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RESEARCH ARTICLE

The Potential of Metaverse Fundamentals, Technologies, and Applications: A Systematic Literature Review

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ABSTRACT Metaverse is a virtual world platform that enables users to create and explore 3D environments. Recently, this technology has gained traction due to its potential to revolutionize the way people interact and share information. This paper provides an overview of the current state of Metaverse technologies. It begins by introducing their core components and surveys recent research and development activities in the area. Next, the paper examines the potential applications of Metaverse technology in different domains, such as gaming, social networking, training, education, healthcare, and marketing. It then outlines the challenges and opportunities associated with the development and deployment of Metaverse technologies, including scalability, privacy, and security issues. Finally, the paper concludes with a discussion of the implications of Metaverse technologies for the future of digital communication and information sharing.

INDEX TERMS Metaverse, metaverse technologies, AI, blockchain, applications, education, medical.

I. INTRODUCTION

The term 'Metaverse' is derived from the Greek words 'Meta' (transcendence) and 'verse' (universe). In his science fiction novel Snow Crash (1992), Neil Stephenson filed a lawsuit against this term [1]. It is a computer-generated world that integrates various new technologies such as 3D objects and graphics and is not controlled by a single authority [21]. Metaverse is the next generation internet that provides a digital world to human beings where they can experience alternative life. Through any type of smart devices smartphones to head mounted display human can freely enter in digital space to communicate and interact with avtars or digital things [2]. It is a combination of physical, human, and digital worlds. It provides an autonomous, fully immersive spatiotemporal virtual space where people can work, buy property, socialize, study, attend concerts, visit libraries, parks, and do many more real-life activities. Metaverse is a broad spectrum that caters to socialization, immersive interactions, real-world building, and expandability, allowing users to transform freely. Forecasts predict that people will spend at least an hour a day on Metaverse [2].

Metaverse is a digital environment where one can find all the physical things, friends, family, services, world map, buildings, houses, societies, and industries [48]. Metaverse is assemblage of virtual things: avatar, virtual goods, and digital things. Avatr is the virtual representation of human users and. Digital things include building,office, parks, libraries, schools and other such things of metaverse world [48]. Virtual goods include the digital arts, and land parcels. Major four modes of content creation in: professional generated content, User generated content, and AI generated content [2]. Virtual services broad of scopes including digital market, digital currency, digital regulation, social service, and many more [31].

Embed technologies of Metaverse are augmented reality (AR) and virtual reality (VR), which provide captivating experiences of the Internet of Things (IoT), and Artificial intelligence (AI), which acts as the brain of Metaverse [2].

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TABLE 1. Comparison of all analyzed papers.

Ref	Paper selection	Key Enabling Technologies	Applications of Metaverse in different domains						Comments
			Medical	Education	Social	Gaming	Industry	Others	
[1]	2008-2022	X	✓	✓	X	✓	✓	X	This study focus on the AR, VR technologies of metaverse and applications
[2]	2008-2022	✓	X	X	X	X	X	X	Discuss the major technologies of Metaverse
[3]	2020-2022	✓	X	X	X	X	X	X	In this paper they discuss the role of blockchain in metaverse
[4]	2018-2022	✓	X	X	X	X	X	X	The author give detail on metaverse technology
[5]	2007-2021	✓	X	X	X	X	X	X	Thi paper discuss the part of different technologies along security and privacy concern
[6]	2008-2022	✓	X	X	X	X	X	X	This paper gives the discussion of role of AI in metaverse with other technologies
[7]	2008-2022	✓	X	X	X	X	X	X	It discuss the role of AR and VR technology in metaverse and their security and privacy concerns
[9]	2014-2022	✓	✓	X	X	X	X	X	Healthcare metaverse discussion along with major metaverse technologies.
[10]	2008-2022	✓	X	X	X	X	X	X	
[11]	1998-2021	✓	X	X	X	X	X	X	Provide a detail on major technologies of metaverse
[12]	1995-2022	✓	X	X	X	X	X	X	Blockchain and AI role in metaverse
[13]	2009-2022	✓	X	✓	X	X	X	X	Discuss educational metaverse and its characteristics
[14]	2009-2022	X	X	✓	X	X	X	X	Focus on the Educational metaverse
[15]	2018-2022	X	X	✓	X	X	X	X	Educational metaverse and its comparison with traditional education
[16]	2018-2022	✓	X	✓	X	X	X	X	This study focus on the training education in different domains like military training, industrial training and Aircraft training
[12]	2017-2022	✓	X	X	X	X	X	X	Role of Blockchain and Artificial intelligence in metaverse
[17]	1992-2022	X	X	✓	✓	✓	✓	✓	This paper discuss the metaverse components and its application in different domain except medical
[18]	2008-2022	✓	X	✓	X	X	X	X	Discussion about education
[19]	2020-2022	✓	✓	X	X	X	X	X	This study discuss the Metaverse technology and its applications in health sector
[20]	1998-2022	✓	X	X	✓	✓	X	X	
[21]	2018-2022	✓	X	X	X	X	X	X	Discuss about blockchain and NFt in metaverse
[22]	2013-2022	✓	X	X	X	X	X	X	Digital twin and metaverse
[23]	1998-2022	✓	X	X	X	X	X	X	Some technologies of metaverse: blockchain, AI, Networking.
[24]	2016-2022	X	✓	✓	✓	✓	X	X	Applications of metaverse
[25]	1992-2022	✓	X	X	X	X	X	X	Different metaverse technologies
[26]	2020-2022	X	✓	X	X	X	X	X	Metaverse in cancer care
[27]	2018-2022	X	✓	X	X	X	X	X	Metaverse in current medical system or Digital health
[28]	2002-2022	✓	✓	X	X	X	X	X	
[29]	2018-2022	X	X	✓	X	X	X	X	Educational metaverse and digital learning
[30]	2008-2022	✓	✓	✓	X	X	X	X	Discussion about AI: Medical education and metaverse in health sector

TABLE 1. *(Continued.)* **Comparison of all analyzed papers.**

[31]	1998-2021	✓	X	X	✓	X	X	X	
[32]	2008-2022	✓	✓	X	X	X	X	X	Technologies of metaverse and major focus on 6G
[33]	2018-2022	✓	X	X	X	X	X	X	Detail discussion of technologies
[34]	2017-2022	X	✓	X	X	X	X	X	Metaverse in medical sector
[45]	1992-2022	✓	X	✓	X	✓	X	X	
[46]	1995-2022	✓	✓	✓	X	✓	X	X	Discuss the detail of AR,VR,XR technologies and some metaverse applications
[47]	1992-2023	✓	✓	X	X	X	X	X	Discuss the role of metaverse in healthcare
[48]	2018-2022	X	X	X	✓	X	X	X	Study describe the Social metaverse in depth
[49]	1992-2022	✓	X	X	X	X	X	X	Study describe the Digital twin role in metaversen
Ours	**2018-2023**	✓	✓	✓	✓	✓	✓	✓	We discuss major technologies of metaverse, Application of metaverse in all domains

Moreover, digital twins (DT) create exact virtual copies of physical objects, whereas blockchain is a base of the Metaverse economic system, and cloud computing is based on data sharing, computing, and storage.

Meta received world recognition when Mark Zuckerberg replaced the Facebook title with Meta on October 2021. This aims to bring technologies and applications under one umbrella and focus on bringing the Metaverse application to life [42]. Metaverse has no boundaries, which helps humans in the education and job sector by providing virtual classrooms and offices. Travelers can experience the traveling of places while at home with its help, and gamers can experience a versatile gaming experience.

The prime focus of this manuscript is to identify the technologies and applications of Metaverse. Due to the popularity of virtual space, numerous studies have been reported in this area, which is gaining importance. Therefore, recognizing and summarizing the most recent developments in the field necessitates a thorough investigation.A comprehensive comparison of our paper with all the other analyzed papers is presented in Table 1. As Table 1 consists of four major columns, each serving a specific purpose. The "Paper Selection" column indicates the analyzed papers and their corresponding review years, providing a range for the selected papers. The "Metaverse Enabling Technologies" column signifies whether each paper discusses any of the technologies related to the Metaverse or not.Moving on, the "Applications of Metaverse" column is further divided into various domains, such as Medical, Educational, Social, Industrial, Gaming, and Others. This division clarifies which domain applications of the Metaverse are discussed in each selected study.Finally, the last column of our table offers comments related to each paper's focus on technologies and applications. This commentary provides valuable insights into the specific technologies and application areas explored in each study.According to our best information, no such study has been conducted. This systematic literature review (SLR) reflects various aspects of the investigation in this field, such as data collection from different research, current challenges, and prospects.

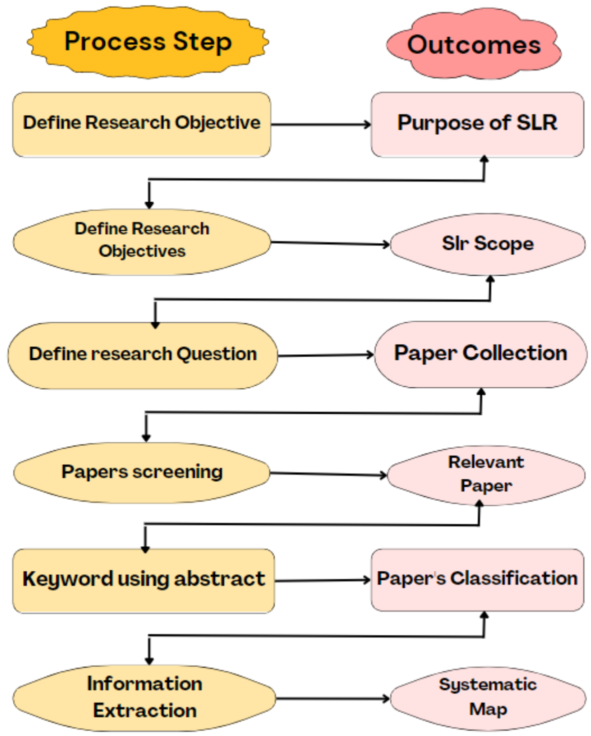

FIGURE 1. SLR process model.

