," "Internet of Things," "Internet of Everything," and "Artificial Intelligence." In shaping the criteria for source selection in this review, we considered several factors. We employed the Boolean logical operator "AND" to merge the search terms "Education" and "Metaverse," facilitating a focused exploration of articles that encompass both concepts. Furthermore, we utilized the Boolean logical operator "OR" to establish a connection between "Internet of Everything" and "Internet of Things," thereby ensuring that articles addressing these interconnected themes were included in our search across the databases. In addition, we incorporated "Extended Reality" into our search criteria to encompass a broader scope of relevant articles.

B. Inclusion and Exclusion Criteria

We exclusively considered primary articles in the English language, with further refinement based on specific domains, including Computer Science, Engineering, Medicine, Business, Management, and Health Professions. Notably, we did not impose any restrictions on publication dates, as research related to education and the metaverse has predominantly emerged in recent years, with relevant publications originating within the last three years. In this systematic review, the evaluation focused on primary studies addressing specific research inquiries, while excluding secondary studies and other document types, such as books, book chapters, editorials, patent documents, letters, and conference papers, to ensure a comprehensive examination of primary studies relevant to our research question.

C. Data Extraction and Structured Meta-Analysis

In the initial screening phase, all titles and abstracts were scrutinized to identify articles potentially pertinent to the education in metaverse. Subsequently, we conducted the initial identification of relevant studies, and full-text screening was then independently performed, with any disparities resolved through peer discussion among all the authors. The data management process was facilitated using Google Sheets, which enabled the recording of reasons for inclusion or exclusion and the storage of extracted data. We used key questions to evaluate the selected studies, including assessing whether they represented primary research, addressed the application of metaverse, XR, and IoT technology in the education domain, and adhered to the specified inclusion and exclusion criteria. Primary insights into the methodological approaches described in the selected studies, with articles lacking a clear definition of their study type or posing ambiguities in their methodology, were excluded. The data extraction strategy primarily entailed tabulation to ensure alignment with the research question and study objectives. All

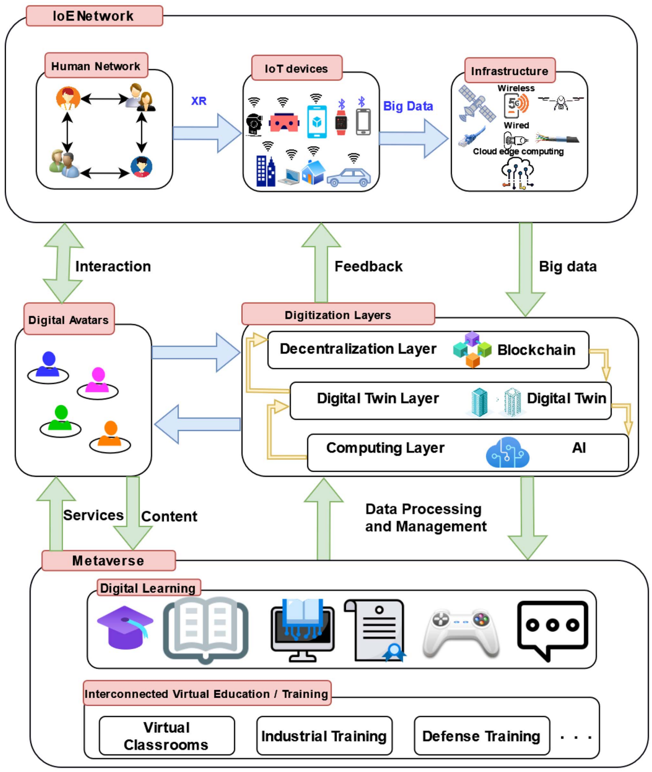

Fig. 4. Digital interconnection between the physical and virtual worlds through the IoE and digitization layers for immersive education and training.

data, along with the final evaluations, were documented in a Google Sheet. The methodological data from the 182 selected articles were meticulously evaluated, analyzed, and subsequently presented in this systematic review.

III. Metaverse Applications in Education

In this section, we discuss some key aspects of education, training, and skill development that can benefit from the metaverse. The major benefits of metaverse over conventional online educational platforms can be handcrafted by establishing digital interconnections between the physical and virtual worlds. The illustration of the relationship between the metaverse, digitization processes, and IoE networks with XR support is represented at a high level in Fig. 4. The figure highlights the role of IoE, XR, and other supporting technologies in overcoming the existing challenges of education and training by imparting digital interconnection among the physical and virtual worlds through the metaverse.

A. Metaverse Classroom

XR technology brings educational services closer to students and learners in remote places. This minimizes the need to travel and emphasizes interactive and collaborative means of remote education. Zikky et al. [31] demonstrated the efficacy of solar system learning through interactive VR services and the provision of an immersive learning environment with virtual meeting spaces along with the digital avatars of the teachers and learners.

Some recent works exploit the potential of metaverse-based platforms for exploring educational, training, and learning activities through information technology services, such as cloud service, AI, and Big Data. This can help in shifting the focus of educational institutions toward metaverse-based education [32]. In such a platform, students can gain an immersive learning experience and feel their physical presence in the collaborative classroom environment regardless of their physical location. Despite the technical and moral impediments, the metaverse imparts more interactions and cooperation among students resulting in a healthy learning experience.

In the literature, the natural visual cognition capabilities of humans have been well exploited through the immersive metaverse platforms for making education to be more interactive and immersive across multiple ranges of cultural backgrounds [33]. The metaverse has been used as a digital education tool by including various ICT tools and technology for promoting education and learning through collaborative platforms [27]. In [27], its impact was validated through the observed enthusiasm and cooperation of students beyond the classroom environment.

The metaverse can also help teachers in several ways. For instance, with the potential of metaverse implementation through AR for educators, MacCallum and Parsons [11] explored the potential of AR tools in further enhancing the preservice and in-service experience of teachers. Recently, in another similar work [34], for enhancing the teaching skills of preservice teachers, a metaverse environment is used with the support of the Virbela platform. The experimentation involved analyzing microteaching for a group of preservice teachers in virtual teaching through their digital avatars. The authors analyzed the teachers' competence in handling the queries and suggestions. Such practices help teachers in developing their teaching skills by closely involving them in their profession in a more realistic and immersive way while imparting training and skill-enhancement activities for the students. Furthermore, the audio metaverse through virtual mainstreaming enables the provision of interoperable experiences by rendering spatial sound along with the XR-enabled video streaming services [35].

The metaverse enhances student engagement through immersive learning and fosters teamwork and cultural skills via remote collaboration [1], [24], [36]. The platform strengthens skill acquisition through problem-solving simulations, fostering critical thinking and creativity as students engage with and adapt 3-D elements, consequently improving technological literacy. AI-driven avatars in the metaverse provide personalized learning experiences, while role-playing scenarios enhance emotional intelligence [37]. Moreover, it allows for the detailed exploration of historical and architectural sites, as Gaafar [38] has shown, by providing interactive 3-D models that integrate theoretical and practical learning.

B. Industrial Training

Sustainable evolution of industrial infrastructure in terms of design and training of the employees is an important aspect of modern industries, especially after the fourth industrial revolution [39]. Thanks to the metaverse and associated technologies, the training of employees has also been enhanced in industries allowing the workers a hands-on experience on different tasks in a risk-free environment. Moreover, AR-based training within industries helps to analyze customer demands, classify the requirements in industries, and use sustainable value proposition design strategies [40].

In the industrial assembly system powered by metaverse, we can visualize the entire factory through simulations. Global teams can collaborate to operate in synchronization using different software packages, such as CATIA, Revit, or point clouds to design and plan the factory in real time [41]. For instance, the 3-D-enabled capability to operate in a perfect simulation has revolutionized the planning process of BMW car manufacturing plants. They regularly reconfigure their factories and train their employees to accommodate new vehicle launches. Planning experts located in different parts of the world could be trained and involved in testing new designs through a metaverse.

The metaverse in industries with IoE-enabled machines and digital humans allows sharing workspace with many robots that make jobs much easier. As robots are crucial for the modern production system, they are involved in logistics for improving the material flow in the production process. This agility is highly mandatory as the volume of tasks done in each modern industry is huge and most customers demand custom-made designs for their products. The metaverse frameworks could also operate on the synthetic data, apart from the data acquired through IoE devices. From the millions of synthetic images generated across diversified categories of environments, they assist in teaching the robots [20]. Domain randomization could generate an infinite permutation of photorealistic objects, textures, orientation, and lighting conditions [42]. It is an ideal platform for generating ground truth images and objects, whether it is meant for detection, segmentation, or depth perception for the metaverse platform.

C. Aircraft and Maritime Training

The potential of AR technology in the aviation, automotive, and astronautics industries has been well utilized for a long period for several tasks including environment monitoring, control, and learning purposes [43]. Regenbrecht et al. [44] proposed and tested an aerospace training platform by developing augmented scenes through AR in association with state-of-the-art machine vision and computer graphics. Similarly, XR and other metaverse technologies have also been used for training workers to carry out maintenance and inspection processes in the aviation industries. The literature reports the proven effectiveness of the technology in the task. For instance, Eschen et al. [45] demonstrated that the deployment of XR technology for training is less error prone and takes on less effort, as well as less time consuming. Another study reports the effectiveness of AR in operations to support, train, and maintain aircraft [46]. The study of the technology results in a significant reduction in errors during the training and subsequently reduces procedure violations. These studies hinder the motivation toward modern-day metaverse to further enhance the performance of the learning platform with the significant reduction in training time and provisions of cost-effective strategies.

The literature already reports some efforts in this direction. For instance, Siyaev and Jo [47] developed a simulator for training employees to carry out efficient maintenance of Boeing-737 aircraft through metaverses along with the 3-D models of the aircraft. The simulator is evaluated in terms of the amount of technical guidance and directions provided to field experts. This metaverse-based aircraft maintenance system provides a more economical and scalable solution for aviation educational institutions. In another similar work by Siyaev and Jo [48], a convolutional neural network architecture is used for enabling the learning and classification of audio features for identification of the commands for controlling the virtual digital twin of the Boeing 737 aircraft. Furthermore, this work has reported higher prediction accuracy with improved training capabilities through immersive interaction and effective control of virtual objects in the 3-D twin model of the aircraft. More recently, Kim [49] has employed metaverse technology to train employees to cope with the cybersecurity risks involved in maritime industries. It includes the development of educational content for addressing cybersecurity issues through virtual ships, maritime accident reproduction, maritime operations, and related online learning content.

D. Military Training

In the defense sector, training of the troops plays an imperative part, as it is not always feasible to place the military personnel in active war locations for training. Through the DIS protocol, the DARPA used different military simulations with the support of advanced high-level architectures for providing rich collaborative training and preparation of war strategies. XR technology could be used to replicate such an environment for training the soldiers more realistically. It can help to train the soldiers in a similar location created in a virtual environment allowing them to be prepared for dynamic adaptation. It also results in a significant reduction of expenses involved in traveling and shifting goods for troops' exercises. Moreover, the use of virtual objects helps to train the soldiers with special armed equipment without putting them at risk. However, even though a complete replacement of military training through XR could be established with state-of-the-art techniques, the integration of IoE and metaverse technology could further enhance it. Although AR cannot completely supplant conventional military preparation, there are now frameworks that kill the need to go to far-off areas and assist troopers with preparing without placing them at risk.

The diversity provided by technology compared to real-world military training shifted the focus from traditional training methods to military simulations [50] by providing immersive training through the virtual environment. To this aim, several interesting solutions have been proposed. For instance, DEIMOS Military VR Trainers [51], which is a metaverse-based military training, assists in creating scenarios with a diversified range of environmental conditions, particularly meant for professional military training on shooting, tactical behavior, and observation.

