Explainable AI for the Metaverse: A Short Survey

Conference Paper · September 2023

DOI: 10.1109/iMETA59369.2023.10294907

Explainable AI for the Metaverse: A Short Survey

Chemmalar Selvi G*, Gokul Yenduri*, Gautam Srivastava†, Ramalingam M*,
Dasaradharami Reddy K*, Muhammad Uzair§, and Thippa Reddy Gadekallu‡

* Vellore Instituite of Technology, Vellore, Tamil Nadu, India.
† Dept. of Math and Computer Science, Brandon University, Brandon, MB R7A 6A9, Canada.
‡ Department of Electrical and Computer Engineering, Lebanese American University, Byblos, Lebanon.
§ Institute of Computer Science, University of Tartu, Estonia
E-mails: chemmalarselvi.g@vit.ac.in, gokul.yenduri@vit.ac.in, SrivastavaG@brandonu.ca,
ramalingam.m@vit.ac.in, dasaradharami.k@vit.ac.in, muhammad.uzair@ut.ee, thippareddy.g@vit.ac.in

***Abstract*—Virtual reality, augmented reality, and immersive technologies have advanced rapidly, giving rise to the concept of the metaverse. As users delve into these virtual environments, it becomes crucial to understand the decision-making processes of intelligent systems within the metaverse. Explainable AI (XAI) provides a framework for interpreting and understanding the outcomes of artificial intelligence, making it an essential component for ensuring transparency, trust, and user engagement within the metaverse. This paper aims to explore the fusion of XAI in the context of the metaverse, including key enabling technologies, the impact of XAI on metaverse applications, integration challenges, and future directions.**

***Index Terms*—Explainable Artificial Intelligence, Virtual Reality, Augmented Reality, Virtual world, immersive environment.**

I. Introduction

The metaverse is an ever-expanding digital universe that incorporates virtual reality (VR), agumented reality (AR), artificial intelligence (AI), blockchain (BC), and Internet of Things (IoT) technologies, creating a seamless and interconnected realm that has the potential to transform various domains [1]. The applications of the metaverse are vast and far-reaching, from social interactions and communication to gaming, education and training, virtual workspaces and collaborations, e-commerce, real estate, and cultural and artistic experiences. By bridging the virtual and physical realms, the metaverse offers immersive experiences, virtual economies, and limitless possibilities for creativity and interaction, transforming industries and shaping the future of human engagement [2]. However, with such vast and complex systems, the need for understanding the decision-making processes of AI systems within the metaverse becomes crucial. Explainable AI (XAI) provides a framework for interpreting and understanding the outcomes of AI, making it an essential component for ensuring transparency, trust, and user engagement within the metaverse [3]. Integrating XAI in the metaverse has the potential to enhance user experiences, build trust, and enable ethical and responsible use of AI. Therefore, the fusion of XAI in the context of the metaverse has become a crucial research area for ensuring the success and sustainability of this digital frontier.

Definition 1: The metaverse is an interconnected web of ubiquitous virtual worlds partly overlapping with and enhancing the physical world. These virtual worlds enable users represented by avatars to connect and interact with each other, to experience and consume user-generated content in an immersive, scalable, synchronous and persistent environment. An economic system provides incentives for contributing to the metaverse [4].

Definition 2: The metaverse is the post-reality universe, a perpetual and persistent multiuser environment merging physical reality with digital virtuality. It is based on the convergence of technologies that enable multisensory interactions with virtual environments, digital objects and people such as VR and AR. Hence, the metaverse is an interconnected web of social, networked immersive environments in persistent multiuser platforms [5].

The metaverse is a complex and dynamic environment where AI plays a significant role in empowering various aspects, such as virtual characters, environments, and interactions. AI focuses on developing algorithms and models that can perform complex tasks and make accurate predictions. XAI, subset of AI, enhances user experiences in the metaverse by promoting trust, transparency, control, personalization, and ethical AI practices. It empowers users to understand, interact with, and shape AI systems, leading to more immersive and rewarding experiences within the virtual universe.

XAI plays a crucial role in building the metaverse by providing transparency and understanding in AI-driven systems. XAI enables users to comprehend the reasoning behind AI decisions and actions within virtual environments. AI techniques provide explanations for the decisions and actions taken by AI models within the virtual environment. By offering insights into the underlying factors, algorithms, or data sources that influenced AI outputs, XAI enables users to understand why certain recommendations, interactions, or behaviors occur. This transparency fosters trust, allowing users to have confidence in AI systems and their interactions with virtual entities. With XAI, users can gain a deeper understanding of the rationale behind AI-driven outcomes, empowering them to make informed decisions, customize their experiences, and collaborate effectively with AI entities within the metaverse.