The paper structure in which Section II presents the methodology used in this review, which is devoted to the search strategy, the procedure for selecting relevant articles, abstract-based keywording for article classification, and quality assessment criteria. Section III presents a representation of the analysis and outcomes to consider the retrieved results and offer systematic solutions to research questions. Section IV provides future study directions, while section V concludes the review.

II. RESEARCH METHODOLOGY

This section presents the research methodology, research objective, research questions, search scheme, and search string.

TABLE 2. Research question and major motivations.

	Research Question	Major Motivation
RQ1	What major technologies, algorithms, and tools were utilized in the creation of the Metaverse?	To identify all the technologies that take part in Metaverse development.
RQ2	Development of Metaverse application across different domains	To explore the Metaverse application in various industries
RO3	What are the key gaps and challenges that should be addressed to create a successful Metaverse	To determine the gaps and obstacles

A. RESEARCH METHODOLOGY

This study adhered to the SLR criteria established by [35] in 2004 to gather data objectively and present the analysis and extraction outcomes. Figure 1 illustrates the research technique employed for this SLR. This rigorous and thoughtful evaluation process consists of six stages: 1) Defining the research objectives; 2) Formulating the research questions; 3) Developing a search strategy; 4) Screening and selecting papers; 5) Utilizing keywords to categorize papers; and 6) Synthesizing and extracting information.

B. RESEARCH OBJECTIVES (RO)

This study's primary objectives are as follows:

RO1: The primary focus is to recognize the high technologies, tools, and algorithms used in the creation of Metaverse

RO2: Development of Metaverse applications in different domains.

RO3: To identify the gaps and challenges in the domain.

C. RESEARCH QUESTIONS (RQ)

The primary research questions have been identified to begin carrying out this SLR in an efficient manner. In addition, a thorough search strategy for the review's identification and extraction of the most significant articles has been developed. The major motivations for the research questions discussed in this review are listed in Table 1. The questions are addressed and answered using the well-defined procedure described in [35] and [36].

D. SEARCH SCHEME

The most important part of SLR is making a search strategy to properly find and collect potentially important articles in the chosen field. This process includes the description of a search string, the literature resources used in the search, and the plan for finding the most relevant articles from the collection through segregation (inclusion/exclusion). To represent various research perspectives, qualitative and empirical evaluations of numerous aspects of the collected articles were used.

TABLE 3. Terms and keywords used in the search.

Terms (Keywords)	Synonyms / Alternate Keywords
Metaverse	Virtual World(VW), Digital world(DW)
Technologies	Modern Technologies(MT), AI, Blockchain(BC), Networking(NT), IOT,
Applications	Medical (MD), Education (EU), Gaming(GM),

TABLE 4. Publisher-wise search string.

Repository	*Search Strings*
ArXiv	((METAVERSE) AND (TECHNOLOGIES OR ENABLING TECHNOLOGIES) AND (APPLICATIONS))
Science Direct	((METAVERSE) AND (TECHNOLOGY))
IEEE Explore	((METAVERSE OR INTERNET 3.0) AND (TECHNOLOGIES OR BLOCKCHAIN OR AI OR NETWORKING)) ((METAVERSE) AND (APPLICATION OR EDUCATION OR MEDICAL))
MDPI	((METAVERSE OR METAVERSE TECHNOLOGY) AND (ENABLING TECHNOLOGIES OR BLOCKCHAIN) AND (APPLICATION OR EDUCATION OR MEDICAL OR GAME))
PUBMED	((METAVERSE) AND (MEDICAL OR APPLICATION))

1) SEARCH STRING

To track down important papers for this examination, a total request has been directed utilizing indicated words (catchphrases) furthermore, strings utilizing different computerized data sets. The principal ideas what's more, their equivalents are utilized to view as genuine and related articles. Table 2 includes a mention of the final words.

Using the "AND" and "OR" operators, the selected keywords and alternative terms that corresponded to them were combined to create a search string. The wildcard character "*" was used to represent zero or more characters in some instances. By concatenating the terms with the "AND" operator, the search options were defined and the query was refined to produce relevant search results. Then again, the "OR" administrator was utilized to give strengthening search choices.

The finished search string comprises three parts. The first part aims to retrieve results related to Metaverse or its related terms. The second part focuses on Metaverse technologies, while the last part pertains to studies related to Metaverse applications in different domains. The mathematical formulation of the search string is presented in the first equation.

$$R = \forall[(MT \vee VW \vee DW) \wedge (MT \vee AI \vee BC \vee NT \vee VIoT) \wedge (APP \vee MD \vee ED)] \quad (1)$$

The search results obtained by using the search string are represented by "R" in equation (1). The letters "" denote the "OR" operator, "" denotes the "AND" operator, and "" denotes the "for all" operator. These administrators are utilized related to the pursuit terms recorded in Table 2 to build the total quest string for each chosen vault. Equation (1) can be used to formulate the general search term, which can be expressed as:

((Metaverse OR digital World OR Virtual Space) AND ("Technologies" OR "AI" OR "Blockchain" OR "Networking" OR "IOT") AND ("Applications" OR "Medical" OR "Education"))

2) LITERATURE RESOURCES

To conduct the literature search, we selected reputable journals and conferences that were relevant to the topic from various online publishing and collection sources. Table 3 provides details about the selected repositories, the keywords used for the search, and the obtained results.

3) INCLUSION AND EXCLUSION CRITERIA

Parameters defined for inclusion criteria (IC) are:

- IC 1) Contain studies that were primarily conducted for technologies and algorithms and methods used in Metaverse.
- IC 2) if the study was targeting applications of Metaverse.

The exclusion criteria used to all publications were designed to remove studies that did not involve lab-based research and included the following points:

- EC 1) If the study does not involve the technologies used in Metaverse and its application.
- EC 2) If the study does not discuss applications of Metaverse in different domains.
- EC 3) If the study is not in the English language.

4) SELECTION OF RELEVANT PAPERS

The search period for this study was from January 2018 to January 2023 to ensure relevance. The primary search process produced numerous research articles, but not all of them were explicitly relevant to the study topics, and several were duplicates. Therefore, to obtain truly significant papers, the searched papers had to be reevaluated and screened. We followed the procedure described in [37] to determine the relevance of the articles and conduct the screening.

In the screening phase, the first step was to eliminate any papers that did not have the appropriate keywords in the title and to remove duplicate searches from different repositories. Since there were many papers in the intended area, and many of them were irrelevant to the subject being discussed, they were excluded from the outset. Continuing with the process, all abstracts were carefully screened. After the inclusion process, papers that did not provide definitive or concrete evidence regarding Metaverse technologies and applications were discarded using the exclusion criteria. Final assessments were conducted on the papers selected through the preceding procedure.

5) ABSTRACT-BASED KEYWORDING

To obtain relevant papers, further filtering and categorization were performed. The abstracts of the papers were analyzed to gain an understanding of their major contributions. Important keywords were identified and used to review the articles. The selected 35 articles were then classified into two major categories: Technology-based (TEC) and application-based (MED/EDU or APP).

TABLE 5. Questionnaire to assess the quality.

Sr.	Assessment Questions	Expected Answers	Score
Internal Scoring			
1	Was the abstract well labelled?	a. Yes b. Intermediate c. No	a. 1 b. 0.5 c. 0
2	Was the literature review defined in detail?	a. Yes b. Intermediate c. No	a. 1 b. 0.5 c. 0
3	Was the data collection mechanism clearly defined?	a. Yes b. Intermediate c. No	a. 1 b. 0.5 c. 0
4	Was the feature description/selection defined clearly?	a. Yes b. Intermediate c. No	a. 1 b. 0.5 c. 0
5	Was the methodology section clearly defined?	a. Yes b. Intermediate c. No	a. 1 b. 0.5 c. 0
6	Was the result assessment well described valid and reliable?	a. Yes b. Intermediate c. No	a. 1 b. 0.5 c. 0
7	Is an open access tool, service / API, or web service available for test results on providing a dataset?	a. Yes b. No	a. 1 b. 0
8	Was the conclusion relevant and effectively based on the results?	a. Yes b. Intermediate c. No	a. 1 b. 0.5 c. 0
External scoring (based on publication-source)			
9	A study published in CORE ranked conferences, proceedings, and symposiums.	a. CORE rank A b. CORE rank B c. CORE rank C d. No CORE rank	a. 2 b. 1.5 c.1 d. 0.5
10	A study published in JCR listed ranked journal	a. JCR rank Q1 b. JCR rank Q2 c. JCR rank Q3/Q4 d. No JCR ranking	a. 2 b. 1.5 c.1 d. 0.5

6) QUALITY ASSESSMENT CRITERIA

A comprehensive quality assessment of the selected papers is an important stage in a systematic review because the designs of the research varied, the quality was assessed using the sequential assessment approach outlined in [38]. This approach includes quality evaluation criteria that include all of the important components involved in research [39], such as the concept, study design, data collecting technique, data analysis, discussion, and conclusions. Based on the aforementioned considerations, a questionnaire was designed in conjunction with other authors (see Table 4) to improve the quality of the research. Furthermore, internal and external quality standards were implemented to improve assessment quality, as indicated by [40].

The article's internal quality is assessed using the internal criteria, while the article's external quality is assessed using

TABLE 6. Publisher based stage wise selection process.

Database/Repository	Primary Search	P-I	P-II	P-III	P-IV
PubMed	28	10	6	5	2
ArXiv	103	36	23	16	9
Science Direct	254	25	19	17	10
IEEE Explore	200	37	23	18	14
MDPI	84	15	12	10	5
Other	-	-	-	-	2
Total	**669**	**123**	**83**	**66**	**42**

the constancy and dependability of the publication source. External quality has been evaluated and measured using the ''Journal Citation Reports (JCR)'' and ''Computer Science Conference Rankings (CORE)'' [33]. The sum of each criterion's scores is the total score. The final score can range from a zero to a maximum of ten, and it can be ranked high if it is higher than eight, average if it is between six and eight, or low if it is lower than six.