TABLE II
METAVERSE-ENABLED EDUCATION, TRAINING, AND SKILL DEVELOPMENT CHALLENGES AND COUNTERMEASURES

Application	Challenges	Goal	Countermeasures
Health-care education	Handling multimodal medical data and streamlining.	Innovative drive in medical education.	New directions to the healthcare education sector could be driven through the integration of metaverse with AI, VR, AR, IoMT, Web3, intelligent edge, cloud services, robotics, and quantum computing.
Online education	Collaborative efforts and interactions.	Immersive experience for teachers and students.	Appropriate choice of XR and IoE equipment with dedicated seamless connectivity targeted for meeting the demands of the teachers and learners.
Industrial training	Training robots and skill enhancement for laborers	Monitor and control complex manufacturing units.	Binding the hardware and software components of a metaverse in the manufacturing, supply chain, design, development, and virtual warehousing to drive the market revenue and forecast the impact of technology over the next few years and make decisions accordingly.
Aircraft maintenance training	Maintenance, status monitoring, and control	Intuitive and efficient control of functional modules in aircraft.	3D twin models of aircraft help to read the aircraft log books and records, which include the entries of the condition of the internal equipment, status, and intimates the requirements for the learners and users in the remote place.
Marine maintenance training	Handling of cybersecurity issues	Robust defense mechanisms against threats.	Integration of metaverse with blockchain-based technological trends helps to reduce errors in maintenance tasks with secured means of handling the challenges with increased safety through alerts and notifications.
Military training	Replicating the war scenes and dynamic adaptation.	Trained to face adverse conditions.	Improved productivity with clear instructions through metaverse-driven equipment for dynamic handling of war situations.
Arts upskilling	Managing 3-D virtual objects.	Imagination and creativity to reality.	Enhanced quality and accuracy with object recognition for immersive learning with applied creativity beyond the imagination.
Gaming expertise	Integration of AI for provisioning immersive experiences.	Collaborative learning	With unified and interoperable spaces rendered through the graphics, interaction with the people and objects in the virtual worlds makes the gaming platform to make use of metaverse as a diversified range of education, training, and skill development applications.

E. Privacy and Privacy Policies in Metaverse

In the realm of metaverse-driven educational services, learners and teachers assume virtual identities represented by digital avatars, which raises significant risks regarding privacy [52] and social harm [53]. Organizations involved in educational and training services must strictly adhere to best practices that mitigate potential privacy risks. The adoption of digital identities and immersion within the metaverse give rise to data privacy issues related to educational content and potential violations of trainer identities. For instance, biometric data or facial gestures captured by AR/VR technologies can be misused if not adequately safeguarded. Therefore, ensuring user privacy protection within the metaverse necessitates implementing privacy safeguards such as data transparency, enhanced or newly formulated laws and regulations, improved control mechanisms, and enhanced technical design [54].

As the advent of Web3 ushers in a new era of innovation in conjunction with the metaverse, organizations swiftly leverage its capabilities, including social connectivity and automation, to advance educational services [55]. The next stage of evolution in online education within the metaverse will revolve around immersive cyberspaces, offering real-time virtual experiences of social interactions between teachers and learners through interoperable platforms. Despite its potential, the metaverse poses significant privacy challenges for various stakeholders, including AR/VR hardware and software providers, platform developers, regulatory bodies, crypto service providers, teachers, and learners themselves [56]. These challenges arise from the potential misuse of intimate personal data accessible to metaverse platforms, which can enable pervasive surveillance and behavioral modification to support commercial interests [57]. Thus, safeguarding privacy becomes an urgent collective responsibility for all parties involved.

To ensure comprehensive privacy protection, it is crucial to establish and enforce regulations and laws that govern the collection and streaming of educational data from various sources, ensuring its preservation and appropriate usage. International privacy laws, such as the General Data Protection Regulation, along with other relevant international laws, especially those focused on protecting children's privacy, should be considered. For instance, the U.S. Federal Law Children's Online Privacy Protection Act (COPPA) imposes restrictions on the collection and processing of personal information from children under the age of 13, and metaverse platforms targeting or collecting data from children must comply with COPPA's requirements. These legal frameworks provide important guidelines and requirements for privacy practices within the metaverse, thereby protecting user data and privacy rights.

F. Discussion and Summary of Lessons Learned

We summarize the content of provisioning metaverse-driven educational services for various user scenarios with the key characteristics and probable solutions. In Table II, we summarize key objectives/goals, challenges, and countermeasures for handling challenges associated with metaverse-based training in different application domains. From the table, it is obvious that for achieving the goal of an immersive learning platform through metaverse, the mentioned key challenges need to be addressed with appropriate countermeasures. After discussing the relevant research on metaverse for education platforms, we draw insights on providing favorable countermeasures to address those challenges.

1) *Multimodal medical data streamlining in health-care education* could be handled effectively through intelligent cloud services and quantum computing.
2) *Immersive collaboration and interactions in online education* could be ensured with appropriate choice of XR applications and IoE devices.
3) *Industrial workers' skill enhancement* in handling challenging sections could utilize metaverse-driven collaborative robots for achieving effective design, development, and supply chain management.
4) *Effective exploration of aircraft's control and functional modules* can be assisted using aircraft's 3-D digital twin.
5) *Adverse condition anticipation in war scenes for military personnel* could be dealt with the quality instructions and dynamic situation handling through the metaverse.

6) *Upskilling of creativity in arts and skill enhancements in gaming* could be driven through metaverse with accurate object recognition and handling.

IV. Technology Enablers for Metaverse in Education

A. XR Technologies for Metaverse

The impact of XR on the metaverse has made a significant contribution toward education and skill development for the workforce. The process of selecting appropriate hardware and software stacks for developing and deploying a wide range of metaverse applications is closely associated with XR technology at its core. Besides the significant role played by the IoE, XR is responsible for defining the immersive experience for users in metaverse [137]. For example, in the context of virtual meetings, the interaction with the remote users in training and educational applications in an immersive metaverse is possible only if the end devices are deployed with the provision of XR services. Furthermore, with the support of other enabling technologies, such as cloud services, it reduces the high networking costs and enables persistent training experiences for the users [138]. Despite expensive VR headsets, XR apps and services act as the main driving force for the present state metaverse.

The virtual, remote, and immersive experiences via XR provided by the metaverse could largely enhance the e-commerce experiences and cost reduction in travel, and information sharing [20]. To impart adaptive and sustainable education, the transformations through XR could provide the teachers and learners with opportunities for critical thinking, better communication, collaboration, and a higher level of creativity [139]. Such multidimensional aspects of learning provide pedagogical benefits and enhanced learning experiences. Table III summarizes the works on educational, training, and upskilling driven by XR services targeted for metaverse applications.

B. IoE Technologies for Metaverse

The impact of metaverse on IoE technology will ensure enhanced remote real-world training by providing smarter and better planning for real-world items through the virtual world. As digital twins represent the software model of physical systems/assets, the role of IoE and metaverse in this arena has become imperative from the research and application perspective [140]. With the advancements of IoE technology and the data streams acquired through the smart devices, they serve as a basic block for the metaverse thereby providing immersive interconnectivity between the real and virtual worlds.

By enabling IoE along with XR technology, the metaverse also aspires to establish a new perspective of collaboration between workers, trainers, and learners to operate with much higher potential. In such situations, the IoT devices and other gadgets that can assist in processing data allow AI-powered educational content processing for the metaverse at the edge. This could be incorporated in the mobile towers, in the data acquisition points, or at the IoT devices [141]. Furthermore, the constellation of local IoT devices and educational data acquisition sources must be incorporated in coordination for application in the metaverse. Table IV summarizes the IoE-driven works on educational, training, and upskilling that could be tailored for metaverse applications.

C. Big Data and Predictive Analytics for Metaverse

In the modern world, social networks, industries, the healthcare sector, and people with smart gadgets are generating large volumes of data about different aspects of life, including the preferences and choices of individuals. At present, there is more demand for virtual online spaces for interaction among people from a multidimensional perspective. This allows people to immerse themselves in digital content rather than simply viewing it. All these potential applications generate large volumes of data. The data require real-time data analytics for predicting future outcomes in metaverse-driven businesses involved in sales, marketing, advertising, and other training applications [142]. With the bloom of spatial computing technology that specifically relies on the processing of data from XR gadgets, there are rising concerns about handling large volumes of digital data generated from them [143]. Furthermore, the co-equal collaboration among the educators and learners established through spatial computing could provide potential insights into the educational content, which is one of the ambitious goals of metaverse-driven educational frameworks.

Kim et al. [144] analyzed the big data generated by the digital avatars on the Zepeto platform, which enabled them to communicate with a huge community. The case study was conducted to integrate real and virtual worlds through the metaverse for analyzing news articles. This could also be extended to analyze the quality of educational content shared through metaverse, which can assist in solving associated social and legal issues. The next generation of VR headsets will also collect more user data including facial recognition and even stress level detection of the users. As the technology matures, it could also collect biometric data from individuals and impart enhanced training experiences for the users. The potential of predictive analytics in the metaverse can help in extracting significant meaningful insights from the collected data. Metaverse can also assist in transforming the data with a more user-friendly and interactive means of portraying the information [145]. With the clear benefits of predictive analytics on XR and IoE data, it is imperative to use it in the metaverse for several potential educational applications.

Hwang and Chien [146] explored the applications of metaverse in education, addressing research challenges, and highlighted the intersection of AI and metaverse-based education. Here, the metaverse's potential for educational purposes fosters the anticipation for future studies in metaverse-based education. The work in [147] reveals the conceptual discussions on the challenges and opportunities of metaverse education, alongside practical experiments demonstrating higher learning outcomes and enhanced spatial and social presence in virtual environments. It also elaborates on the challenges involved in creating