Thus, the integration of XAI in the metaverse goes beyond user understanding and control. It also aligns with ethical considerations, as XAI enables the identification and mitigation of biases, discrimination, or unfairness within AI systems. By providing explanations, users and developers can detect problematic behaviors and ensure the metaverse remains a safe, inclusive, and ethical space. Hence, the motivation of this paper is to highlight the potential impact of XAI on the metaverse and explore the enabling technologies, diverse applications of XAI techniques within virtual environments along with the practical integration challenges of XAI for the metaverse.

The rest of the article is organized into following sections. Section II discusses the related works of XAI for the metaverse. Section III provides the detailed study of the enabling technologies used in the metaverse. Section IV presents critical applications of the metaverse in real-world. Section V highlights the major integration challenges of XAI for the metaverse. Finally, the paper concludes the potential benefits of integrating XAI for the metaverse and its future directions.

II. Literature Review

This section presents the recent research studies conducted related to the metaverse and the summary of the current research works are summarized in the Table I.

TABLE I
HIGHLIGHTS OF OUR SURVEY PAPER WITH EXISTING WORKS

Research Paper	Contributions	Limitations
[6]	Presents comprehensive overview of AI for the metaverse, Applications of AI and technical aspects for the metaverse with future directions	Key Integration challenges of AI for the metaverse is missing
[7]	Reviews the importance of the metaverse with its applications, key challenges and future research scope	Preliminaries and current research works are not explored
[8]	Explores the impact of VR, IoT sensors, and their integration within the metaverse for educational purposes.	Challenges and open research problems are not presented
[9]	Studied the application of the digital metaverse in the fields of AI, medical education, and integrative health by highlighting the implementation challenges	Open problems and future research is missing
[10]	Highlights the key technologies of AI for the metaverse	Application of AI in the metaverse with research problems were not found
Our Survey Paper	Presents an in-depth analysis of XAI for the metaverse with key enabling technologies, important applications, integration challenges and future research directions	NA

Thien et al [6] provides a comprehensive survey of AI for the metaverse. This paper presents a comprehensive overview of AI, encompassing Machine Learning algorithms and Deep Learning architectures by highlighting their significance in the metaverse. In addition, they explored various AI-aided applications, along with the technical aspects and future research directions in AI for the metaverse.

Alex et al [7] presents an extensive overview of using XR technologies to enable instantaneous interactions and experiences that could surpass the limitations of the physical realm. They presented the key application areas of the metaverse and discussed the key challenges and their future directions.

Mahul et al [8] focuses on investigating the educational implications and benefits of recent Information and Communication Technology (ICT) advancements in the metaverse environment. The study explores the impact of VR, IoT sensors, and their integration within the metaverse for educational purposes. By examining the learning outcomes and experiences facilitated by these technologies, they studied how to enhance engagement, interactivity, and knowledge acquisition within virtual learning environments. Thus,this research sheds light on the potential of ICT advancements to revolutionize education and provides insights into the efficacy of VR and IoT in promoting immersive and effective learning experiences within the metaverse.

Ahuja et al [9] reviews the application of the digital metaverse in the fields of AI, medical education, and integrative health. They highlighted how AI technologies can be integrated into the metaverse to enhance medical education and training, facilitate personalized healthcare experiences, and support integrative health practices. Finally, they presented the challenges associated with implementing the digital metaverse in medical education and integrative health.

Wischgoll et al [10] provides an in-depth exploration of the key technologies related to the metaverse. They presented the technological foundations of the metaverse, highlighting key components such as VR, AR, computer graphics, network infrastructure, and AI. They examined the role of AI in the metaverse, future prospects and key challenges associated with the enabling technologies in the metaverse.

Thus, this section discusses the current research works related to the metaverse and its key enabling technologies. The following section focuses on various enabling technologies playing their significant role in the metaverse.

III. Impact of XAI on enabling technologies of the metaverse

The advancement of the metaverse is reliant on various enabling technologies that enable the establishment of captivating virtual landscapes, smooth user interactions, and secure transactions in the virtual realm [11]. However, interoperability is the bedrock of the which connects multiple disruptive technologies by building collaboration between applications to scale beyond a series of disconnected silos, and to evolve a platform that is open and inclusive for all. The innovators and tech domain experts face new demand towards regulators and standard bodies. Based upon the application scenarios, several protocols such as General Data Protection Regulation (GDPR), EU AI Strategy, National Institute of Standards and Technology (NIST), and 3rd Generation Partnership Project (3GPP) could be employed. Thus, this subsequent section outlines crucial technologies that play a significant role in the development of the metaverse.