III. DATA ANALYSIS

This section presents a compilation of the results and provides a clear evaluation of all the selected articles. The articles were carefully examined to effectively address the research questions. The first part of this section discusses the search results obtained through the defined search string. This is followed by a description of the assessment score, and the final part is dedicated to comprehensive discussions to answer the research questions.

A. SEARCH RESULTS

Most papers in the field of Metaverse technology require a specific dataset to be incorporated into the computational models or frameworks they propose. A total of 669 articles were retrieved from various online data sources during the primary search process. The selection procedure outlined in the previous section was applied to this collection. Figure 2 provides a description of the selection process phases and the outcomes at each phase.

During Phase I (P-I), title-based selection was conducted by two authors, resulting in the identification of 123 publications. In Phase II (P-II), duplicate articles were eliminated, and domain-unrelated articles were screened using the inclusion and exclusion criteria outlined in the previous section. In Phase III (P-III), abstract-based screening was performed on the 83 publications that passed the previous phase. In Phase IV (P-IV), full-text analysis was conducted on 66 publications, of which 35 were selected for inclusion in this systematic literature review for data extraction and analysis.

Table 3 shows the highly recognized digital libraries (DL) used to select studies for this systematic literature review, which publish research studies for various journals, conferences, and workshops. Figure 3 depicts the DL-wise distribution ratio of the selected articles, with Science Direct having the largest percentage at 30%, followed by IEEE

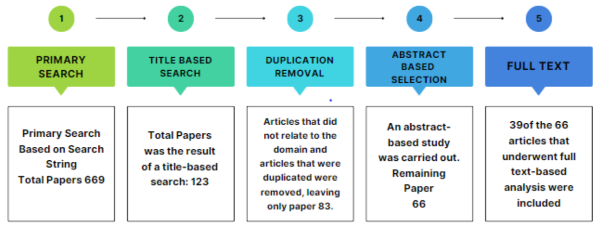

FIGURE 2. Paper selection procedure.

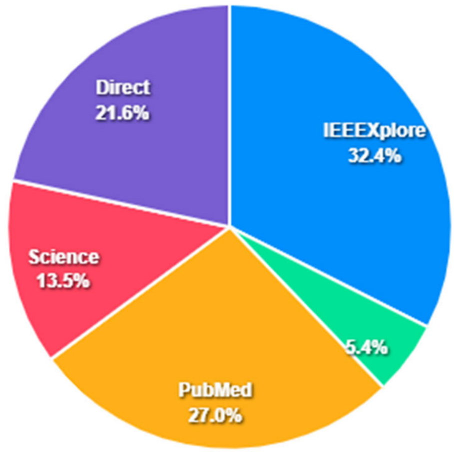

FIGURE 3. The DL-wise proportion of chosen examination.

Xplore at 32.4%, ArXiv at 21%, MDPI at 15%, and PubMed at 6%. Table 5 shows the distribution ratio and selection status of the selected research based on the publication date.

B. QUALITY ASSESSMENT SCORE

Each selected research was awarded a score using the scoring system outlined above, and it was evaluated using the internal and external criteria indicated in Table 6. Internal and external criteria scores are marked by the letters I-Score and E-Score, respectively, while the publication type is denoted by the letter P. Type. According to the criteria, four articles earned a score more than eight and were classed as high-ranked, eight had an average rank, and four (10%) were labelled as low rank. These facts are depicted in Figure 4, indicating a high degree of trust in the quality of selected publications. Nonetheless, no quality-based exclusion was carried out.

C. ASSESSMENT AND DISCUSSION OF RESEARCH QUESTIONS

The thirty-five key papers were analyzed in this section based on the research questions listed in Table 1. The facts retrieved from the relevant research were addressed using questions for evaluating fragmentary information.

1) ASSESSMENT OF QUESTION 1. WHAT ARE THE MAJOR TECHNOLOGIES, ALGORITHMS, AND TOOLS UTILIZED IN THE CAND REATION OF METAVERSE?

Technologies that enable the creation of Metaverse are listed here. This includes augmented reality, Virtual Reality, Mixed

TABLE 7. Quality assessment score and classification table.

Ref. No.	P. Type	Category	I-Score	E-Score	Total Score
[1]	Journal	TEC	7	2	9
[2]	Journal	TEC, APP	7	2	9
[3]	Conference	TEC	7.5	0.5	8
[4]	Conference	TEC	7.0	0.5	7.5
[5]	Conference	TEC	6.5	1.5	8.0
[6]	Journal	TEC	5.5	0.5	6.0
[7]	Journal	TEC	6.0	0.5	6.5
[9]	Journal	MED, TEC	6.5	2	8.5
[12]	Journal	MED	4.5	2	6.5
[17]	Journal	TEC, APP	5.0	2	7
[18]	Journal	EDU	5.5	2	7.5
[19]	Journal	EDU, MED	6.0	1.5	7.5
[20]	Journal	TEC	7.5	2	9.5
[21]	Journal	TEC, APP	5.5	0.5	6.0
[22]	Journal	TEC	6.0	0.5	6.5
[23]	Journal	TEC	5.5	0.5	6.0
[24]	Journal	TEC, APP	6.0	2	8.0
[25]	Journal	APP	7.0	2	9.0
[26]	Journal	APP, MED	5.5	0.5	6
[27]	Journal	MED	6.0	0.5	6.5
[28]	Journal	MED	6.0	0.5	6.5
[30]	Journal	TEC, MED, EDU	5.5	0.5	6
[32]	Journal	TEC	7.0	2	9
[33]	Conference	TEC	5.5	0.5	6
[34]	Journal	MED	5.5	2	7.5
[29]	Journal	EDU, APP, TEC	6.0	0.5	6.5
[45]	Journal	TEC,APP	6.0	2	8.0
[46]	Journal	TEC	6.0	2	8.0
[47]	Journal	APP	7.5	2	9.5

Reality, AI, Blockchain, IoT, and many more. These technologies are used to create an immersive and interactive experience where people can expand their social circle by interacting with one another, fix their jObs, buy property and do many more. Some technologies are used to create virtual education, virtual market, virtual offices, virtual gaming, and virtual tourism.

The utilization of Artificial Intelligence in the Metaverse can possibly reform the manner in which we cooperate and draw in with virtual conditions. With progressions in artificial intelligence advancements, the Metaverse can give clients more customized and vivid encounters that adjust to their inclinations and ways of behaving. Computer based intelligence can likewise empower the production of additional reasonable and clever virtual symbols, which can impart and communicate with clients in a more regular and human-like manner. Besides, simulated intelligence can work with the advancement of insightful menial helpers and robotized frameworks that can help oversee and improve the client experience inside the Metaverse. Accordingly, the combination of simulated intelligence in the Metaverse has immense potential for improving the general client experience and opening up additional opportunities for virtual communication and commitment. Artificial intelligence can produce content on a large scale and continuously for Metaverse due

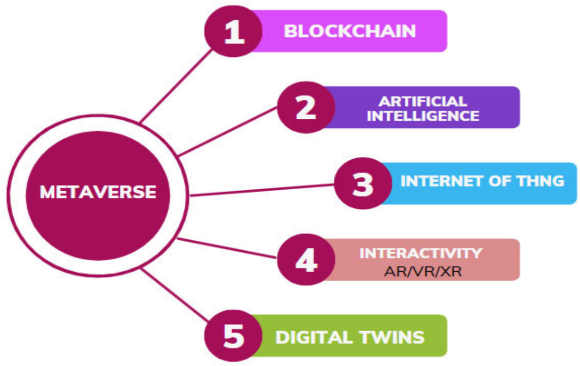

FIGURE 4. Metaverse technologies.

to the large amount of content produced in this digital world. AI has been used for decision-making, strategy planning, and face recognition and in many more applications [1]. In Metaverse AI algorithms provide 3D or 2D creation like Avatar [2]. Studies say that AI can predict users' movement in virtual space and provide customized services like customized avatars and also empower smart interaction, and smart Shopping guides [3]. The Metaverse foundation and growth would be greatly influenced by AI, as would the provision of immersive user experiences [23]. Running the Metaverse and automating a variety of processes will rely heavily on artificial intelligence (AI) technology. AI technology includes Machine learning (ML), Deep Learning, Computer vision, and Natural Language processing [7]. Machine learning provides support to all the Metaverse systems so that they exceed the limits of human learning. It affects the operations efficiency and intelligence of Metaverse [12]. AI plays various roles in the Metaverse such as Object detection, Speech and text processing (speech-to-text and text-to-speech), Generating content for virtual space, and action recognition. AI can potentially aid in the detection, prevention, and recovery of cyber assaults in the Metaverse [32]. AI learns from experience just like humans, and based on experience it performs a different task and also mimics the human brain. The most important technology that will aid in the realization of the concept of the Metaverse is artificial intelligence (AI). The key to connecting the two worlds is Artificial Intelligence, it also helps the Metaverse to participate freely and safely in both economic and social activities [9].

In 2008, Nakamoto Satoshi [41] introduced blockchain, also known as a distributed ledger, which is made up of blocks linked to each other and having the same hash value as the header of the previous block. Its advancements can play a critical role in the Metaverse by providing a decentralized and secure environment for transactions and data management. Blockchain can enable the creation of digital assets and currencies that can be traded and exchanged within the Metaverse. With improved network security, blockchain technology manages all interactions between the physical and virtual environments [9] and records every interaction to keep track of everything. It plays a dual role in the Metaverse by providing a decentralized database accessible by anyone, anywhere in the Metaverse. It is the building block of the Metaverse economic system that connects the real world with the virtual space. Key blockchain technologies like smart contracts, NFTs, DAOs, DeFi, and dApps can be used to create economic, financial, and governance systems in the metaverse [54].