TABLE III
SUMMARY OF RESEARCH UTILIZING XR FOR METAVERSE-DRIVEN EDUCATION AND TRAINING APPLICATIONS

References	Applications	XR Solutions	Major Contributions
Andrews et al. [58]	Medical practice	Touch-free interface and 3D visualization	Discuss the catheter tracking, visualize scars and patient anatomy.
Doolani et al. [59]	Manufacturing training	Workforce training	Introduces XR in training the workforce on maintenance and assembling tasks.
Palmas and Klinker [60]	Industrial training	Innovative corporate training	Provides a set of characterizations and competencies to handle XR-enabled training
Zweifach et al.and Triola [61]	Medical Education	Realistic simulation	Envision the concept of adopting XR tools in medical education.
Gandolfi et al. [62]	Teacher training	360 video research	Present the compatibility of XR by enabled training for teachers.
Stanney et al. [63]	Casualty care training	Multi-faceted paradigm	Introduce a competency-based training platform through AI models.
Alizadehsalehi et al. [64]	Construction industry	Simulate construction project	Implement a BIM-based XR process/workflow.
Ilić et al. [65]	Higher education	Realistic learning-by-doing	Enhances collaborative learning skills through XR, AI and ML.
Kaplan et al. [66]	Training enhancement	meta-analysis	Enhances collaborative skills among students.
Kim et al. [67]	Nursing skill training	Smart glasses	Assists in self-practice and learning at own pace.
Xi et al. [68]	Workload	Subjective workload measurement	Cost and resources reduction in operating through metaverse are assessed.
Heirman et al. [69]	Firefighting training	MR simulator	Adapting of the fire hose controller based on the scenario is trained.
Mcguirt et al. [70]	Nutrition education	Descriptive observations	Dietary behaviors among the community are assessed.
Ong et al. [71]	Ophthalmology	Ophthalmoscopy simulators	Improves procedural success and reduces complication rates in ophthalmic surgery.
Logeswaran et al. [72]	Health-care education	Pedagogical models	Improved learning outcomes were identified through learner-centered models.
Kosko et al. [73]	Teacher education	Representations of practice	Perceptual capacity assessment for theory and practice was performed.
Noury et al. [74]	Sports training	Ecological dynamics	Motor and perceptual-cognitive skills improvements were identified.
Zwoliński et al. [75]	Management Education	Projector, mobile, HMD AR/VR	Business environment enhancement skills were imparted through different approaches.
Koh et al. [71]	Ophthalmology	Ophthalmic surgical simulators	Presented proof of concept based on ocular imaging data.
Mystakidis [76]	Community building	Gamify distance education	Formulates the recommendations for building practitioners.
Fast-Berglund et al. [77]	Manufacturing	Remote guidance	Learning, operational and disruptive phases were explored in 6 case studies.
Al-Adhami et al. [78]	Construction quality	BIM-based XR	Quality control inspection has experimented on construction site.
Parsons et al. [79]	Neurosciences	High-dimensional simulations	Enhanced ecological validity is ensured in the clinical, and social interactions.
Koo et al. [80]	Lung cancer surgery training	Smart operating room	Reflecting on the haptic inputs of the surgeon's tactile sensations provides training.
Zagury-Orly et al. [81]	Otolaryngology training	Evaluation framework.	Educational outcomes and skills transfer in bone surgery were analyzed.
Jeršov and Tepljakov [82]	Control system	Digital twins	Real-time HIL simulation for control applications.
Liang et al. [83]	Stroke assessment	Training mannequin in simulation	Traceable symptom of stroke were easily identified in the clinical training.
Alnagrat et al. [84]	Virtual laboratories	Virtual environment of things	Established a virtual training platform to increase the efficiency of the students.
Yang et al. [85]	Education framework	XR-Ed framework	Increases efficiency of student education through the design spaces provisioned considering six dimensions.
Andrade and Bastos [86]	IoT scenarios	3-D visualization	Developed a data communication model for translation of IoT data into XR scenarios, events or objects.
El-Jarn and Southern [87]	Design process	Cocreation and Codesign	Establishes a unique platform to improve, co-create, and co-design the visuals in the design process.
Shankhwar and Smith [88]	Arc welding training	3-D interactive interface	Guides with visual aids on correct welding position and procedures.
López-Ojeda and Hurley [89]	Medical Education	Holographics	Holographic rendering and depiction of anatomical structures extend better clinical care.
Guo et al. [90]	Educational development	Bibliometric analysis	Provides suggestions for sustainable development in the education sector.
Minchev [91]	Digital Society	Society 5.0	Enables foreseeing the future digital society on new cognitive skills and behavior.
Goh et al. [92]	Surgical training	Immersive XR	Assists in visualizing the anatomy of patients in real-time for the surgeons involved in knee arthroplasty
Cross et al. [93]	Flight simulator	Gaming consoles	Simulator provides empirical evidence on the challenges faced due to hardware constraints by the trainers.
Gandolfi et al. [94]	Presence scale	Multimodal presence	Improvement in the efficiency of the educators and instructors were observed along with their cognitive skills.
Hoover and Winer [95]	Expertise instructors	Head-mounted displays	Suggestion on design recommendations for XR training developers based on expert instructor behaviors.
Pomerantz [96]	Teaching and learning	Exploratory evaluation	Articulates the learning experience through several learning goals and effectively meeting them.
Çöltekin et al. [97]	Spatial sciences	Human factor	Identifies the role of XR in spatial science and its associated research platforms that hinder the scientific interest.
Xing et al. [98]	Educational trend analysis	Interactive connections	Indicates the futuristic view on the education and industrial development trends through XR.
Southworth et al. [99]	Cardiology	3D visualization	Provides guidance for cardiologists in terms of cardiac rehabilitation, planning, and other procedures.

metaverse learning environments, demands of new resources and qualifications, as well as ensuring access to necessary end devices.

D. Machine Intelligence

On the road map to unleash the true potential of AI in the metaverse, machine intelligence evolves from machine learning (ML) by prioritizing the goals through deductive logic, where the learning algorithms fine-tune messaging, marketing, and online interactions. Machine intelligence in conjunction with the XR and IoE contributes to making a significant impact on the creativity in educational services through the metaverse. Teaching through gestures interpreted through eye glances of the teacher, their emotion, and communicating cues could serve as a part of sophisticated enablers in the educational sector via metaverse. In fact, machine intelligence supports the metaverse by serving as a design advisor. Being a critical part of the service architecture, it can be integrated with low code and no code platforms [148]. Moreover, as the virtual world gets denser with virtual avatars, AI-based design for the fabrication of metaverse chips could also assist programmers in generating code [142]. However, unleashing the full potential and impact of machine intelligence on this virtual landscape in the education sector demands creative progress from the developers for supporting and enhancing the features of virtual education and training platforms.

The literature reports several studies emphasizing the potential of machine intelligence in the metaverse for educational and training services. For instance, the authors in [148], [149], [150], and [151] emphasize the promotion of integrated machine intelligence and human experience for provisioning an elegant

TABLE IV
SUMMARY OF RESEARCH UTILIZING IOE FOR METAVERSE-DRIVEN EDUCATION AND TRAINING APPLICATIONS

References	Applications	IoE Solutions	Major Contributions
Bandara and Ioras [100]	Student performance enhancement	Global higher education	Catering to the demands of students, filters out essential educational contents with enhanced performance.
Fiaidhi and Mohammed [101]	Automation	M2M	Democratization of automation skills are perceived through haptics, robotics, and IoE in real-time.
Bachir and Abenia [102]	University 4.0	CPS	Proposed educational ecosystem through CPS as a key component in teaching and learning process.
Gul et al. [103]	Education	Smart campus	Demonstrated the applications and usefulness of IoT in the education sector.
Chou and Lai [104]	Educational institutions	Sensor devices	Focus on attendance tracking in educational institutions and ensures campus safety.
Abd-Ali et al. [105]	Development of education	Digital campus	Development of education envisioned through smart class and smart laboratories
Al-Emran et al. [106]	Social education	Wearable technologies	Summarized the prospects of IoT in a diversified range of educational services.
Ding et al. [107]	Physical education	Cloud platform	Designed XR system for physical education that assists in promotion effect and emphasizes a scientific reference.
Ramlowat and Pattanayak [108]	Design education	M2M	Improvement in the efficiency of teaching and learning were assessed.
Burd et al. [109]	Computer science education	Data analytics	Summarizes four major strategies for computer science educators by integrating IoT into their curricula.
Cornetta et al. [110]	STEM education	Fabrication-as-a-service	Provisions an innovative web-based master-slave approach to monitor and control the Fab lab in schools.
Pervez et al. [111]	Higher education	Smart lesson plans	With specialized strategies suggests optimal teaching model with improvements.
Shaikh et al. [112]	Higher education	User behavior	Demonstrated a conceptual framework for education with an in-depth network analysis approach.
Al-Malah et al. [113]	Intelligent schools	Smart classroom	Scientific research and educational services developments were assessed.
Jean-Charles [114]	AI classroom	Voice assistance	Serves teaching assistants in the classroom through intelligent personal assistants.
Mawgoud et al. [115]	Higher education	Social IoT	Deals with the threats from essential domains in higher education with security solutions.
Turcu and Turcu [116]	Industrial Education	Industry 4.0	Transformation of industries and involved business practices were analyzed in the industrial setting.
Leisenberg and Stepponat [117]	Remote labs	Data analysis	Feasible solutions for improving the teaching strategies were analyzed along with the usage of cloud platforms.
Hickman and Akdere [118]	Education and learning	Low-cost VR	The data triangulation process provide valuable suggestions on the learning outcomes and the role of emotions.
Xiao and Liu [119]	Mental health education	MQTT protocol	For the chosen mental health education architecture, a combination of differential privacy policies was used for security.
Somantri et al. [120]	Industrial training	Low-cost IoT	Affordable trainer kits were developed for industrial training practices for automation.
Fragou and Mavroudi [121]	Computer science education	Ubiquitous computing	Effective learning strategies were emphasized through digital tools, affordances, and other learning approaches.
Jiang [122]	Sports rehabilitation	Wearable sensors	Developed system is capable of analyzing the ECG and EMG signals of sports personals with real-time monitoring.
Mershad and Wakim [123]	Learning management system	Integrated learning	Presented an IoT-enhanced learning management system that integrates arts, technology, and science.
Qi [124]	University education	Network education	RFID tags were used to network the teachers and students in the college education.
Khan [125]	Higher education	Industry 4.0	Ensures to guarantee uniform vibrant learning skills.
Kravčík et al. [126]	Learning and training	Big educational data	With the novel educational tools and services, effective training and knowledge acquisition was instilled.
Li [127]	Visual education system	Intelligent campus	More convenient means of visual educational functionalists were highlighted with intelligent equipment that promotes classroom interaction.
Moreira et al. [128]	Science learning	Hypersituation environments	Programmatic contents in physical and natural sciences were made ease considering the student's reality.
Zhang and Liu [129]	Entrepreneurship education	Edge computing and AI	Improved understanding of entrepreneurship and innovation education system were analyzed.
Xu [130]	Mass education	Probability model network	Bayesian network is used to integrate university citizenship with the curriculum teaching.
Gurgu et al. [131]	Business education	Blockchain and AI	Spread awareness on the technological changes to the educational institutions from the perspective of enhancing global economy.
Cui and Zhou [132]	Table tennis training	AI	The knowledge information system assists in promoting the performance of table tennis enthusiasts by assessing their skills and confidence.
Li and He [133]	Music education	Smart classroom	Assists in the enhancement of cultural literacy by building an efficient music wisdom classroom.
Gkamas et al. [134]	Learning Outcomes	Data Science	Focuses on the upskilling of the competencies of the IT workforce through a macro-level design driven by desktop research and a survey.
Bright [135]	Educate disabled students	Wireless assistive technology	Improves accessibility to technology-mediated education for the disabled students.
Li et al. [136]	Basketball training	Big data	Training plans are devised through gesture recognition from videos and information fusing, effectively recognizing player actions.

framework that could drive the metaverse with a rich experience for the learners involved.

E. Blockchain Adoption

Blockchain adoption grows exponentially across various industries [152]. It is a distributed ledger technology that enables decentralized and autonomous management of assets and applications. Despite the popularity and benefits of the metaverse, securing the data and digital information of its users is a common concern for learners and educators. Blockchain could provide a promising solution in this arena, due to its unique characteristics of decentralization, immutability, and transparency. Its support in metaverse applications is enabled through the programmability of blockchain, which could drive the educational content by putting together smart contracts among decentralized locations [153].

The literature reports several interesting solutions for the integration of blockchain in metaverse applications. For instance, Huynh-The et al. [154] provided a detailed overview of the approaches to the seamless integration of blockchain in the metaverse by considering the data acquisition, storage, privacy preservation, and interoperability aspects. Furthermore, the impact of the metaverse on its supporting technologies, such as IoE, digital twins, AI, and Big Data, was explored in association with the role of blockchain in securing the platform [155]. This stands as a crucial drive toward the implementation of secure educational content for the metaverse-based educational frameworks.

Trust and authority enhancement through blockchain adoption for the metaverse enables more IoT devices to participate and assist in developing educational content from active gaming to embedding financial services with the contents [156]. However, as the social scalability of metaverse-enabled educational services may take a longer period, trustless education contents, components, and contracts may be rooted up. We could gain benefits from earlier adoption of blockchain to establish on-chain educational data feeds along with the bloom of virtual commodities [157]. Furthermore, avatar customization and new-generation educational feeds could be made more immersive and trustworthy in the metaverse through the widespread adoption of blockchain and by associating them with cloud computing components.

F. Accelerating Distributed Networks

The computing networks are said to be distributed when the programming and the data are spread out across more than one computing resource. Accelerating the performance of distributed networks in terms of their networking speed, latency, and concurrency could be driven through 5G and 6G services [41]. This acceleration will sustain the metaverse and also help to provide more fascinating applications in the education sector by enabling users to share real-time educational content. As data-intensive networks are key resources in metaverse applications, their association with distributed networks needs to be tightly coupled and accelerated [158]. Furthermore, the metaverse frameworks need to be end-to-end optimized, and the computation and communication should be promising for imparting a rich educational experience. As the metaverse educational platforms are integrated with the IoE, they could gain maximum benefit through edge computing. However, for low-performance IoE devices, it remains a huge challenge. ScissionLite [159], a holistic framework, was developed by the authors to assist in accelerating the distributed deep neural network (DNN) through the insertion of a traffic-aware layer, thereby increasing the network traffic. This framework greatly enhanced the interference latency multifold in comparison with the conventional slicing approaches used in the learning models. Furthermore, the interference latency could be considerably reduced through the implications of acceleration DNNs.