A. Digital twin

Digital twin technology can play a significant role in the development of the metaverse. A digital twin is a virtual replica of a physical object or system that can simulate and analyze the behavior of its real-world counterpart in a virtual environment. By providing a realistic and interactive virtual representation of physical objects or systems, digital twins can contribute to the development of the metaverse in several ways. Firstly, digital twins can create realistic and interactive virtual environments that enhance the user's virtual experience. They can also help improve the performance and optimization of physical systems by identifying potential issues and inefficiencies in a virtual environment. Additionally, digital twins can be used for training and educational purposes in a safe and controlled environment, reducing the risk of accidents or errors in real-world settings. Lastly, digital twins can generate large amounts of data, which can be analyzed to provide valuable insights into the behavior of real-world systems. For instance, let's consider the development of a digital twin of a large commercial building. By combining data from various sources such as architectural plans, building automation systems, and sensor data, a digital twin can be created. Similarly, XAI can also help to improve digital twin technology by providing transparency, identifying biases, and facilitating communication with human operators. This can increase trust, accuracy, and user-friendliness of the technology, leading to better decision-making and improved outcomes in various industries.

B. Extended reality

The use of XR technologies can have a significant impact on the development of the metaverse, as it provides users with immersive and interactive virtual experiences. XR encompasses a variety of technologies such as VR, AR, and MR. VR can create fully immersive virtual environments that users can interact with using specialized headsets and controllers, allowing for gaming, training simulations, and social experiences. In the metaverse, VR can facilitate the exploration and interaction with virtual worlds, objects, and other users in a highly engaging and immersive manner. On the other hand, AR overlays digital information onto the real world, augmenting physical spaces and objects in the metaverse with additional information and interactivity. This can include directions, information about landmarks or historical sites, or adding virtual objects to physical spaces. MR blends elements of VR and AR, creating environments that combine the virtual and physical worlds. This enables users to interact with virtual objects in real-world environments, resulting in highly immersive and interactive experiences. In the metaverse, MR can enable users to engage with virtual objects and other users in real-world environments, creating highly realistic and engaging experiences. Additionally, XAI can help improve XR technology by identifying potential biases or inaccuracies in the data or models.Additionally, it provides transparency and interpretability of complex algorithms used in XR systems, allowing users to understand how and why certain decisions are made within the system.

C. Brain Computer Interface

The technology known as BCI allows for direct communication between the brain and an external device or computer system. Typically, BCI systems utilize sensors or electrodes attached to the scalp or implanted in the brain to measure brain activity, which is then translated into signals that can control external devices or computer systems. BCI technology has many potential applications, including assistive technologies, neuroprosthetics, and gaming and entertainment. The integration of BCI technology and the metaverse could revolutionize it by enabling more natural and intuitive interactions between users and virtual environments. By allowing direct communication between the brain and a computer system, BCIs could allow users to control their virtual avatar or environment through their thoughts or intentions, without the need for physical input devices. This could lead to more immersive and intuitive experiences in the metaverse, where users can interact with virtual environments and objects more naturally. Additionally, BCIs could enable new forms of social interaction, where users can communicate and interact with each other through their thoughts or emotions. BCIs could also have applications in virtual training simulations, where users can learn and practice skills in a virtual environment while receiving real-time feedback based on their brain activity. Overall, the integration of BCI technology into the metaverse could create new possibilities for human-computer interaction and significantly enhance the immersive and interactive nature of virtual environments. As like other enabling technologies, XAI also help improve BCI in terms of transparency and interpretability by providing explanations to the decision made within the system.

D. Blockchain

The BC is a digital ledger that records transactions across a network of computers in a decentralized and distributed manner. It ensures the security and integrity of stored data using cryptographic techniques. When integrated with the metaverse, BC technology provides a secure and decentralized infrastructure for ownership and transactions of virtual assets such as digital currencies, virtual land, and goods. This integration can help establish a platform for virtual economies in the metaverse, where users can trade virtual assets using cryptocurrency-based systems that are transparent and secure. It can also facilitate the creation and governance of decentralized virtual communities within the metaverse. With its potential to enhance security, transparency, and interoperability of virtual environments, BC technology enables users to conduct secure and transparent transactions and manage digital assets and identities in virtual spaces. Moreover, BC technology enables users to transfer assets and identities between different virtual environments and platforms, thereby creating new opportunities for virtual commerce, gaming, and social interactions. XAI can also benefit BC through facilitating better communication between blockchain systems and users, making it easier for users to understand how the system works and how to use it effectively. This can lead to increased adoption and trust in blockchain technology. Additionally, XAI can help ensure regulatory compliance and accountability in blockchain systems by providing evidence of transparency and accountability in the decision-making processes of these systems.