Blockchain helps to improve the quality of data gathered in the Metaverse by applying verification checks [4]. Metaverse collects and stores various amounts of user data, including sensitive information, which requires high storage capacity that is usually expensive [11]. Blockchain provides a distributed database for data storage and ensures data protection, security, and transfer of virtual assets. Therefore, blockchain has the potential to enhance trust and transparency within the Metaverse and enable new business models and revenue streams. Blockchain users can collaborate to validate and record transactions and create data blocks. Cross-chain Protocol of blockchain aims to enable easier interaction, data sharing, and resource movement between blockchains. Cross-chain protocols can facilitate mass adoption and eliminate the need for intermediaries in blockchain connections, enhancing efficiency [3].

Blockchain also allows digital asset ownership, digital payment, and accessibility in the Metaverse. Cryptocurrency is used as a digital currency in the Metaverse, and Bitcoin is the most popular cryptocurrency. Blockchain facilitates bitcoin transactions and records them in consecutive blocks to prevent double-spending. Products or assets can be bought and traded in the digital world using cryptocurrency. Blockchain helps support massive storage, sharing, and privacy of data for Metaverse users [25].

In the present age, many applications have been built on decentralized architecture to avoid single points of failure. Blockchain provides decentralized architecture to the Metaverse and offers other services like NFT and De-Fi. NFT (non-fungible token) is an indivisible and irreplaceable token that helps identify and verify ownership of assets or property [3]. NFT is immutable, meaning no one can erase, destroy, or manipulate the recorded data [6]. Another study suggests that NFT also helps in virtual certification [21]. When a buyer purchases a digital property, a private digital key password is issued, which can be used to verify that the buyer has a specific digital asset [32]. De-Fi offers secure financial services.

In the Metaverse, a Digital Twin refers to the virtual representation of physical objects. It serves as the digital counterpart to the real world and creates an accurate copy of any physical object [3]. In other words, it creates a digital replica of a real-world object in the virtual space, with the help of comprehensive mathematical modeling, simulation modeling, experimental modeling, and data-driven modeling [53]. Digital twins consist of three main components: the real object, the virtual equivalent, and the data connection between the real and virtual worlds [9]. By creating Digital Twins, we can examine the entire life cycle of physical substances and processes, seamlessly transfer data between the virtual and real worlds, and achieve real-time and bidirectional information feedback. A study describes the process of data gathering in a digital twin system, from micro-level data collected through microscopes, to regional images from panorama cameras, to satellite observations of the Earth and beyond. This data is used to create digital twins. Content creation, review, and appearance are integral parts of the services provided by the Metaverse, with content being a crucial element in creating a virtual world that is either similar to or even better than the real world [22]. To achieve this, the Metaverse requires a large amount of data simulation and powerful computing power. The digital twin (DT) serves as the central component of this virtual world, and is the bedrock of the Metaverse [10]. The digital world based on distributed technology (DT) offers a comprehensive platform that encompasses avatars, businesses, retail markets, and manufacturing facilities, providing high-accuracy industrial capabilities. This digital environment efficiently caters to the daily needs of both individuals and managers, enabling remote and cost-effective operations. Notably, Duan et al. introduced a three-layer architecture for the Metaverse in their work, focusing on a general model [49]. the Metaverse is a virtual, interconnected digital universe, providing immersive experiences and interactions, while a Digital Twin is a virtual replica or representation of a physical object or system, primarily utilized for monitoring and optimization purposes. Sensors in virtual models actively transmit data about their function and environment to their digital twins in real-time, allowing for an accurate representation of real systems or objects. Any modification made to a physical system or object alters the digital representation, and vice versa. Therefore, the Metaverse needs Digital Twins to create a realistic environment and provide an immersive experience.

AR/VR/XR technologies are crucial components of the Metaverse because they offer users a highly immersive and interactive virtual world. Extended reality (XR) is a blend of augmented reality (AR) and virtual reality (VR) [46]. These technologies form one of the technical pillars in the construction of the Metaverse [34]. The term "Extended reality" was first used in 1960 and includes all virtual and real environments [7]. Basically XR is a medium that connect avatar to user in metaverse and user to avatar in real world [17]. Extended Reality also benefit in profiling users identities or personal information like gender [46]. Meta (Facebook) considers VR technology to be the building block of Metaverse development [9].As humans require devices to access the Metaverse, such as mobile phones and computers, Oculus to connect through the internet, XR devices are the primary terminal for entering the Metaverse [3].

Virtual reality creates a realistic environment for users to communicate with each other, regardless of physical distance [5]. It allows users to view the world from a different perspective. VR is a completely separate, artificially generated digital world where users feel as though they are in a different world and can interact as they would in real surroundings [8]. Virtual environments enable users to create VR paintings and interact with virtual entities, such as changing the shape of a virtual object or creating new artistic objects, which can be used to study user affordance. In such virtual environments, multiple users can collaborate in real-time, fulfilling the clear requirements of virtual environments, such as a shared sense of time, presence, and space [28].VR devices help users interact and consist of a combination of software and hardware. Software components include head-mounted displays, VR glasses, VR helmets, motion input, and base input devices. Hardware components include scene and object recognition, creation software, and sound and speech recognition [9]. VR technology provides users with an immersive experience using a head-mounted display. With the help of software and hardware, users can immerse themselves in a 3D virtual world and enjoy the freedom of movement in a digital world.

Another technology that has transformed the world is augmented reality, which enhances users' real-world views. In Augmented Reality user is present in the physical world and there is no need for any special headset [1]. In the Metaverse, AI and AR aid in image classification, speech and face recognition, and data processing. Importantly, the AR base system works for all five senses. It add digital elements to the real world by using a devices like camera or smartphones and there is no need for a special gadgets like Head mounted displays or any glasses. Or in other words we can say AR display different digital content in the real world. In augmented reality user are present in physical world [1]. AR provides a genuine presence experience and allows users to see digital objects in real space, while VR offers an immersive experience, enabling users to enter the processed world through headsets. Mixed reality combines physical and virtual spaces to provide interactivity of three dimensions: Humans, Environment, and Computers

Mixed reality (MR) combines the immersive virtual environment of virtual reality (VR) with the overlay of virtual content in augmented reality (AR), allowing users to interact with virtual objects within a 3D environment. AR provides a realistic solution using simple hardware like glasses, offering a reflection of reality, but it is more suitable for shorter content. Conversely, VR provides a fully immersive experience, covering the entire field of view, and is better suited for long-term content, albeit with potential physical fatigue. MR, leveraging a blend of these advantages and disadvantages, is considered a solution that can transition between AR and VR using a single device. Extended reality (XR) is an encompassing term that includes VR, AR, and MR, and is used in applications such as virtual commerce (v-commerce) to create computer-mediated indirect experiences [46]. Mixed Reality (MR) is an additional technique that breaks free from screen limitations and significantly enhances user immersion. Unlike creating a fully virtual environment, MR emphasizes the seamless interactions between the real world and the digital space, allowing for instinctual engagement [23].MR is also used for hand tracking, eye tracking, spatial mapping, and speech output, allowing users to interact with objects in the virtual world [6].

The integration of 5G, 6G, and IoT technologies into the Metaverse will provide unprecedented levels of connectivity and data processing. 5G networks will provide high-speed internet access and support services such as streaming media, gaming, and virtual/augmented reality. 6G networks will provide increased bandwidth and capacity to support ultra-high-speed data transmission across multiple devices, enabling the expansion of the Metaverse. A study of [32] provided information that 6G will give users near-zero-latency sensory connectivity experiences in virtual engagement, such as the user's virtual mobility in the Metaverse, virtual meetings, virtual artwork, and other interactive, immersive holographic experiences. 6G also provides high-speed connectivity, transparency, high bandwidth, and reliability. IoT technologies will enable the Metaverse to incorporate vast amounts of real-time data from connected devices, increasing the depth and breadth of the virtual world. Together, these technologies will enable the Metaverse to become an ever-evolving, immersive experience that can be enjoyed by all.

The Internet of Things (IoT) is a rapidly growing technology that connects physical objects to the web and allows them to interact with each other and users in the virtual world or Metaverse. As more objects are connected to the web, the Metaverse is becoming increasingly interconnected, transforming the way we interact with our environment. IoT creates a link between the real world and the internet with the help of gadgets and sensors. It gathers data from the physical world and transfers it to the Metaverse to provide services to users [1]. IoT will be crucial for connecting the real human world to the virtual space (Metaverse). It obtains data from the physical world to enhance physical reality [7]. A vast network of objects helps build connections, process data, and transfer data [2]. IoT provides a wide range of technologies for connecting and communicating with a large number of devices, including smartphones, smartwatches, and healthcare devices. These technologies include sensors, wireless networks, and nanotechnology [9]. IoT allows for the collection of real-time data due to its access to a vast number of sensors and IoT devices implanted throughout the physical world [33]. IoT is transforming human lives and making things easier for us. IoT is also an integral part of the Metaverse economy. IoT devices are used to gather and observe the physical status of an object, which helps VSPs synchronize digital twins. The most common task IoT performs in the Metaverse is data collection and availability [5].

BCI, also known as a brain port, is a direct connection between the brain and external equipment. The development of BCI technology in the future will make it possible to track, record, and share human thoughts. Robots, as physical simulations, have the potential to enhance human capabilities in the real world and serve as an additional means of connecting to the Metaverse [23]. With the help of brain waves, users can control their avatars in the Metaverse [5]. Using brain implants and technologies such as Neuralink, BCI seeks to acquire the senses of touch and smell in the Metaverse. It is a neural network designed to collect electrical signals from the brain waves and convert them into meaningful inputs for external computers or apparatus. The value of the Metaverse to humans is directly impacted by the boundary of human senses, which is determined by its performance level. In the near future, it will be possible to control objects with brain waves in the Metaverse [15].

2) ASSESSMENT OF QUESTION 2. DEVELOPMENT OF METAVERSE APPLICATIONS ACROSS DIFFERENT DOMAINS

Metaverse applications are quickly gaining popularity across many different domains. They provide a unique platform for users to interact with 3D virtual environments realistically and engagingly. From gaming and entertainment to education and business, Metaverse applications are being used to create immersive experiences that are far beyond what was previously possible. With the ability to connect and interact with others in a virtual world, these applications offer an exciting new way to explore and interact with digital content. Here we discuss some applications of Metaverse in different domains.