Toward the realization of the edge-enabled metaverse, Xu et al. [160] surveyed the networking and communication aspects in the implementation of edge solutions. With distributed edge computing solutions, the resource constraint challenges existing in such platforms could be effectively addressed [161]. Furthermore, acceleration in computing enables rendering an immersive experience for the learners delving into the metaverse platforms. Moreover, it also authorizes the sharing of virtual user-generated educational content with low-cost data transfer frameworks.

V. Challenges and Issues Related to Metaverse

Despite the significant efforts to address various aspects of the metaverse in the field of education, its essential requirements and perspectives need the attention of the research community. This section provides a road map of challenges that could impact the implementation and deployment of metaverse for educational services. We also discuss the adaptable environments and consider the use of emergent paradigms from social and technological trends that could shape the future trends of the metaverse for educational services.

A. Virtual Mainstreaming

XR and particularly IoE frameworks have to deal with the genuine aspects of the virtual world to be just like the real one, as well as the trust aspects to the functioning of relationships and organizations. Establishing standards for such technology is the foundation for how we establish and assess our connections and continue to function in harmony with the legal systems. Each of these technologies is scalable because of trust. The scalability of the metaverse in conjunction with the IoE and XR technology will improve trust in the virtual domain as the trend grows with virtual objects, crypto assets, smart contracts, virtual friends, and live online educational experiences. Since users believe that the possessions of virtual connections and data exchanges are genuine, online bullying, abuse, cheating, and cheating in relationships will all become more damaging. These issues need to be solved through proper education, training, virtual literacy, and supportive communities. However, as people respect the virtual world more, there are usually groups of people that exploit the trend for selfish benefits. Researchers aim at providing infrastructure through the virtual streaming of resources and thereby ensuring to address the trust issues in each of the core domains to combat cybercrimes, such as phishing, online frauds, virus distribution, and ransomware attacks [162].

B. Challenges by Open Platforms

Open platform systems have become a common social phenomenon mainly due to the large range of collaborators involved in developing software modules [163]. The graphical and immersive experiences gained through the metaverse with the support of XR and IoE can be distributed outside of app stores with open platforms. Data-oriented technology stack platforms leveraging these features help to deliver efficient metaverse experiences, particularly for the educational sector. However, the exponential growth in the usage of open-source apps in permissionless social networks, operating systems, and PCs often imparts challenges for developers. Furthermore, new technology and open standards are emerging that have the potential to democratize the future of metaverse [164]. The technology with decentralized digital identities, such as the avatars of individuals, and zero-knowledge proofs must help to claim control over their valuable data. More breakthrough opportunities persist in the development of free applications with XR and IoE framework support through open platforms for the massive increase in the impact of the metaverse on educational services.

C. Walled Garden Ecosystems

The walled garden is the most prominent strategy used by the technological giants, such as Google, Facebook, and Amazon, for restricting user navigation within their network premises by providing access and provisioning only required operational services [165]. Technological trends that impact the metaverse favor the usage of a well-organized and attractive walled garden ecosystem. The challenges that exist in the open systems could be addressed through the walled garden, which allows the creators to collaborate, modify, and link with their designs [166].

However, technologies for portable avatars, portable social networks, and interoperability are on the horizon, and this could help connect diverse walled gardens using open platforms while also allowing for discovery and curation options. Furthermore, there are very few walled gardens, and it is required to be configured by creators and could assist in inviting other creators and joining with them to manipulate the shared components, link with them, and collaborate in the metaverse-based educational services. As educational services have access to a vast range of audiences, the equivalent virtual world hyperlinks on websites for the metaverse and hypermedia-like structures with portals may provide immersive experiences for the users.

D. Simulating Reality

The notion of simulating the universe and reality is not new. It could be traced from numerous philosophies, the distinction between reality and dream, which was once termed as an illusion. With the proper usage of the physics of light energy, the ray-tracing simulation defines the appearance of images and enables 3-D graphics for real-time visuals [167]. The utilization of prerendered content and realistic graphics for the metaverse demands more computing power for the IoT devices used for such tasks. However, real-time ray tracing could solve these issues by enhanced AI models that could mimic the machines and provide an immersive experience for the metaverse through virtual objects, people, places, and machines. For instance, the data accumulated from digital twins, IoT devices monitoring traffic, and geospatial data could impose real-time data of processes, objects, machines, and people and provide real-time visualization of the data through AI and predictive analysis [168]. Furthermore, these features add a layer of immersive experience for the metaverse and could assist next-generation education with more interactiveness and engage the learners and educators with a better platform.

E. Ethical Considerations and Potential Pitfalls

In this section, we summarize ethical considerations and potential pitfalls of using metaverse for educational services. Furthermore, we will survey the state of the current literature on the legal issues involved in the use of metaverse for educational services. Interoperability and openness of the metaverse raise the question of the ethics and values of the future Internet. The ethical judgments based on the philosophical nature of the technology imparted in the metaverse need to identify the responsible members building this infrastructure. With the core objective of preserving human well-being, the ethical guidelines provided in [169] could well suit the metaverse applications with an increased focus on the use of AI for autonomous frameworks.

1) *Privacy policies:* The XR devices along with BCI could provide access to the metaverse applications, which are capable of detecting the thought processes of the users. Despite using them for predicting consumer behavior, they gather private user data and keep storing them in the blockchain forever. Privacy policies of metaverse applications should be read by understanding the consequences of data leaks, misuse of data, and hacking of personal data. Casey et al. [170] demonstrated potential solutions for securing such systems. For social VR learning environments, security and privacy attack trees are demonstrated in [171], in which stochastic timed automata representations are used for statistical model checking. Furthermore, integrity loss and privacy leakage are also assessed before and after the adoption of the aforementioned design principles.
2) *Digital citizenship:* Digital citizenship refers to the way of being and acting online in a safe and meaningful way. It drives toward critical thinking and not trusting everything the user observes. It ensures being safe with the information and getting connected to the intended persons. Digital citizenship ensures that metaverse users act with responsibility in communication and behavior. Kim and Choi [172] proposed a five-factor digital citizenship model that ensures social engagement online through reasonable activities. Such models driven by the educators for the metaverse could provide reliable education and training content as a digital citizenship scale for the learners.
3) *Netiquettes:* Digital etiquette is normally termed Netiquette, where having the proper communication is key in terms of asking, and responding with respect and protection. By proper greeting, and asking specific queries, with professional and proper endings, Netiquette could be ensured in communication. In the metaverse-based education implemented in high schools, colleges, or industries, being a responsible digital citizen is key. Soler-Costa et al. [173] reviewed the necessity of Netiquette in online educational platforms, where ICTs have changed the way of communication and socialization. The metaverse with a new reality for education and training learners with proper Netiquette, arrests cyberbullying, and digital scams, in social networks.
4) *Acceptable use policies:* It refers to the set of rules or policies applied by the owner, creator, or administrator of the educational content or the system, which restricts the way the content can be used. It is an integral part of the framework of security policies, where new users gain access to the resources by signing the policy. Theoretical and historical understanding of the policies on educational contents is evaluated in [174] for steering distance education. An online consent maturity model developed in [175], with a sociotechnical context, argued the legalistic adoption of ethics in the paradigm for informed consent in online education. The stakeholders of educational institutions may request the learners and teachers to sign an acceptable use policy, before allocating them a network ID for gaining access to the metaverse-enabled educational content.
5) *Network security:* As security concerns are rising in immersive educational platforms, the attacks on HMD devices could enable the attackers to disorient users and overlay or modify the images in their vision. Casey et al. [170] demonstrated the exploitation of VR systems for controlling the users immersed in their metaverse world without their knowledge. These attacks were termed HJAs.
6) *Copyrights:* With the widespread bloom of numerous online educational platforms, the management of

digital rights on educational content against infringement of copyrights of learning resources is challenging. Blockchain-enabled digital copyright management system in [176] ensures sharing of multimedia educational content through private and public blockchains. It ensures data protection of educational content, which could be an appropriate choice for metaverse platforms as well. Furthermore, Guo et al. [177] presented the usage of blockchain for protecting of intellectual property rights on the ownership of technology transfer resources.

As stated in the aforementioned sections, XR is all set to modify our perceptions. As XR becomes a more powerful component of the metaverse, we still need the technology to tell what is authentic. The industry needs to invest in developing standards and policies that allow XR gadgets to operate ethically, and prevent the misuse of metaverse technology.

VI. Future Research Directions

This section explores the analysis of the metaverse in various applications, emphasizing the interplay of methodologies, architecture, and frameworks for education, training, and skill development. In addition, we touch upon open research topics in the metaverse and related areas for future exploration.

A. Accuracy and Authentication of Material

Offering truly quality and immersive education through metaverse demands the provision of high-quality content. The usage of substandard and highly incompatible XR and IoT devices also impacts the accuracy and authentication of educational content. There is a need to put efforts into defining a common authentication mechanism along with the features to deliver accurate and high-quality educational content. However, this initiative to create a robust educational platform needs to enable cross-border interoperability across a diversified range of supporting technologies.

Moreover, ensuring smooth connectivity with current learning management systems would increase the educational platform's usability and uptake. Working together with key players and industry experts in the educational technology space will make it easier to create standardized norms and guidelines that will guarantee a dependable and consistent user experience. Incorporating AI-powered analytics and adaptive learning algorithms can also customize the educational experience, taking into account the particular requirements and learning preferences of each student [178]. These components when put together can actually revolutionize education and empower students all around the world.

B. Access to Reliable Broadband

Seamless Internet connectivity for metaverse-driven education relies on reliable broadband services with broader coverage and high-speed access to educational resources, enabling the streaming of educational content. Optical communication and 5G/6G services lay the foundation for high-capacity communication, including reliable video streaming and the sharing of high-quality immersive educational content [179]. However, the use of heterogeneous radio technologies based on availability often affects trust in educational communication services [180]. To overcome these challenges, collaborative efforts among telecom companies, academic institutions, and governmental organizations are essential to prioritize the installation of broadband infrastructure in underserved areas, closing the digital gap and ensuring equal access to metaverse-driven education. Initiatives like fiber-optic expansion projects and satellite internet connectivity [181], along with investment in advanced communication technologies, such as dynamic spectrum sharing and next-generation satellite networks, can make educational communication services more dependable and effective, fostering a comprehensive learning environment for students worldwide.

C. Marginalized Communities

The research community should ensure focus on the technology and design that could satisfy the demands of the marginal group of individuals and communities participating in the metaverse-driven educational services. This will allow them to have full access to the services provided by the metaverse. Education for physically impaired learners and people with cognitive impairments should be considered by the metaverse platform and enable fairness policy to treat such individuals [182]. Attribution-based learning models with the Shapley values are largely used in XAI frameworks, depending on the game theory approach to interpret explanations from DNNs. This enables the marginalized community to provide immersive education [183]. Furthermore, such XAI models are largely used in the identification of vulnerable groups and aid in exploring how the decisions were made by the models. Particularly for the educational services driven through metaverse, the threats over the educational contents and the inherent contextual exploration need attention from the research community.

Research efforts should also concentrate on building strong governance frameworks to address dangers and issues linked to educational content within the metaverse, in addition to using XAI models to explain choices made by DNNs. To guarantee the usefulness and the availability of educational resources for all, this includes researching approaches for content verification, moderation, and dispute resolution [184]. By proactively addressing these issues, the research community may contribute to the development and adoption of a safe and reliable educational environment within the metaverse.