- **Gaming:** Games are one of the most popular applications in the Metaverse.Virtual environments are being utilized in the game development field to create immersive and captivating experiences [24]. Hide and Seek, a blockchain-based game, has been introduced as a simple and effective simulation environment suitable for multi-agent work [17]. In addition, Stanica et al. introduced the Immersive Virtual Reality Neurorehabilitation System (INREX-VR) for neurorehabilitation exercises that use virtual reality. They capture real-time user movements to execute complex movements in a gamified environment [5]. The gaming industry has been a fertile ground for the development of the Metaverse and its applications. Companies such as Roblox Corp., Epic Games Inc., and Active Worlds Inc. have created fully digitalized virtual environments where players can create avatars and engage in active gameplay with other players. Popular games like Second Life and World of Warcraft have contributed to the growth of the Metaverse [20], [21]. Roblox and Fortnite are also among the most popular applications of the Metaverse. In addition, Stanica et al. introduced Neurorehabilitation Exercises Using Virtual Reality (INREX-VR), a blockchain-based game that captures real-time user movements and executes complex movements in a gamified environment to encourage competition and self-improvement [43]. Some other popular games are Second-Life: in which players can do anything by the use of avatar in the virtual world from job seeking to getting married. Plyer can customized their environment. The other one is Minecraft: In rhis game User can generate or build any structure using 3D cubes. VR device Oculus Rift can be used to play the game [45].
- **Healthcare:** Ensuring the general physical, social, and mental well-being of the global population is a crucial factor, with healthcare being one of the most significant components. Digital healthcare has played an instrumental role in catalyzing change in the healthcare sector. The COVID-19 pandemic has been the driving force behind the rapid transformation of the healthcare system [12]. The interaction between patients and doctors has been impacted by digital health, aided by blockchain, AR, and VR technologies. These modern tools have helped explore new, cost-effective ways of delivering treatment and enhancing patient outcomes. Furthermore, physicians can diagnose diseases and plan treatments more efficiently using these technologies. Plastic surgery is a complex procedure, involving the reconstruction of human body parts. The use of VR in Metaverse is a critical aspect in this area. Surgery on a virtual avatar can predict the outcome of the procedure [9]. Additionally, virtual reality technology can be employed in surgery, physical therapy, stress and pain management, cognitive rehabilitation, and more. Follow-up consultations and visits can be conducted virtually by a cardiologist or a cardiac surgeon to monitor disease progression and discuss exam results [34].
- Virtual reality (VR) and augmented reality (AR) are emerging technologies with promising applications in neurosurgery, particularly for the training of neurosurgical trainees. VR- and AR-based simulators provide a low-risk setting for trainees to practice technical skills, improve their understanding of operative anatomy, and enhance surgical techniques. These technologies have the potential to revolutionize neurosurgical training by providing more efficient and impactful educational experiences [52].Metaverse can also support diagnostic and surgical procedures. Telemedicine services, as well as home-based wearable sensors and smartphone applications, can be used by physicians in the Metaverse to monitor their patients' health in a 3D virtual clinic. By connecting the digital and real worlds, it is possible to monitor health conditions directly from home. Smartwatches are a widely accepted tool that monitors heart frequency, blood saturation, and physical performance. Avatar nurses or virtual nurses can interact with patients and monitor their care [19]. Metaverse healthcare professionals can accompany patients to specific, individualized environments to improve treatment efficacy. Metaverse blockchain can be utilized to protect patient data in the healthcare industry, increasing the record's security for the patient. The patient's data is immutable once it is stored on the blockchain, and it can be expedited, lowering the cost of patient care and aiding in the management of electronic medical records [9].
  Furthermore, the Metaverse provides facilities for data exchange, integrity, interoperability, and data security. For example, if a physician needs a patient's CT scan, the radiologist can share the report on the patient's

TABLE 8. Metaverse technologies in health sector.

Technology	*Role in Health Sector*
XR Technology	In the Metaverse, XR reaches its full potential, enabling immersive experiences and virtual presence. In healthcare, the COVID-19 pandemic has accelerated the adoption of XR for virtual telemedicine and diagnosis. The Metaverse with XR offers medical students realistic 3D environments to learn and practice, while surgeons can visualize and enhance their skills using XR representations of patients' bodies. XR in the Metaverse also enables remote therapies and secure access to health records for improved healthcare. However, challenges such as data security and cost of implementation need to be addressed to ensure widespread accessibility and effectiveness of XR technologies in healthcare
Blockchain	Blockchain-enables metaverse to deliver patient data to doctor accurately and provide data security to patient sensitive information from being modified, temper and attacked. In the Metaverse, patients will have more choices and a more helpful climate for speaking with specialists
Artifical Intelligence	The health industry is embracing progressive methods like XR, big data, artificial intelligence, and the Metaverse to work on clinical gadgets' viability, diminish medical services costs, upgrade activities, and increment admittance to clinical consideration. AI aids in the analysis of patient data for diagnosis, while the Metaverse enables immersive learning and the sharing of health data with doctors. Computer based intelligence, joined with the Metaverse, furnishes specialists with top notch 3D pictures and sweeps for mediation. It additionally offers vital experiences, focuses on basic patients, limits mistakes in examining electronic wellbeing records, and helps in exact judgments. The coordinated effort of the Metaverse and AI further contributes to drug discovery, disease forecasting, and emergency response.
Internet of things	The IoT-enabled Metaverse has revolutionized healthcare through remote patient monitoring. Vital health metrics can be automatically collected by IoT devices and displayed in the Metaverse's 3D environment, eliminating the need for physical visits. Nanobots deployed in the body can be monitored in the virtual 3D environment, enabling surgeons to perform complex procedures and reducing the invasiveness of surgeries. The collaboration of the Metaverse and IoT also improves chronic disease management, sleep cycles, medication refills, and health emergency alerts.
Digital Twin	By creating a digital twin of the hospital in the Metaverse, operational strategies, staffing, and care models can be assessed, leading to improved patient treatment, cost management, and staff performance. The virtual models in the Metaverse aid in addressing issues like bed shortages, pathogen transmission, doctor scheduling, and operating room availability. Additionally, the digital twin-enabled Metaverse allows for virtual simulations of surgical procedures, enabling safer and more efficient brain and heart surgeries, as well as personalized artificial organ creation. This technology is crucial for making strategic decisions in the complex and sensitive healthcare environment.
Brain Computer Interaction	In the Metaverse, wearable head-mounted displays (HMDs) and haptic wearable devices enhance visual and sensory interactions. These HCI technologies enable users to communicate, experience touch, smell, and taste, and perform tasks remotely with the help of robots. Holographic building, emulation, and integration, along with XR inter-connectivity, further enhance healthcare in the HCI-enabled Metaverse. Medical education, research dissemination, improved consultation, accurate diagnosis, and better treatment are facilitated. Users benefit from various medical services such as prevention, tele-healthcare, diagnosis, rehabilitation, chronic disease management, in-home care, and surgical procedures performed remotely through robotic assistance in the realistic Metaverse environment

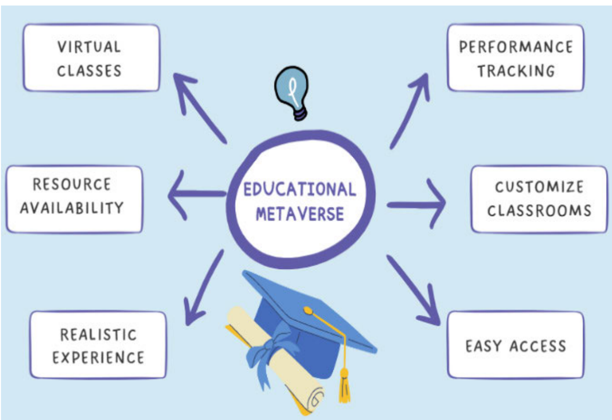

FIGURE 5. Educational metaverse.

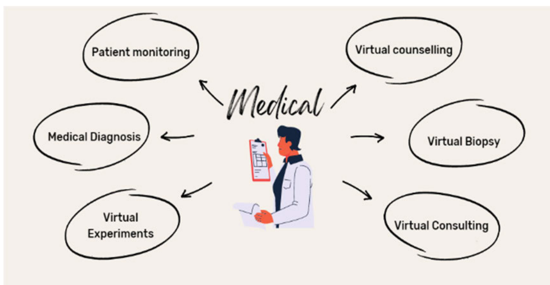

FIGURE 6. Metaverse application in medical.

blockchain, thus making it accessible to the doctor. In the Metaverse, several clinical applications merit consideration, including healthcare, physical examination, self-care, disease diagnosis and treatment, drug and device therapy, surgical treatment, hospital management, pharmacy, quality control in medicine, and disease prevention. Johns Hopkins removed a cancerous tumor from a patient's spine using augmedics [25]. Metaverse technology Digital twin helps to assist individuals in monitoring their health and identifying potential issues early, allowing them to take necessary actions and possibly halting the progression of their condition. Using data from various sources, such as sensors that continuously collect data from the human body, electronic health records from medical institutions, and others, a digital twin can be constructed [28]. The Metaverse, with the use of VR technology, can help in remote health monitoring, clinical data collecting, and enhanced robotic surgery [32]. When the virtual medical environment achieves the level of holographic construction and simulation and is infinitely close to the genuine medical environment, VR will be able to provide patients and physicians with a completely immersive medical experience. Advanced medical devices, such as Holographic lenses (HoloLens 2), human sensors (Reskin), organoids, and organ chips, bring users a meta-medical experience. In 2020, the neurosurgeons in the Johns Hopkins Hospital performed a surgery using AR headset developed by Augmedics. Indepth role of metaverse technologies in Healthcare is discuss the **Table** [47]. Through 3D imaging, doctors, particularly surgeons, can use augmented reality visualization tools to explain complex medical phenomena patients [27].

- **Education:** The Metaverse and its components offer excellent opportunities to develop novel strategies and methods for improving educational standards [18].

Through the educational Metaverse, experts in the field, universities, or governments can organize cost-effective health education programs that can be accessed online and remain available for an indefinite amount of time, reaching people all over the world at any time [19]. Key methodologies like Machine Vision and Neural Interfaces can play vital roles in educational metaverse [51]. Physical and behavioral education programs are practical examples of elements that can be included in distance learning. Jon Radoff suggested co-creating an existing term for both instructors and students to study together and produce a solution that can enhance society [13]. Teachers and students collaborate to create and improve learners' cognitive behavior, gain scientific information, scientific attitudes, and scientific abilities, and apply the value that corresponds to the usage of this talent, continuing to contribute and lead the trend [13]. The Metaverse concept has also been widely used to incorporate teaching activities into classroom instruction since 2022. As a collection of comprehensive human knowledge, the Metaverse also enables anyone to learn at any time and from any location, not just in the classroom. Authentic Metaverse learning will need to provide students with tasks, boost learning motivation, and maximize learning [14].

- **VR Technology and Educational Metaverse:** The Digital Media Department introduces Meta Oculus VR headsets for virtual reality courses, creating a new learning paradigm. These headsets enable students to generate digital avatars for class. Although the Meta Horizons Workrooms platform is in beta, it shows potential for improving virtual classrooms. To ensure effective usage, an onboarding process is developed to help students and instructors understand the technology, particularly for larger classes. While this virtual learning space offers exciting opportunities, it presents challenges. The platform is still in development, and questions arise about the effectiveness of tools like a virtual projector in simulating a traditional classroom. Moreover, there are concerns about students experiencing VR fatigue. Nonetheless, students are enthusiastic about avatars, VR headsets, and participating in virtual discussions [50]. In Decentralized Metaverse Education, learning materials are not created by one person or a specific group of people, but rather through the participation of all users. This enhances the quality of educational materials by incorporating diverse perspectives. Unlike traditional education systems, anyone in the Metaverse can create various digital knowledge materials and products. In this paragraph, we discuss some of the major characteristics of virtual education in the Metaverse. According to recent research, the educational process is well-organized, with a proper management system in place to handle interactions between teachers and students. The virtual education system is divided into two categories: Personal Teaching Environment (PTE) and Personal Learning Environment (PLE). In PTE, the main character is the teacher or knowledge sharer, who uses network tools and services to share their knowledge. Visitors are free to download learning materials and contribute their own work. Virtual educational spaces are easily organized through the cloud on the internet. It is a good practice for learners to maintain and build their PLE themselves, enabling continuous learning for everyone. Exposure to the latest information and communication technologies has caused a shift in educational spaces from offline to online, leading to updates in educational methods and teaching systems. The virtual educational system strengthens learners' memorization and understanding, and teachers can easily share information using available templates and tools [15].Metaverse education offers a unique opportunity to experience and conduct experiments that would be dangerous or impossible in real life, such as exploring radiation. Many people study Metaverse education, examining the pros and cons of multi-user virtual environments for education and demonstrating how to interact and generate content for higher education. Metaverse is utilized in the problem-based learning (PBL) method, and studies suggest that learners will be more effective in a realistic environment. Additionally, Metaverse helps students to visualize biological cells and molecules and easily conduct physics, chemistry, and other experiments at a low cost. The best part is that there are no time limitations in Metaverse Education, and academic publications can be easily tracked and monitored during distribution and publication using blockchain technology [17]. The primary purpose of educational Metaverse is to prevent student data loss and allow teachers to organize classes and project work. Metaverse provides a highly impactful educational experience [29] and helps medical students visualize body organs or parts of a live person. With 3D visualization, professors can easily teach aspiring cardiologists about the inner workings of the heart and the cardiovascular system [9], [19].
- An important aspect of modern industries, particularly after the Fourth Industrial Revolution, is the sustainable evolution of industrial infrastructure in terms of design and employee training. The Metaverse and associated technologies have improved employee training in industries, providing workers with hands-on experience in a risk-free setting. Metaverse education helps in various fields of training, including military, aircraft, and industrial and support training. In industrial training, the Metaverse allows workers to visualize the entire factory through simulation, while robots facilitate tasks and make them much easier. The fashion industry has also benefited from the Metaverse, as designers can create outfits tailored to the needs of their customers using digital avatar trails and customizing the garments. In the aviation industry, Metaverse technologies like XR have

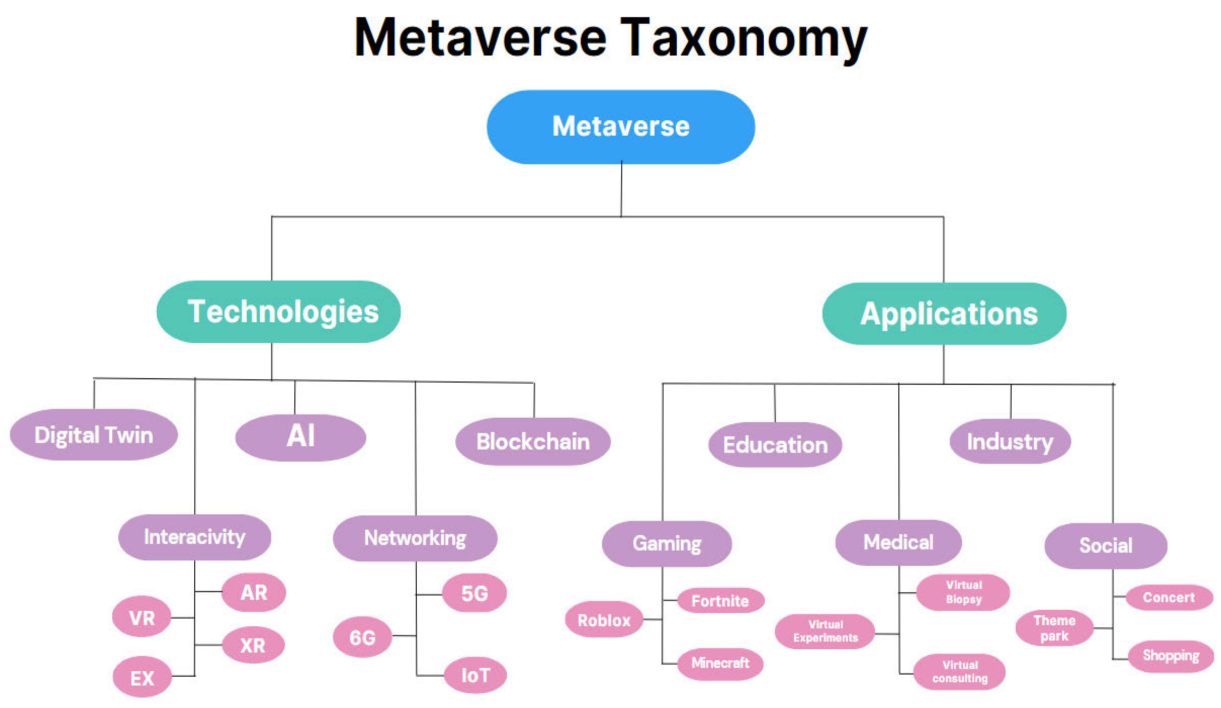

FIGURE 7. Taxonmy of metaverse.

been used for worker training to carry out inspection and maintenance processes. Eschen et al. (45) indicate that XR technology for training is less error-prone, requires less effort and time consumption.

- **Social Metaverse:** The social metaverse is a collaborative digital environment that brings together a collection of interconnected virtual worlds. It offers users the opportunity to engage in various activities such as gaming, shopping, working, and socializing. Metaverse offering a range of immersive social applications like virtual lives, virtual shopping, virtual dating, virtual chatting, global travel, and even space/time travel. Notably, Lil Nas X's virtual concert on Roblox attracted over 30 million fans, who could unlock special goods in the digital store. Similarly, UC Berkeley celebrated graduation festivities virtually in Minecraft, recreating the campus scenery, while Tencent developed a Digital Palace Museum that offers panoramic and immersive views for visitors to explore exhibitions from the comfort of their homes using VR helmets [48]. Online cultural experiences, such as museums and performances, are becoming more popular. While they address issues like limited capacity and time constraints of offline venues, there is still a need for better texture and fine detail that can be felt offline.Choi and Kim examined how visitors experience museums by combining beacons and head-mounted displays (HMDs). Hazan explored the evolving social and cultural experiences in museums [17]. The Metaverse provides a solution to the challenges of designing and building theme parks in the real world, offering an accessible and convenient platform for creating immersive spaces that cater to socialization, entertainment, and fun. Altspacevr: Virtual meeting space design for live and virtual events. User are allowed to meet and engage through avatar. To reduce the risk of harassment and inappropriate behavior a safety bubble feature has been implemented recently [45].
- The Metaverse is not just a platform for virtual reality experiences, it also has its own economic ecosystem. Economic activities such as the sale of goods and clothing to the general public are an important aspect of the Metaverse. Users can try on new clothes for their avatars before making a purchase, just like in the real world [17]. In addition, businesses can create various types of content such as visual art, songs, and written content and market them in the Metaverse. This allows businesses to engage with customers more effectively and conduct more efficient advertising campaigns [20], [21]. The Metaverse office provides a simulated real-world environment for its users. Unlike video calls, it offers an immersive experience with a sense of space. This allows avatars to move around the virtual workspace and enhances social interactions with coworkers. The sound of footsteps and other ambient sounds change based on the distance, providing a realistic environment

for workers. With the virtual display, the Metaverse provides overlay inventory trends and sales volume. Additionally, workers can conduct virtual meetings with long-distance clients and deliver presentations more effectively [24].

3) ASSESSMENT OF QUESTION 3. WHAT ARE THE KEY GAPS AND CHALLENGES THAT SHOULD BE ADDRESSED TO CREATE A SUCCESSFUL METAVERSE?