D. Mobile Technology and Pedagogical Integration

A key component in provisioning metaverse-driven educational services is its integration with mobile technologies. With a lot of pedagogical methodologies coming up with interactive mobile apps, the adoption of metaverse further enhances the usage of these apps for streamlining education towards immersive and interactive means. Mobile technologies are important because, although people are at different geographical locations, they are interconnected through their sophisticated gadgets, particularly with IoE and XR modules. Moreover, there are provisions for imposing user-defined sharing and restrictions on educational content through the apps. However, constraints on power management, high-speed networking, and coverage limitations need to be addressed to meet the balance with the demands of using immersive pedagogical methodologies. The influence of perceived trust and pedagogical faith on the trainers and educators are largely enhanced through the acceptance of AI-based tools and services [185]. Encouragement on the acceptance of the education XAI platforms with metaverse could enable the teachers to make pedagogical decisions and actions on the learners. With mobile technology, XR's next-generation human-centric services could be triggered through discrete event simulations driven through metaverse platforms [186], [187]. This, in turn, largely assists educational services with the usage of immersive XR apps and low-cost VR/AR gadgets for learner-centric sophisticated educational services.

Individuals can engage in education regardless of where they are in the world thanks to interconnected IoE and XR modules, and educational content can be controlled by users through user-defined sharing and content limitations [141]. To meet the needs of immersive educational techniques, it is necessary to address issues with power management, networking speed, and coverage limits. While mobile technology unlocks the next generation of human-centric services through metaverse platforms, empowering learner-centric educational experiences with accessible VR/AR devices and immersive XR apps, the acceptance of AI-based tools and education XAI platforms among educators increases trust and pedagogical confidence among educators, allowing them to make informed decisions and actions for learners.

E. Integrated Learning

Conventional online learning strategies, often inefficient due to numerous distractions, face challenges when gadgets need to handle high-speed educational content, leading to the degradation of network, smartphone, and desktop capabilities for immersive learning experiences. The advent of integrated learning through XR and IoE modules, bolstered by metaverse technology, paves the way for incorporating educational content into games and storylines, as highlighted in [188]. Nevertheless, the full potential of the metaverse in enhancing integrated learning can only be realized by addressing significant challenges such as device size, power management, and resource management across the learning platforms. This realization necessitates investments in advanced hardware infrastructure, increased network capacities, and effective strategies for power and resource management, as discussed by Zhou et al. [189] to optimize the educational experience and ensure seamless functioning within the metaverse.

F. Developing Values of Responsible Usage

While the metaverse, XR, and IoT architecture can enhance immersive educational services, users face challenges in responsibly managing this technology. Despite secure communication support, IoT devices and VR/AR gadgets are often misused, neglecting their inherent value [190]. Each technology supporting the metaverse has unique characteristics. Besides robust security and privacy measures, fostering responsible usage rooted in user and developer values is essential. In the context of educational services, learners and teachers bear the responsibility for delivering quality education through the metaverse [68]. While current technological implications are limited, educational service providers play a crucial role, and their challenges require urgent attention from the research community. Promoting ethical technology use in the metaverse demands a comprehensive strategy, encompassing education, digital literacy, and critical thinking. Continuous monitoring and evaluation processes are needed to address emerging issues. Collaboration with business leaders and engagement with various communities can help formulate policies aligned with societal values [191]. This approach can create an inclusive metaverse that enhances education while upholding ethical standards and prioritizing user safety and responsibility.

VII. Conclusion

The latest advancements in XR applications have illuminated the path to seamlessly merge the physical and virtual realms, enabled by the IoE devices. Metaverse platforms, entwining XR and IoE technologies, have emerged as prominent focal points in both commercial and research domains, promising to usher in transformative improvements in human life through IoE-driven applications. Within this metaverse framework, we explore the immersive visualization and interpretation of educational services, leveraging the stream of raw data generated by IoE devices. These IoE datasets are meticulously analyzed by digital models, offering profound insights and a high level of abstraction from the data originating from IoT devices. Our comprehensive survey delves into XR solutions, dissecting the associated challenges in education, training, and skill enhancement across diverse domains through IoE applications within the metaverse context. Specifically, we spotlight the foundational concepts underpinning XR and IoE technology, along with the critical features embedded within metaverse frameworks to enhance training and skill development. Furthermore, we underscore the invaluable contributions made by the metaverse, leveraging XR and IoE technology to cater to a diversified array of training and educational services. In addition, we identify pending issues that must be addressed to sustain the development of XR-based training supported by IoE devices, to expand services into the realm of immersive education. Although the scope of this survey does not encompass the latter, it offers a comprehensive understanding of the state-of-the-art features of XR and IoE devices, which align seamlessly with the demands of a metaverse in the realm of training. Finally, our article outlines potential avenues for future research, signaling promising directions in this domain.

References

[1] M. Ball, *The Metaverse: And How it Will Revolutionize Everything*. New York, NY, USA: Liveright Publishing, 2022.

[2] Y. Wang et al., "A survey on metaverse: Fundamentals, security, and privacy," *IEEE Commun. Surv. Tut.*, vol. 25, no. 1, pp. 319–352, First Quarter 2023.

[3] R. Cheng, N. Wu, S. Chen, and B. Han, "Will metaverse be NextG Internet? Vision, hype, and reality," *IEEE Netw.*, vol. 36, no. 5, pp. 197–204, Sep./Oct. 2022.

[4] H. Wang et al., "A survey on the metaverse: The state-of-the-art, technologies, applications, and challenges," *IEEE Internet Things J.*, vol. 10, no. 16, pp. 14671–14688, Aug. 2023.
[5] "The insane future of web 3.0 and the metaverse," 2023. Accessed: Dec. 26, 2023. [Online]. Available: https://tinyurl.com/mr3uraf9
[6] Y. K. Dwivedi et al., "Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy," *Int. J. Inf. Manage.*, vol. 66, 2022, Art. no. 102542.
[7] "Metaverse for education: How virtual reality can help schools and colleges," 2022. Accessed: Apr. 09, 2022. [Online]. Available: https://tinyurl.com/3uuxm63t
[8] S.-M. Park and Y.-G. Kim, "A metaverse: Taxonomy, components, applications, and open challenges," *IEEE Access*, vol. 10, pp. 4209–4251, 2022.
[9] S. Sung, K.-H. Kim, Y.-J. Kim, H. Lee, and B.-K. Lee, "Development of 'Metaverse' XR service using virtual reality," in *Proc. Korean Soc. Comput. Inf. Conf.*, 2021, pp. 633–635.
[10] J. Kemp and D. Livingstone, "Putting a second life "Metaverse" skin on learning management systems," in *Proc. 2nd Life Educ. Workshop Second Life Community Conv.*, 2006, pp. 13–18.
[11] K. MacCallum and D. Parsons, "Teacher perspectives on mobile augmented reality: The potential of metaverse for learning," in *Proc. World Conf. Mobile Contextual Learn.*, 2019, pp. 21–28.
[12] A. Bec, B. Moyle, V. Schaffer, and K. Timms, "Virtual reality and mixed reality for second chance tourism," *Tourism Manage.*, vol. 83, 2021, Art. no. 104256.
[13] M. Sparkes, "What is a metaverse," *NewScientist*, vol. 251, pp. 5–56, 2021.
[14] Y. Siriwardhana, P. Porambage, M. Liyanage, and M. Ylianttila, "A survey on mobile augmented reality with 5G mobile edge computing: Architectures, applications, and technical aspects," *IEEE Commun. Surv. Tuts.*, vol. 23, no. 2, pp. 1160–1192, Second Quarter 2021.
[15] L. Cao, "Decentralized AI: Edge intelligence and smart blockchain, metaverse, Web3, and DeSci," *IEEE Intell. Syst.*, vol. 37, no. 3, pp. 6–19, May/Jun. 2022.
[16] H. F. Ahmad, W. Rafique, R. U. Rasool, A. Alhumam, Z. Anwar, and J. Qadir, "Leveraging 6G, extended reality, and IoT Big Data analytics for healthcare: A review," *Comput. Sci. Rev.*, vol. 48, 2023, Art. no. 100558.
[17] M. A. I. Mozumder, M. M. Sheeraz, A. Athar, S. Aich, and H.-C. Kim, "Overview: Technology roadmap of the future trend of metaverse based on IoT, blockchain, AI technique, and medical domain metaverse activity," in *Proc. 24th Int. Conf. Adv. Commun. Technol.*, 2022, pp. 256–261.
[18] Y.-C. Tsai, "The value chain of education metaverse," 2022, *arXiv:2211.05833*.
[19] "The seven layers of the metaverse," 2023. Accessed: Dec. 26, 2023. [Online]. Available: https://www.leewayhertz.com/seven-layers-of-metaverse/
[20] L.-H. Lee et al., "All one needs to know about metaverse: A complete survey on technological singularity, virtual ecosystem, and research agenda," 2021, *arXiv:2110.05352*.
[21] M. Hu, X. Luo, J. Chen, Y. C. Lee, Y. Zhou, and D. Wu, "Virtual reality: A survey of enabling technologies and its applications in IoT," *J. Netw. Comput. Appl.*, vol. 178, 2021, Art. no. 102970.
[22] S. Lanka, S. Ehsan, and A. Ehsan, "A review of research on emerging technologies of the Internet of Things and augmented reality," in *Proc. Int. Conf. I-SMAC (IoT Social, Mobile, Analytics Cloud)*, 2017, pp. 770–774.
[23] R. Minerva, G. M. Lee, and N. Crespi, "Digital twin in the IoT context: A survey on technical features, scenarios, and architectural models," *Proc. IEEE*, vol. 108, no. 10, pp. 1785–1824, Oct. 2020.
[24] B. Kye, N. Han, E. Kim, Y. Park, and S. Jo, "Educational applications of metaverse: Possibilities and limitations," *J. Educ. Eval. Health Professions*, vol. 18, 2021, Art. no. 32.
[25] Y. Han, D. Niyato, C. Leung, C. Miao, and D. I. Kim, "A dynamic resource allocation framework for synchronizing metaverse with IoT service and data," in *Proc.-IEEE Int. Conf. Commun.*, 2022, pp. 1196–1201.
[26] B. Falchuk, S. Loeb, and R. Neff, "The social metaverse: Battle for privacy," *IEEE Technol. Soc. Mag.*, vol. 37, no. 2, pp. 52–61, Jun. 2018.
[27] K. J. Nevelsteen, "Virtual world, defined from a technological perspective and applied to video games, mixed reality, and the metaverse," *Comput. Animation Virtual Worlds*, vol. 29, no. 1, 2018, Art. no. e1752.
[28] L.-H. Lee et al., "When creators meet the metaverse: A survey on computational arts," 2021, *arXiv:2111.13486*.
[29] B. Shen, W. Tan, J. Guo, L. Zhao, and P. Qin, "How to promote user purchase in metaverse? A systematic literature review on consumer behavior research and virtual commerce application design," *Appl. Sci.*, vol. 11, no. 23, 2021, Art. no. 11087.
[30] D. Chen and R. Zhang, "Exploring research trends of emerging technologies in health metaverse: A bibliometric analysis," 2022. [Online]. Available: https://ssrn.com/abstract=3998068
[31] M. Zikky, K. Fathoni, and M. Firdaus, "Interactive distance media learning collaborative based on virtual reality with solar system subject," in *Proc. IEEE/ACIS 19th Int. Conf. Softw. Eng., Artif. Intell., Netw. Parallel/Distrib. Comput.*, 2018, pp. 4–9.
[32] J. Jeon and S. K. Jung, "Exploring the educational applicability of metaverse-based platforms," *Korea Assoc. Inf. Educ.*, vol. 12, no. 2, pp. 361–368, 2021.
[33] H.-C. Han, "From visual culture in the immersive metaverse to visual cognition in education," in *Cognitive and Affective Perspectives on Immersive Technology in Education*. Hershey, PA, USA: IGI Global, 2020, pp. 67–84.
[34] Y. Jeong, T. Lim, and J. Ryu, "Teaching practice for pre-service teachers in the metaverse learning environment," in *Proc. SITE Interact. Conf. Assoc. Advance. Comput. Educ.*, 2021, pp. 398–403.
[35] J.-M. Jot, R. Audfray, M. Hertensteiner, and B. Schmidt, "Rendering spatial sound for interoperable experiences in the audio metaverse," in *Proc. Immersive 3D Audio: Architecture Autom.*, 2021, pp. 1–15.
[36] D. Beck, L. Morgado, and P. O'Shea, "Educational practices and strategies with immersive learning environments: Mapping of reviews for using the metaverse," *IEEE Trans. Learn. Technol.*, vol. 17, pp. 319–341, 2024.
[37] P. Pataranutaporn et al., "AI-generated characters for supporting personalized learning and well-being," *Nature Mach. Intell.*, vol. 3, no. 12, pp. 1013–1022, 2021.
[38] A. A. Gaafar, "Metaverse in architectural heritage documentation & education," *Adv. Ecol. Environ. Res.*, vol. 6, no. 10, pp. 66–86, 2021.
[39] S. K. Jagatheesaperumal, M. Rahouti, K. Ahmad, A. Al-Fuqaha, and M. Guizani, "The duo of artificial intelligence and Big Data for industry 4.0: Applications, techniques, challenges, and future research directions," *IEEE Internet Things J.*, vol. 9, no. 15, pp. 12861–12885, Aug. 2022.
[40] S. Werrlich, K. Nitsche, and G. Notni, "Demand analysis for an augmented reality based assembly training," in *Proc. 10th Int. Conf. PErvasive Technol. Related Assistive Environ.*, 2017, pp. 416–422.
[41] L. Swikatek, "From industry 4.0 to nature 4.0—Sustainable infrastructure evolution by design," in *Proc. Int. Conf. Appl. Hum. Factors Ergonom.*, 2018, pp. 438–447.
[42] A. Assadzadeh, M. Arashpour, I. Brilakis, T. Ngo, and E. Konstantinou, "Vision-based excavator pose estimation using synthetically generated datasets with domain randomization," *Autom. Construction*, vol. 134, 2022, Art. no. 104089.
[43] N. D. Macchiarella, D. Liu, S. N. Gangadharan, D. A. Vincenzi, and A. E. Majoros, "Augmented reality as a training medium for aviation/aerospace application," in *Proc. Hum. Factors Ergonom. Soc. Annu. Meeting*, vol. 49, no. 25, 2005, pp. 2174–2178.
[44] H. Regenbrecht, G. Baratoff, and W. Wilke, "Augmented reality projects in the automotive and aerospace industries," *IEEE Comput. Graph. Appl.*, vol. 25, no. 6, pp. 48–56, Nov./Dec. 2005.
[45] H. Eschen, T. Kotter, R. Rodeck, M. Harnisch, and T. Schuppstuhl, "Augmented and virtual reality for inspection and maintenance processes in the aviation industry," *Procedia Manuf.*, vol. 19, pp. 156–163, 2018.
[46] F. D. Crescenzio, M. Fantini, F. Persiani, L. D. Stefano, P. Azzari, and S. Salti, "Augmented reality for aircraft maintenance training and operations support," *IEEE Comput. Graph. Appl.*, vol. 31, no. 1, pp. 96–101, Jan./Feb. 2011.
[47] A. Siyaev and G.-S. Jo, "Neuro-symbolic speech understanding in aircraft maintenance metaverse," *IEEE Access*, vol. 9, pp. 154484–154499, 2021.
[48] A. Siyaev and G.-S. Jo, "Towards aircraft maintenance metaverse using speech interactions with virtual objects in mixed reality," *Sensors*, vol. 21, no. 6, 2021, Art. no. 2066.
[49] J. Kim, "A study on the development of information protection education contents in the maritime using metaverse," *J. Korea Inst. Inf. Secur. Cryptol.*, vol. 31, no. 5, pp. 1011–1020, 2021.
[50] B. Shen, W. Tan, J. Guo, H. Cai, B. Wang, and S. Zhuo, "A study on design requirement development and satisfaction for future virtual world systems," *Future Internet*, vol. 12, no. 7, 2020, Art. no. 112.
[51] T. Nakamura et al., "Science operation plan of Phobos and Deimos from the MMX spacecraft," *Earth, Planets Space*, vol. 73, no. 1, pp. 1–27, 2021.
[52] C. B. Fernandez and P. Hui, "Life, the metaverse and everything: An overview of privacy, ethics, and governance in metaverse," in *Proc. IEEE 42nd Int. Conf. Distrib. Comput. Syst. Workshops*, 2022, pp. 272–277.
[53] Y. K. Dwivedi et al., "Exploring the darkverse: A multi-perspective analysis of the negative societal impacts of the metaverse," *Inf. Syst. Front.*, vol. 25, pp. 2071–2114, 2023.