We take the help of almost all the research mentioned previously to answer this question. Nearly every article discusses the issues that Metaverse faces. After going through all chosen papers, some common issues were found are discussed below.

Privacy and security issues: One of the most significant concerns in the Metaverse is privacy and security. With the extensive usage of Metaverse platforms, there are concerns regarding the security and privacy of users' data. To provide an optimal experience, the Metaverse collects personally identifiable data of the user from wearable devices. The user or avatar identity can be stolen, which may result in the loss of all digital assets, relations, digital life, bank details, and other credentials. Additionally, a hacker can steal confidential data from the Metaverse Network. Therefore, it is crucial to develop stronger security measures and privacy policies to ensure that user data is secure and protected.

Scalability Issues: Metaverse platforms have to handle large amounts of data and traffic, which can lead to scalability issues. As more users join the Metaverse, it is important that the system is able to support the increasing demand for data, storage, and bandwidth. There is a need to develop better strategies and technologies to ensure that Metaverse platforms can handle large amounts of data and traffic without any performance issues.

Interoperability: A main issue with achieving interoperability between different Metaverse platforms is the lack of standards and protocols. Each Metaverse platform is built with its own set of features and capabilities, making it difficult to share data and content between them. Additionally, each platform is built with its own proprietary scripting language and software architecture, making it difficult to ensure compatibility between different platforms. Without a set of agreed-upon standards and protocols, it is difficult to ensure that the content, data, and user experiences are consistent and interoperable across multiple Metaverse platforms. There is still a need to develop better interoperability between different platforms. This would enable users to move between different Metaverse platforms without any hassle.

Adoption by users: The Metaverse ability to attract and retain a large user base is critical to its success. However, many users may be hesitant to adopt new technologies or apprehensive about spending a lot of time in a virtual setting.

IV. CONCLUSION AND FUTURE DIRECTIONS

In conclusion, the Metaverse idea has received a lot of attention in recent years, and with the growth of many technologies including AI, blockchain, AR, VR, XR, and IoT, the Metaverse is becoming a more feasible prospect. The Metaverse has the potential to revolutionize how we live, work, and connect with one another. It has numerous and potential uses in fields like as education, healthcare, entertainment, and gaming. The creation of the Metaverse, on the other hand, must emphasize ethical issues and assure accessible to all persons. With appropriate implementation, the Metaverse has the potential to transform our society and open up new avenues for human connection and cooperation.

The figure 7 provides a concise overview of the taxonomy surrounding Metaverse technologies, the foundational elements that enable this virtual universe. It explores the diverse applications of the Metaverse across healthcare, education, gaming, industries, and social interactions. Virtual reality (VR), augmented reality (AR), and mixed reality (MR) are instrumental in shaping the Metaverse's immersive experience, while its applications revolutionize traditional paradigms in healthcare training, interactive education, gaming experiences, industry advancements, and virtual social gatherings. Through this taxonomy, we gain valuable insights into how the Metaverse is transforming various sectors and reshaping the future of digital experiences.

The literature review suggests a number of potential directions for future research in the Metaverse. There are several areas where more research on the implications of the Metaverse is needed. Firstly, there is a need to study the impact of the Metaverse on data ownership, privacy, and digital identity. It is important to ensure that users have control over their data and identities as the Metaverse becomes an increasingly integrated part of our daily lives. Secondly, there is a pressing need to research the potential social and economic impacts of the Metaverse. For example, the Metaverse has the potential to create new employment opportunities, and research could explore how these opportunities could be leveraged to advance social and economic progress. Thirdly, research on the impact of the Metaverse on education and learning is required. The Metaverse has the potential to revolutionize the way we learn and acquire knowledge, and research could investigate how it can be used to create more engaging and immersive educational experiences. Finally, there is a need for more research on the underlying technologies that enable the Metaverse. The integration of Metaverse technologies with the physical world holds tremendous potential. Future research and development efforts could focus on advancing augmented reality (AR) and mixed reality (MR) technologies to seamlessly merge virtual and physical elements. This could lead to applications such as real-time virtual collaboration, virtual showrooms, immersive training simulations, and enhanced telepresence. Major metaverse technologies like AI, blockchain, IoT, digital Twin, BCI can be further integrated and optimized to produce a more realistic and seamless Metaverse experience.

Future research in the Metaverse should encompass a wide array of critical areas. Firstly, researchers need to focus on improving accessibility within the Metaverse, ensuring inclusivity for individuals with disabilities. Moreover, as the Metaverse expands, understanding and mitigating its environmental impact, particularly in terms of energy consumption, data centers, and hardware, will be vital. Research should also delve into the transformative potential of the Metaverse in the workplace and its impact on productivity and employee well-being. Ensuring the security of virtual spaces is paramount, necessitating in-depth studies on cyber threats and identity protection. Content creation and curation tools need to be automated, preserving quality and legality. Legal frameworks for the Metaverse must be developed, addressing complex jurisdiction and intellectual property issues. In healthcare, optimizing telemedicine and therapy within the Metaverse while maintaining data privacy is an important avenue. Entertainment and art can find new avenues for expression in the Metaverse, and understanding these dynamics is essential. Additionally, research can explore evolving social interactions, hardware development, data management, and many other facets of this emerging digital frontier. These diverse research areas will be integral to realizing the full potential of the Metaverse in society and technology.

As the Metaverse becomes more prevalent, it is essential to address the ethical and social implications that arise. Future research can delve into areas such as privacy concerns, data security, digital identity management, and the impact on social interactions and well-being. Exploring ways to mitigate potential negative effects and ensure responsible use of Metaverse technologies will be crucial.Lastly, research could look into how the Metaverse affects various fields like gaming, entertainment, and healthcare, as well as how the Metaverse can be used to come up with novel solutions to problems in these fields. Ethical considerations, the potential for social and economic development, the impact on education and learning, the development of underlying technologies, and the impact on various domains should all be given priority in future Metaverse research.

REFERENCES

[1] A. M. Al-Ghaili, H. Kasim, N. M. Al-Hada, Z. B. Hassan, M. Othman, J. H. Tharik, R. Md. Kasmani, and I. Shayea, "A review of metaverse's definitions, architecture, applications, challenges, issues, solutions, and future trends," *IEEE Access*, vol. 10, pp. 125835–125866, 2022.

[2] Y. Wang, Z. Su, N. Zhang, R. Xing, D. Liu, T. H. Luan, and X. Shen, "A survey on metaverse: Fundamentals, security, and privacy," *IEEE Commun. Surveys Tuts.*, vol. 25, no. 1, pp. 319–352, 1st Quart., 2023.

[3] S. Mishra, H. Arora, G. Parakh, and J. Khandelwal, "Contribution of blockchain in development of metaverse," in *Proc. 7th Int. Conf. Commun. Electron. Syst. (ICCES)*, Jun. 2022, pp. 845–850.

[4] Y. Canbay, A. Utku, and P. Canbay, "Privacy concerns and measures in metaverse: A review," in *Proc. 15th Int. Conf. Inf. Secur. Cryptography (ISCTURKEY)*, Oct. 2022, pp. 80–85.

[5] R. Di Pietro and S. Cresci, "Metaverse: Security and privacy issues," in *Proc. 3rd IEEE Int. Conf. Trust, Privacy Secur. Intell. Syst. Appl. (TPS-ISA)*, Dec. 2021, pp. 281–288.

[6] M. Pooyandeh, K.-J. Han, and I. Sohn, "Cybersecurity in the AI-based metaverse: A survey," *Appl. Sci.*, vol. 12, no. 24, p. 12993, Dec. 2022.

[7] Y.-W. Chow, W. Susilo, Y. Li, N. Li, and C. Nguyen, "Visualization and cybersecurity in the metaverse: A survey," *J. Imag.*, vol. 9, no. 1, p. 11, Dec. 2022.

[8] M. Stylianos, "Metaverse," *Encyclopedia*, vol. 2, no. 1, pp. 486–497, 2022.

[9] S. Ali, T. P. T. Armand, A. Athar, A. Hussain, M. Ali, M. Yaseen, M.-I. Joo, and H.-C. Kim, "Metaverse in healthcare integrated with explainable AI and blockchain: Enabling immersiveness, ensuring trust, and providing patient data security," *Sensors*, vol. 23, no. 2, p. 565, Jan. 2023.

[10] J. Sun, W. Gan, H.-C. Chao, and P. S. Yu, "Metaverse: Survey, applications, security, and opportunities," 2022, *arXiv:2210.07990*.

[11] L.-H. Lee, T. Braud, P. Zhou, L. Wang, D. Xu, Z. Lin, A. Kumar, C. Bermejo, and P. Hui, "All one needs to know about metaverse: A complete survey on technological singularity, virtual ecosystem, and research agenda," 2021, *arXiv:2110.05352*.

[12] 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.

[13] Y.-C. Tsai, "The value chain of education metaverse," 2022, *arXiv:2211.05833*.

[14] M. Wang, H. Yu, Z. Bell, and X. Chu, "Constructing an edu-metaverse ecosystem: A new and innovative framework," *IEEE Trans. Learn. Technol.*, vol. 15, no. 6, pp. 685–696, Dec. 2022.

[15] H. Lin, S. Wan, W. Gan, J. Chen, and H.-C. Chao, "Metaverse in education: Vision, opportunities, and challenges," 2022, *arXiv:2211.14951*.

[16] S. K. Jagatheesaperumal, K. Ahmad, A. Al-Fuqaha, and J. Qadir, "Advancing education through extended reality and Internet of Everything enabled metaverses: Applications, challenges, and open issues," 2022, *arXiv:2207.01512*.

[17] S.-M. Park and Y.-G. Kim, "A metaverse: Taxonomy, components, applications, and open challenges," *IEEE Access*, vol. 10, pp. 4209–4251, 2022.

[18] I. Ahmad, S. Sharma, R. Singh, A. Gehlot, N. Priyadarshi, and B. Twala, "MOOC 5.0: A roadmap to the future of learning," *Sustainability*, vol. 14, no. 18, p. 11199, Sep. 2022.