[54] Z. Chen, J. Wu, W. Gan, and Z. Qi, “Metaverse security and privacy: An overview,” in *Proc. IEEE Int. Conf. Big Data*, 2022, pp. 2950–2959.

[55] Y. Fan, T. Huang, Y. Meng, and S. Cheng, “The current opportunities and challenges of web 3.0,” 2023, *arXiv:2306.03351*.

[56] V. Kuleto et al., “The potential of blockchain technology in higher education as perceived by students in Serbia, Romania, and Portugal,” *Sustainability*, vol. 14, no. 2, 2022, Art. no. 749.

[57] S. Zuboff, *The Age of Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power: Barack Obama’s Books of 2019*. London, U.K.: Profile Books, 2019.

[58] C. Andrews, M. K. Southworth, J. N. Silva, and J. R. Silva, “Extended reality in medical practice,” *Curr. Treat. Options cardiovasc. Med.*, vol. 21, no. 4, pp. 1–12, 2019.

[59] S. Doolani et al., “A review of extended reality (XR) technologies for manufacturing training,” *Technol.*, vol. 8, no. 4, 2020, Art. no. 77.

[60] F. Palmas and G. Klinker, “Defining extended reality training: A long-term definition for all industries,” in *Proc. IEEE 20th Int. Conf. Adv. Learn. Technol.*, 2020, pp. 322–324.

[61] S. M. Zweifach and M. M. Triola, “Extended reality in medical education: Driving adoption through provider-centered design,” *Digit. Biomarkers*, vol. 3, no. 1, pp. 14–21, 2019.

[62] E. Gandolfi, K. W. Kosko, and R. E. Ferdig, “Situating presence within extended reality for teacher training: Validation of the extended reality presence scale (XRPS) in preservice teacher use of immersive 360 video,” *Brit. J. Educ. Technol.*, vol. 52, no. 2, pp. 824–841, 2021.

[63] K. M. Stanney et al., “Performance gains from adaptive eXtended reality training fueled by artificial intelligence,” *J. Defense Model. Simul.*, vol. 19, pp. 195–218, 2022.

[64] S. Alizadehsalehi, A. Hadavi, and J. C. Huang, “From BIM to extended reality in AEC industry,” *Autom. Construction*, vol. 116, 2020, Art. no. 103254.

[65] M. P. Ilić, D. Păun, N. P. Šević, A. Hadžić, and A. Jianu, “Needs and performance analysis for changes in higher education and implementation of artificial intelligence, machine learning, and extended reality,” *Educ. Sci.*, vol. 11, no. 10, 2021, Art. no. 568.

[66] A. D. Kaplan, J. Cruit, M. Endsley, S. M. Beers, B. D. Sawyer, and P. Hancock, “The effects of virtual reality, augmented reality, and mixed reality as training enhancement methods: A meta-analysis,” *Hum. Factors*, vol. 63, no. 4, pp. 706–726, 2021.

[67] S. K. Kim, Y. Lee, H. Yoon, and J. Choi, “Adaptation of extended reality smart glasses for core nursing skill training among undergraduate nursing students: Usability and feasibility study,” *J. Med. Internet Res.*, vol. 23, no. 3, 2021, Art. no. e24313.

[68] N. Xi, J. Chen, F. Gama, M. Riar, and J. Hamari, “The challenges of entering the metaverse: An experiment on the effect of extended reality on workload,” *Inf. Syst. Front.*, vol. 25, pp. 659–680, 2023.

[69] J. Heirman et al., “Exploring the possibilities of extended reality in the world of firefighting,” in *Proc. IEEE Int. Conf. Artif. Intell. Virtual Reality*, 2020, pp. 266–273.

[70] J. T. McGuirt et al., “Extended reality technologies in nutrition education and behavior: Comprehensive scoping review and future directions,” *Nutrients*, vol. 12, no. 9, 2020, Art. no. 2899.

[71] C. W. Ong, M. C. J. Tan, M. Lam, and V. T. C. Koh, “Applications of extended reality in ophthalmology: Systematic review,” *J. Med. Internet Res.*, vol. 23, no. 8, 2021, Art. no. e24152.

[72] A. Logeswaran, C. Munsch, Y. J. Chong, N. Ralph, and J. McCrossnan, “The role of extended reality technology in healthcare education: Towards a learner-centred approach,” *Future Healthcare J.*, vol. 8, no. 1, pp. e79–e84, 2021.

[73] K. W. Kosko, R. E. Ferdig, and L. Roche, “Conceptualizing a shared definition and future directions for extended reality (XR) in teacher education,” *J. Technol. Teacher Educ.*, vol. 29, no. 3, pp. 257–277, 2021.

[74] P. L. Noury, R. Polman, M. Maloney, and A. Gorman, “A narrative review of the current state of extended reality technology and how it can be utilised in sport,” *Sports Med.*, vol. 52, pp. 1473–1489, 2022.

[75] G. Zwoliński et al., “Extended reality in education and training: Case studies in management education,” *Electronics*, vol. 11, no. 3, 2022, Art. no. 336.

[76] S. Mystakidis, “Motivation enhancement methods for community building in extended reality,” in *Augmented and Mixed Reality for Communities*. Boca Raton, FL, USA: CRC Press, 2021, pp. 265–282.

[77] Å. Fast-Berglund, L. Gong, and D. Li, “Testing and validating extended reality (XR) technologies in manufacturing,” *Procedia Manuf.*, vol. 25, pp. 31–38, 2018.

[78] M. Al-Adhami, S. Wu, and L. Ma, “Extended reality approach for construction quality control,” in *Proc. CIB World Building Congr.*, 2019, pp. 1127–1135.

[79] T. D. Parsons, A. Gaggioli, and G. Riva, “Extended reality for the clinical, affective, and social neurosciences,” *Brain Sci.*, vol. 10, no. 12, 2020, Art. no. 922.

[80] H. Koo, “Training in lung cancer surgery through the metaverse, including extended reality, in the smart operating room of Seoul National University Bundang hospital, Korea,” *J. Educ. Eval. Health Professions*, vol. 18, 2021, Art. no. 1149229.

[81] I. Zagury-Orly et al., “What is the current state of extended reality use in otolaryngology training? A scoping review,” *Laryngoscope*, vol. 133, pp. 227–234, 2023.

[82] S. Jeršov and A. Tepljakov, “Digital twins in extended reality for control system applications,” in *Proc. 43rd Int. Conf. Telecommun. Signal Process.*, 2020, pp. 274–279.

[83] C.-J. Liang, C. Start, H. Boley, V. R. Kamat, C. C. Menassa, and M. Aebersold, “Enhancing stroke assessment simulation experience in clinical training using augmented reality,” *Virtual Reality*, vol. 25, no. 3, pp. 575–584, 2021.

[84] A. J. A. Alnagrat, R. C. Ismail, and S. Z. S. Idrus, “Extended reality (XR) in virtual laboratories: A review of challenges and future training directions,” in *J. Phys.: Conf. Ser.*, vol. 1874, no. 1, 2021, Art. no. 012031.

[85] K. Yang, X. Zhou, and I. Radu, “XR-Ed framework: Designing instruction-driven and learner-centered extended reality systems for education,” 2020, *arXiv:2010.13779*.

[86] T. Andrade and D. Bastos, “Extended reality in IoT scenarios: Concepts, applications and future trends,” in *Proc. 5th Exp. Int. Conf.*, 2019, pp. 107–112.

[87] H. El-Jarn and G. Southern, “Can co-creation in extended reality technologies facilitate the design process?,” *J. Work-Appl. Manage.*, vol. 12, pp. 191–205, 2020.

[88] K. Shankhwar and S. Smith, “An interactive extended reality-based tutorial system for fundamental manual metal arc welding training,” *Virtual Reality*, vol. 26, pp. 1173–1192, 2022.

[89] W. López-Ojeda and R. A. Hurley, “Extended-reality technologies: An overview of emerging applications in medical education and clinical care,” *J. Neuropsychiatry Clin. Neurosci.*, vol. 33, no. 3, pp. A4–177, 2021.

[90] X. Guo, Y. Guo, and Y. Liu, “The development of extended reality in education: Inspiration from the research literature,” *Sustainability*, vol. 13, no. 24, 2021, Art. no. 13776.

[91] Z. Minchev, “Extended reality training analytical transcends in the future digital society,” in *Proc. 12th Nat. Conf. Edu. Res. Inform. Soc.*, 2019, pp. 151–165.

[92] G. S. Goh, R. Lohre, J. Parvizi, and D. P. Goel, “Virtual and augmented reality for surgical training and simulation in knee arthroplasty,” *Arch. Orthopaedic Trauma Surg.*, vol. 141, no. 12, pp. 2303–2312, 2021.

[93] J. I. Cross, C. Boag-Hodgson, T. Ryley, T. Mavin, and L. E. Potter, “Using extended reality in flight simulators: A literature review,” *IEEE Trans. Vis. Comput. Graph.*, vol. 29, no. 9, pp. 3961–3975, Sep. 2023.

[94] E. Gandolfi, R. Ferdig, and K. Kosko, “The extended reality presence scale,” in *Proc. Soc. Inf. Technol. Teacher Educ. Int. Conf.*, 2020, pp. 1027–1033.

[95] M. Hoover and E. Winer, “Designing adaptive extended reality training systems based on expert instructor behaviors,” *IEEE Access*, vol. 9, pp. 138160–138173, 2021.

[96] J. Pomerantz, “Teaching and learning with extended reality technology,” in *Proc. Inf. Technol. Transforming Lives: Connection, Interact., Innov.*, 2019, pp. 137–157.

[97] A. Çöltekin et al., “Extended reality in spatial sciences: A review of research challenges and future directions,” *ISPRS Int. J. Geo-Inf.*, vol. 9, no. 7, 2020, Art. no. 439.

[98] Y. Xing, Z. Liang, J. Shell, C. Fahy, K. Guan, and B. Liu, “Historical data trend analysis in extended reality education field,” in *Proc. IEEE 7th Int. Conf. Virtual Reality*, 2021, pp. 434–440.

[99] M. K. Southworth, J. R. Silva, and J. N. A. Silva, “Use of extended realities in cardiology,” *Trends Cardiovasc. Med.*, vol. 30, no. 3, pp. 143–148, 2020.

[100] I. Bandara and F. Ioras, “The evolving challenges of internet of everything: Enhancing student performance and employability in higher education,” in *Proc. 10th Annu. Int. Technol., Educ. Develop.*, 2016, pp. 652–658.

[101] J. Fiaidhi and S. Mohammed, “Internet of Everything as a platform for extreme automation,” *IT Professional*, vol. 21, no. 1, pp. 21–25, 2019.

[102] S. Bachir and A. Abenia, "Internet of everything and educational cyber physical systems for university 4.0," in *Proc. Int. Conf. Comput. Collective Intell.*, 2019, pp. 581–591.
[103] S. Gul et al., "A survey on role of Internet of Things in education," *Int. J. Comput. Sci. Netw. Secur.*, vol. 17, no. 5, pp. 159–165, 2017.
[104] T. Y. Chou and W.-H. Lai, "Application of the Internet of Everything in educational institutions," in *Proc. Int. Symp. Intell. Signal Process. Commun. Syst.*, 2021, pp. 1–2.
[105] R. S. Abd-Ali, S. A. Radhi, and Z. I. Rasool, "A survey: The role of the Internet of Things in the development of education," *Indonesian J. Elect. Eng. Comput. Sci.*, vol. 19, no. 1, pp. 215–221, 2020.
[106] M. Al-Emran, S. I. Malik, and M. N. Al-Kabi, "A survey of Internet of Things (IoT) in education: Opportunities and challenges," in *Toward Social Internet of Things (SIoT): Enabling Technologies, Architectures and Applications*. New York, NY, USA: Springer, 2020, pp. 197–209.
[107] Y. Ding, Y. Li, and L. Cheng, "Application of Internet of Things and virtual reality technology in college physical education," *IEEE Access*, vol. 8, pp. 96065–96074, 2020.
[108] D. D. Ramlowat and B. K. Pattanayak, "Exploring the Internet of Things (IoT) in education: A review," in *Proc. Inf. Syst. Des. Intell. Appl.*, 2019, pp. 245–255.
[109] B. Burd et al., "Courses, content, and tools for Internet of Things in computer science education," in *Proc. ITiCSE Conf. Work. Group Rep.*, 2018, pp. 125–139.
[110] G. Cornetta, A. Touhafi, M. A. Togou, and G.-M. Muntean, "Fabrication-as-a-service: A web-based solution for STEM education using Internet of Things," *IEEE Internet Things J.*, vol. 7, no. 2, pp. 1519–1530, Feb. 2020.
[111] S. Pervez, S. u. Rehman, and G. Alandjani, "Role of Internet of Things (IoT) in higher education," in *Proc. Int. Conf. Adv. Educ.*, 2018, pp. 792–800.
[112] H. Shaikh, M. S. Khan, Z. A. Mahar, M. Anwar, A. Raza, and A. Shah, "A conceptual framework for determining acceptance of Internet of Things (IoT) in higher education institutions of Pakistan," in *Proc. Int. Conf. Inf. Sci. Commun. Technol.*, 2019, pp. 1–5.
[113] D. K. A.-R. Al-Malah, H. H. K. Jinah, and H. T. S. ALRikabi, "Enhancement of educational services by using the Internet of Things applications for talent and intelligent schools," *Periodicals Eng. Natural Sci.*, vol. 8, no. 4, pp. 2358–2366, 2020.
[114] A. Jean-Charles, "Internet of Things in education: Artificial intelligence voice assistant in the classroom," in *Proc. Soc. Inf. Technol. Teacher Educ. Int. Conf.*, 2018, pp. 883–885.
[115] A. A. Mawgoud, M. H. N. Taha, and N. E. M. Khalifa, "Security threats of social Internet of Things in the higher education environment," in *Toward Social Internet of Things (SIoT): Enabling Technologies, Architectures and Applications*. New York, NY, USA: Springer, 2020, pp. 151–171.
[116] C. O. Turcu and C. E. Turcu, "Industrial Internet of Things as a challenge for higher education," *Int. J. Adv. Comput. Sci. Appl.*, vol. 9, no. 11, pp. 55–60, 2018.
[117] M. Leisenberg and M. Stepponat, "Internet of Things remote labs: Experiences with data analysis experiments for students education," in *Proc. IEEE Glob. Eng. Educ. Conf.*, 2019, pp. 22–27.
[118] L. Hickman and M. Akdere, "Developing intercultural competencies through virtual reality: Internet of Things applications in education and learning," in *Proc. 15th Learn. Technol. Conf.*, 2018, pp. 24–28.
[119] R. Xiao and X. Liu, "Analysis of the architecture of the mental health education system for college students based on the Internet of Things and privacy security," *IEEE Access*, vol. 9, pp. 81089–81096, 2021.
[120] Y. Somantri, D. Wahyudin, R. Pratama, T. Nugraha, and M. Husni, "An affordable Internet of Things training kit for practical work of industrial automation," *J. Phys.: Conf. Ser.*, vol. 1402, no. 3, 2019, Art. no. 033079.
[121] O. Fragou and A. Mavroudi, "Exploring Internet of Things, mobile computing and ubiquitous computing in computer science education: A systematic mapping study," *Int. J. Technol. Edu. Sci.*, vol. 4, no. 1, pp. 72–85, 2020, doi: 10.46328/ijtes.v4i1.47.
[122] Y. Jiang, "Combination of wearable sensors and Internet of Things and its application in sports rehabilitation," *Comput. Commun.*, vol. 150, pp. 167–176, 2020.
[123] K. Mershad and P. Wakim, "A learning management system enhanced with Internet of Things applications," *J. Educ. Learn.*, vol. 7, no. 3, pp. 23–40, 2018.
[124] X. Qi, "University education management based on Internet of Things technology," in *Proc. Int. Conf. Mach. Learn. Big Data Analytics IoT Secur. Privacy*, 2020, pp. 805–810.
[125] S. Khan, "Modern Internet of Things as a challenge for higher education," *Int. J. Comput. Sci. Netw. Secur.*, vol. 18, no. 12, 2018, Art. no. 34.
[126] M. Kravčík, C. Ullrich, and C. Igel, "The potential of the Internet of Things for supporting learning and training in the digital age," in *Positive Learning in the Age of Information*. New York, NY, USA: Springer, 2018, pp. 399–412.
[127] Q. Li, "Intelligent campus and English visual education system design based on Internet of Things," *Adv. Multimedia*, vol. 2022, 2022, Art. no. 1703156.
[128] F. T. Moreira, M. Vairinhos, and F. Ramos, "Internet of Things in education: A tool for science learning," in *Proc. 13th Iberian Conf. Inf. Syst. Technol.*, 2018, pp. 1–5.
[129] H. Zhang and X. Liu, "Teaching system of undergraduate entrepreneurship education under the background of Internet of Things," *Mobile Inf. Syst.*, vol. 2021, pp. 1–9, 2021.
[130] M. Xu, "The combination of Internet of Things technology based on probability model network and mass education," *Wireless Commun. Mobile Comput.*, vol. 2022, 2022, Art. no. 2782473.
[131] E. Gurgu, M. Andronie, M. Andronie, and I. Dijmarescu, "Does the convergence of the blockchain, the Internet of Things and artificial intelligence changing our lives, education and the known world of the internet?! Some changes and perspectives for the international economy," in *Proc. Int. Conf. Econ. Sci. Bus. Admin.*, vol. 5, no. 1, 2019, pp. 69–88.
[132] Y. Cui and C. Zhou, "Application of Internet of Things artificial intelligence and knowledge innovation system in table tennis teaching and training," *Appl. Bionics Biomech.*, vol. 2022, 2022, Art. no. 7625626.
[133] Q. Li and J. He, "Analysis of music wisdom education mode under the background of Internet of Things," *Wireless Commun. Mobile Comput.*, vol. 2022, 2022, Art. no. 4640826.
[134] V. Gkamas, M. Rigou, I. Perikos, I. Gueorguiev, P. Varbanov, and C. Todorova, "Learning outcomes design for data science and Internet of Things training programs," in *Proc. 10th Int. Conf. Inf., Intell., Syst. Appl.*, 2019, pp. 1–2.
[135] D. Bright, "An integrative review of the potential of wireless assistive technologies and Internet of Things (IoT) to improve accessibility to education for students with disabilities," *Assistive Technol.*, vol. 34 pp. 653–660, 2022.
[136] B. Li, X. Wang, and J. Yao, "Application algorithms for basketball training based on Big Data and Internet of Things," *Mobile Inf. Syst.*, vol. 2021, 2021, Art. no. 9934363.
[137] W.-S. Kim, "Edge computing server deployment technique for cloud VR-based multi-user metaverse content," *J. Korea Multimedia Soc.*, vol. 24, no. 8, pp. 1090–1100, 2021.
[138] S. H. Ko and J. Rogers, "Functional materials and devices for XR (VR/AR/MR) applications," *Adv. Funct. Mater.*, vol. 31, 2021, Art. no. 2106546.
[139] H. Lee and Y. Hwang, "Technology-enhanced education through VR-making and metaverse-linking to foster teacher readiness and sustainable learning," *Sustainability*, vol. 14, no. 8, 2022, Art. no. 4786.
[140] H.-C. S.. Han et al., "From visual culture in the immersive metaverse to visual cognition in education," in *Cognitive and Affective Perspectives on Immersive Technology in Education*. IGI Global, 2020, pp. 67–84.
[141] P. Bhattacharya et al., "Coalition of 6G and blockchain in AR/VR space: Challenges and future directions," *IEEE Access*, vol. 9, pp. 168455–168484, 2021.
[142] A. Abdoullaev, "Trans-AI: How to build true AI or real machine intelligence and learning," *Ontol. Des.*, vol. 11, no. 4, pp. 402–421, 2021.
[143] B. Egliston and M. Carter, "Critical questions for Facebook's virtual reality: Data, power and the metaverse," *Internet Policy Rev.*, vol. 10, no. 4, pp. 1–23, 2021.
[144] C.-S. Kim, Y. Lee, and H. Ahn, "A study on the metaverse: Focused on the application of news Big Data service and case study," *J. Korea Soc. Digit. Ind. Inf. Manage.*, vol. 17, no. 2, pp. 85–101, 2021.
[145] R. Stark, "Future virtual product creation solutions with new engineering capabilities," in *Virtual Product Creation in Industry*. New York, NY, USA: Springer, 2022, pp. 555–648.
[146] G.-J. Hwang and S.-Y. Chien, "Definition, roles, and potential research issues of the metaverse in education: An artificial intelligence perspective," *Comput. Educ.: Artif. Intell.*, vol. 3, 2022, Art. no. 100082.
[147] K. Stanoevska-Slabeva, "Opportunities and challenges of metaverse for education: A literature review," in *Proc. 14th Int. Conf. Educ. New Learn. Technol.*, 2022, pp. 10401–10410.
[148] W. Y. B. Lim et al., "Realizing the metaverse with edge intelligence: A match made in heaven," *IEEE Wireless Commun.*, vol. 30, no. 4, pp. 64–71, Aug. 2023.