[19] L. Petrigna and G. Musumeci, "The metaverse: A new challenge for the healthcare system: A scoping review," *J. Funct. Morphol. Kinesiol.*, vol. 7, no. 3, p. 63, Aug. 2022.

[20] M. Zallio and P. J. Clarkson, "Designing the metaverse: A study on inclusion, diversity, equity, accessibility and safety for digital immersive environments," *Telematics Informat.*, vol. 75, Dec. 2022, Art. no. 101909.

[21] S. B. Far, S. M. H. Bamakan, Q. Qu, and Q. Jiang, "A review of non-fungible tokens applications in the real-world and metaverse," *Proc. Comput. Sci.*, vol. 214, pp. 755–762, Jan. 2022.

[22] Z. Lv, S. Xie, Y. Li, M. S. Hossain, and A. El Saddik, "Building the metaverse using digital twins at all scales,states, and relations," *Virtual Reality Intell. Hardw.*, vol. 4, no. 6, pp. 459–470, Dec. 2022.

[23] F. Shi, H. Ning, X. Zhang, R. Li, Q. Tian, S. Zhang, Y. Zheng, Y. Guo, and M. Daneshmand, "A new technology perspective of the metaverse: Its essence, framework and challenges," *Digit. Commun. Netw.*, Mar. 2023.

[24] Y. K. Dwivedi, L. Hughes, A. M. Baabdullah, S. Ribeiro-Navarrete, M. Giannakis, M. M. Al-Debei, D. Dennehy, B. Metri, D. Buhalis, C. M. Cheung, and K. Conboy, "Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy," *Int. J. Inf. Manag.*, vol. 66, Oct. 2022, Art. no. 102542.

[25] K. Giang Barrera and D. Shah, "Marketing in the metaverse: Conceptual understanding, framework, and research agenda," *J. Bus. Res.*, vol. 155, Jan. 2023, Art. no. 113420.

[26] Y. Zeng, L. Zeng, C. Zhang, and A. S. Cheng, "The metaverse in cancer care: Applications and challenges," *Asia–Pacific J. Oncol. Nursing*, vol. 9, no. 12, 2022, Art. no. 100111.

[27] M. Sun, L. Xie, Y. Liu, K. Li, B. Jiang, and Y. Lu, "The metaverse in current digital medicine," *Clin. eHealth*, Jul. 2022, doi: 10.1016/j.ceh.2022.07.002.

[28] M. Shahin, M. R. H. Iman, M. Kaushik, R. Sharma, T. Ghasempouri, and D. Draheim, "Exploring factors in a crossroad dataset using cluster-based association rule mining," *Proc. Comput. Sci.*, vol. 201, pp. 231–238, Jan. 2022, doi: 10.1016/j.procs.2022.03.032.

[29] B. S. Akhmetov, V. Lakhno, B. B. Akhmetov, A. Zhilkishbayev, N. Izbasova, O. Kryvoruchko, and A. Desiatko, "Application of a genetic algorithm for the selection of the optimal composition of protection tools of the information and educational system of the university," *Proc. Comput. Sci.*, vol. 215, pp. 598–607, Jan. 2022, doi: 10.1016/j.procs.2022.12.062.

[30] A. S. Ahuja, B. W. Polascik, D. Doddapaneni, E. S. Byrnes, and J. Sridhar, "The digital metaverse: Applications in artificial intelligence, medical education, and integrative health," *Integr. Med. Res.*, vol. 12, no. 1, Mar. 2023, Art. no. 100917, doi: 10.1016/j.imr.2022.100917.

[31] H. Ning, H. Wang, Y. Lin, W. Wang, S. Dhelim, F. Farha, J. Ding, and M. Daneshmand, ''A survey on metaverse: The state-of-the-art, technologies, applications, and challenges,'' 2021, *arXiv:2111.09673*.

[32] B. Siniarski, C. De Alwis, G. Yenduri, T. Huynh-The, G. GÜr, T. R. Gadekallu, and M. Liyanage, ''Need of 6G for the metaverse realization,'' 2022, *arXiv:2301.03386*.

[33] O. Bouachir, M. Aloqaily, F. Karray, and A. Elsaddik, ''AI-based blockchain for the metaverse: Approaches and challenges,'' in *Proc. 4th Int. Conf. Blockchain Comput. Appl. (BCCA)*, Sep. 2022, pp. 231–236, doi: 10.1109/BCCA55292.2022.9922509.

[34] I. Skalidis, O. Müller, and S. Fournier, ''CardioVerse: The cardiovascular medicine in the era of metaverse,'' *Trends Cardiovasc. Med.*, May 2022, doi: 10.1016/j.tcm.2022.04.004.

[35] B. Kitchenham, ''Procedures for performing systematic reviews,'' Keele Univ. Natl. ICT Aust., Tech. Rep., 2004, doi: 10.1.1.122.3308.

[36] Z. Mushtaq, G. Rasool, and B. Shehzad, ''Multilingual source code analysis: A systematic literature review,'' *IEEE Access*, vol. 5, pp. 11307–11336, 2017, doi: 10.1109/ACCESS.2017.2710421.

[37] T. Dyba and T. Dingsøyr, ''Empirical studies of agile software development: A systematic review,'' *Inf. Softw. Technol.*, vol. 50, nos. 9–10, pp. 833–859, Aug. 2008, doi: 10.1016/j.infsof.2008.01.006.

[38] M. Rowe, J. Frantz, and V. Bozalek, ''The role of blended learning in the clinical education of healthcare students: A systematic review,'' *Med. Teacher*, vol. 34, no. 4, pp. 216–221, Apr. 2012, doi: 10.3109/0142159x.2012.642831.

[39] M. Heyvaert, K. Hannes, B. Maes, and P. Onghena, ''Critical appraisal of mixed methods studies,'' *J. Mixed Methods Res.*, vol. 7, no. 4, pp. 302–327, Oct. 2013, doi: 10.1177/1558689813479449.

[40] A. Fernandez, E. Insfran, and S. Abrahão, ''Usability evaluation methods for the web: A systematic mapping study,'' *Inf. Softw. Technol.*, vol. 53, no. 8, pp. 789–817, Aug. 2011, doi: 10.1016/j.infsof.2011.02.007.

[41] S. Nakamoto. (2008). *Bitcoin: A Peer-to-Peer Electronic Cash System*. Accessed: Nov. 2022. [Online]. Available: https://www.debr.io/article/21260.bitcoin.a.peer.to.peer.electronic.cash.system

[42] Facebook. (2021). *Introducing Meta: A Social Technology Company*. Accessed: Feb. 16, 2022. [Online]. Available: https://about.fb.com/news/2021/10/facebook-company-is-now-meta/

[43] I.-C. Stanica, F. Moldoveanu, G.-P. Portelli, M.-I. Dascalu, A. Moldoveanu, and M. G. Ristea, ''Flexible virtual reality system for neurorehabilitation and quality of life improvement,'' *Sensors*, vol. 20, no. 21, pp. 6045–6059, Oct. 2020, doi: 10.3390/s20216045.

[44] H. Eschen, T. Kotter, R. Rodeck, M. Harnisch, and T. Schuppstuhl, ''Augmented and virtual reality for inspection and maintenance processes in the aviation industry,'' *Proc. Manuf.*, vol. 19, pp. 156–163, Jan. 2018, doi: 10.1016/j.promfg.2018.02.027.

[45] M. Xu, W. C. Ng, W. Y. B. Lim, J. Kang, Z. Xiong, D. Niyato, Q. Yang, X. Shen, and C. Miao, ''A full dive into realizing the edge-enabled metaverse: Visions, enabling technologies, and challenges,'' *IEEE Commun. Surveys Tuts.*, vol. 25, no. 1, pp. 656–700, 1st Quart., 2023.

[46] P. P. Tricomi, F. Nenna, L. Pajola, M. Conti, and L. Gamberini, ''You can't hide behind your headset: User profiling in augmented and virtual reality,'' *IEEE Access*, vol. 11, pp. 9859–9875, 2023.

[47] R. Chengoden, N. Victor, T. Huynh-The, G. Yenduri, R. H. Jhaveri, M. Alazab, S. Bhattacharya, P. Hegde, P. K. R. Maddikunta, and T. R. Gadekallu, ''Metaverse for healthcare: A survey on potential applications, challenges and future directions,'' *IEEE Access*, vol. 11, pp. 12765–12795, 2023.

[48] Y. Wang, Z. Su, and M. Yan, ''Social metaverse: Challenges and solutions,'' *IEEE Internet Things Mag.*, vol. 6, no. 3, pp. 144–150, Sep. 2023, doi: 10.1109/iotm.001.2200266.

[49] S. B. Far and A. I. Rad, ''Applying digital twins in metaverse: User interface, security and privacy challenges,'' *J. Metaverse*, vol. 2, no. 1, pp. 8–15, 2022.

[50] E. Hedrick, M. Harper, E. Oliver, and D. Hatch, ''Teaching & learning in virtual reality: Metaverse classroom exploration,'' in *Proc. Intermountain Eng., Technol. Comput. (IETC)*, May 2022, pp. 1–5.

[51] U. Bilotti, D. Di Dario, F. Palomba, C. Gravino, and M. Sibilio, ''Machine learning for educational metaverse: How far are we?'' in *Proc. IEEE Int. Conf. Consum. Electron. (ICCE)*, Jan. 2023, pp. 1–2.

[52] M. R. Paro, D. S. Hersh, and K. R. Bulsara, ''History of virtual reality and augmented reality in neurosurgical training,'' *World Neurosurg.*, vol. 167, pp. 37–43, Nov. 2022.

[53] L. U. Khan, Z. Han, D. Niyato, M. Guizani, and C. S. Hong, ''Metaverse for wireless systems: Vision, enablers, architecture, and future directions,'' 2022, *arXiv:2207.00413*.

[54] V. T. Truong, L. Le, and D. Niyato, ''Blockchain meets metaverse and digital asset management: A comprehensive survey,'' *IEEE Access*, vol. 11, pp. 26258–26288, 2023.

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