[149] X. Li et al., "SADRL: Merging human experience with machine intelligence via supervised assisted deep reinforcement learning," *Neurocomputing*, vol. 467, pp. 300–309, 2022.

[150] W. C. Ng, W. Y. B. Lim, J. S. Ng, Z. Xiong, D. Niyato, and C. Miao, "Unified resource allocation framework for the edge intelligence-enabled metaverse," in *Proc. IEEE Int. Conf. Commun.*, 2022, pp. 5214–5219.

[151] T. Huynh-The, Q.-V. Pham, X.-Q. Pham, T. T. Nguyen, Z. Han, and D.-S. Kim, "Artificial intelligence for the metaverse: A survey," *Eng. Appl. Artif. Intell.*, vol. 117, 2023, Art. no. 105581.

[152] T. Hewa, M. Ylianttila, and M. Liyanage, "Survey on blockchain based smart contracts: Applications, opportunities and challenges," *J. Netw. Comput. Appl.*, vol. 177, 2021, Art. no. 102857.

[153] A. I. Sanka, M. Irfan, I. Huang, and R. C. Cheung, "A survey of breakthrough in blockchain technology: Adoptions, applications, challenges and future research," *Comput. Commun.*, vol. 169, pp. 179–201, 2021.

[154] T. Huynh-The et al., "Blockchain for the metaverse: A review," *Future Gener. Comput. Syst.*, vol. 143, pp. 401–419, 2023.

[155] S. K. Jagatheesaperumal et al., "Semantic-aware digital twin for metaverse: A comprehensive review," *IEEE Wireless Commun.*, vol. 30, no. 4, pp. 38–46, Aug. 2023.

[156] B. Kommadi, "Blockchain open issues, research gaps, and road map of future blockchain for 2030: Charting the digital future," in *Blockchain Technologies and Applications for Digital Governance*. Hershey, PA, USA: IGI Global, 2022, pp. 200–229.

[157] T. M. Tan and J. Salo, "Ethical marketing in the blockchain-based sharing economy: Theoretical integration and guiding insights," *J. Bus. Ethics*, vol. 183, pp. 1113–1140, 2023.

[158] Y. Cai, J. Llorca, A. M. Tulino, and A. F. Molisch, "Compute-and data-intensive networks: The key to the metaverse," in *Proc. 1st Int. Conf. 6G Netw.*, 2022, pp. 1–8.

[159] H. Ahn, M. Lee, C.-H. Hong, and B. Varghese, "ScissionLite: Accelerating distributed deep neural networks using transfer layer," 2021, *arXiv:2105.02019*.

[160] M. Xu et al., "A full dive into realizing the edge-enabled metaverse: Visions, enabling technologies, and challenges," *IEEE Commun. Surv. Tuts.*, vol. 25, no. 1, pp. 656–700, First Quarter 2023.

[161] H.-S. Lee and D.-E. Lee, "Resource allocation in wireless networks with federated learning: Network adaptability and learning acceleration," *ICT Exp.*, vol. 8, no. 1, pp. 31–36, 2022.

[162] Q. Yang, Y. Zhao, H. Huang, Z. Xiong, J. Kang, and Z. Zheng, "Fusing blockchain and AI with metaverse: A survey," *IEEE Open J. Comput. Soc.*, vol. 3, pp. 122–136, 2022.

[163] C. Liu and S. Fuhrmann, "Enriching the GIScience research agenda: Fusing augmented reality and location-based social networks," *Trans. GIS*, vol. 22, no. 3, pp. 775–788, 2018.

[164] J. McVeigh-Schultz, A. Kolesnichenko, and K. Isbister, "Shaping pro-social interaction in VR: An emerging design framework," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2019, pp. 1–12.

[165] T. M. Key and G. Challagalla, "Information transparency as competitive advantage: Research approaches to platform ecosystem design and competition," *AMS Rev.*, vol. 10, no. 1, pp. 145–147, 2020.

[166] D. S. Hensel, "Ecological prototypes: Initiating design innovation in green construction," *Sustainability*, vol. 12, no. 14, 2020, Art. no. 5865.

[167] R. McHaney, L. Reiter, and I. Reychav, "Immersive simulation in constructivist-based classroom e-learning," *Int. J. E-Learn.*, vol. 17, no. 1, pp. 39–64, 2018.

[168] S. K. Jagatheesaperumal and M. Rahouti, "Building digital twins of cyber physical systems with metaverse for industry 5.0 and beyond," *IT Professional*, vol. 24, no. 6, pp. 34–40, 2022.

[169] K. Shahriari and M. Shahriari, "IEEE standard review—Ethically aligned design: A vision for prioritizing human wellbeing with artificial intelligence and autonomous systems," in *Proc. IEEE Canada Int. Humanitarian Technol. Conf.*, 2017, pp. 197–201.

[170] P. Casey, I. Baggili, and A. Yarramreddy, "Immersive virtual reality attacks and the human joystick," *IEEE Trans. Dependable Secure Comput.*, vol. 18, no. 2, pp. 550–562, Mar./Apr. 2021.

[171] S. Valluripally, A. Gulhane, R. Mitra, K. A. Hoque, and P. Calyam, "Attack trees for security and privacy in social virtual reality learning environments," in *Proc. IEEE 17th Annu. Consum. Commun. Netw. Conf.*, 2020, pp. 1–9.

[172] M. Kim and D. Choi, "Development of youth digital citizenship scale and implication for educational setting," *J. Educ. Technol. Soc.*, vol. 21, no. 1, pp. 155–171, 2018.

[173] R. Soler-Costa, P. Lafarga-Ostáriz, M. Mauri-Medrano, and A.-J. Moreno-Guerrero, "Netiquette: Ethic, education, and behavior on internet—A systematic literature review," *Int. J. Environ. Res. Public Health*, vol. 18, no. 3, 2021, Art. no. 1212.

[174] B. Brown, "'Steering at a distance', Australian school principals' understandings of digital technologies policies during the digital education revolution," *J. Educ. Admin. Hist.*, vol. 53, no. 1, pp. 50–66, 2021.

[175] V. M. Rooney and S. N. Foley, "An online consent maturity model: Moving from acceptable use towards ethical practice," in *Proc. New Secur. Paradigms Workshop*, 2018, pp. 64–79.

[176] J. H. Rooksby and C. S. Hayter, "Copyrights in higher education: Motivating a research agenda," *J. Technol. Transfer*, vol. 44, no. 1, pp. 250–263, 2019.

[177] J. Guo, C. Li, G. Zhang, Y. Sun, and R. Bie, "Blockchain-enabled digital rights management for multimedia resources of online education," *Multimedia Tools Appl.*, vol. 79, no. 15, pp. 9735–9755, 2020.

[178] M. Kamruzzaman et al., "AI-and IoT-Assisted sustainable education systems during pandemics, such as COVID-19, for smart cities," *Sustainability*, vol. 15, no. 10, 2023, Art. no. 8354.

[179] T. Zhang, H. Qiu, M. Mellia, Y. Li, H. Li, and K. Xu, "Interpreting AI for networking: Where we are and where we are going," *IEEE Commun. Mag.*, vol. 60, no. 2, pp. 25–31, Feb. 2022.

[180] D. B. Das and D. Birant, "XHAC: Explainable human activity classification from sensor data," in *Emerging Trends in IoT and Integration With Data Science, Cloud Computing, and Big Data Analytics*. Hershey, PA, USA: IGI Global, 2022, pp. 146–164.

[181] J. Urquizo et al., "Improving the quality of education on the Galapagos islands through a community intranet," in *Proc. IEEE Glob. Humanitarian Technol. Conf.*, 2019, pp. 1–8.

[182] I. Strumke and M. Slavkovik, "Explainability for identification of vulnerable groups in machine learning models," 2022, *arXiv:2203.00317*.

[183] D. Bhargava and L. K. Gupta, "Explainable AI in neural networks using Shapley values," in *Biomedical Data Analysis and Processing Using Explainable (XAI) and Responsive Artificial Intelligence (RAI)*. New York, NY, USA: Springer, 2022, pp. 59–72.

[184] K. Fiok, F. V. Farahani, W. Karwowski, and T. Ahram, "Explainable artificial intelligence for education and training," *J. Defense Model. Simul.*, vol. 19, no. 2, pp. 133–144, 2022.

[185] S. Choi, Y. Jang, and H. Kim, "Influence of pedagogical beliefs and perceived trust on teachers' acceptance of educational artificial intelligence tools," *Int. J. Human–Comput. Interact.*, vol. 39, pp. 910–922, 2022.

[186] C. J. Turner and W. Garn, "Next generation des simulation: A research agenda for human centric manufacturing systems," *J. Ind. Inf. Integr.*, vol. 28, 2022, Art. no. 100354.

[187] I. Ahmed, G. Jeon, and F. Piccialli, "From artificial intelligence to explainable artificial intelligence in industry 4.0: A survey on what, how, and where," *IEEE Trans. Ind. Inform.*, vol. 18, no. 8, pp. 5031–5042, Aug. 2022.

[188] M. Tsapara and T. Bratitsis, "A board game for sustainable development education: Kindergarten students as game designers," in *Proc. Interact. Mobile Commun., Technol. Learn.*, 2022, pp. 1072–1084.

[189] X. Zhou, C. Liu, and J. Zhao, "Resource allocation of federated learning for the metaverse with mobile augmented reality," *IEEE Trans. Wireless Commun.*, early access, doi: 10.1109/TWC.2023.3326884.

[190] R. V. Kozinets, "Immersive netnography: A novel method for service experience research in virtual reality, augmented reality and metaverse contexts," *J. Service Manage.*, vol. 34, pp. 100–125, 2022.

[191] M. Anshari, M. Syafrudin, N. L. Fitriyani, and A. Razzaq, "Ethical responsibility and sustainability (ERS) development in a metaverse business model," *Sustainability*, vol. 14, no. 23, 2022, Art. no. 15805.

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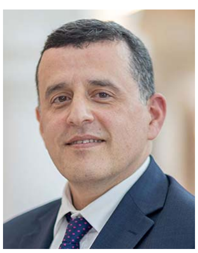

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