E. Internet of Things

IoT is a network of physical devices, appliances, and vehicles embedded with electronics, software, sensors, and connectivity, which allows them to connect and exchange data. It improves efficiency, automation, and decision-making in various industries by collecting, storing, and analyzing data. The data from IoT devices can enhance the immersive and interactive experiences in applications of the metaverse like virtual shopping, smart homes, and gaming. In the metaverse, IoT can be used for collecting and sharing data from smart objects within virtual environments, monitoring and controlling virtual systems and devices in real-time, and improving immersive experiences through physical sensors and actuators. For instance, IoT sensors can be utilized to automate adjustments to lighting, temperature, and other environmental settings in a virtual building. Similarly, XAI can also have the potential to address the challenges associated with transparency and interpretability in IoT systems. With its ability to provide insights into the functioning of IoT systems, identify biases and inaccuracies, and enhance the reliability and trustworthiness of data generated by IoT devices, XAI can greatly improve decision-making processes and optimize resource usage. Furthermore, it can improve communication between IoT systems and users by simplifying the system's functionality and usability.

IV. Applications

This section presents the need to adapt XAI for various applications in the metaverse.

A. Healthcare

The healthcare sector has recently begun utilizing cutting-edge methods, such as VR and big data integrated with XAI, in both hardware and software to enhance the effectiveness of healthcare devices, lower the cost of medical treatments, enhance the operation of healthcare facilities, and increase access to healthcare [12]. The metaverse is a platform for the transition from two-dimensional (2D) to three-dimensional (3D) virtual environments for the purpose of learning about and communicating information about patients' health issues and medical records. The use of VR and XR systems contributes to the advancement of XAI in many medical and healthcare sectors, such as improving diagnosis efficiency, delivering faster and more accurate medical decisions, and providing better real-time imaging in healthcare [13].

Various wearable devices are now using XAI to recognise complex patterns of sensory information, which can be useful for healthcare and wellness applications and services [14]. The physical activity recognition method [15] was developed by using sensory data from multiple wearable devices to support doctors and health-wellness experts when making decisions about daily living assistance. To enhance activity identification, local deep features (those generated by a CNN) were combined with global handmade features. For CNN-based human activity classification based on inertial sensor signals (e.g., accelerometers, gyroscopes, and magnetometers), a novel encoding algorithm, Iss2Image, was introduced in [16]. Wearable devices were proposed in [17] as a fall detection service using IoT, which used a hierarchical deep learning framework with CNN architectures to process local and remote sensory data. The system was able to accurately detect a wide variety of wearable devices (such as smartwatches, and smartphones) while respecting the privacy of data. Some early healthy risk attentions, such as the detection of falls and heart failure [18], also used recurrent neural network (RNN) and long short-term memory (LSTM) networks for processing wearable sensory data. Healthcare staff as well as patients might benefit from XAI techniques since they provide clear and comprehensible justifications for the model's predictions. Health outcomes for patients could be improved, and confidence could increase. XAI techniques might be employed in the context of a metaverse for intelligent healthcare to describe the system's thinking behind a diagnosis based on a patient's symptoms and medical record. Providing this information in a graphic or engaging style might make it more accessible to the patient.

B. E-commerce

Despite the general public's lack of interest in VR devices, many consumer brands have begun to immerse themselves in the digital world in order to bring about more enjoyable and streamlined shopping experiences by integrating E-commerce into the metaverse. Many companies have taken the first steps towards creating something completely new by incorporating e-commerce platforms that may provide the best of both the physical and online purchasing experiences [19]. VR and XAI technologies enable virtual shopping to convey a real-time experience of static products to consumers, who are represented by avatars and interact with virtual cashiers and sellers in a 3D-rendered space. Manufacturers are personalising consumer experiences for business sustainability and revenue development, which can be done easily in the metaverse with XAI-based purchasing behaviour analysis [20].

C. Finance

A cryptocurrency-based financial service known as decentralised finance (DeFi) [21]. It is an open system of finance in which smart contracts are used to build exchanges as well as provide a wide range of services, such as insurance, yield farming, and lending, without relying on central authority [6]. DeFi, powered by BC technology, is decentralised as opposed to centralised finance, which is governed by a single institution or person. This gives consumers complete control over their financial information and protects their confidentiality and safety. Most DeFi features are supplied using decentralized applications (Dapps), which are programmes written completely in code that are made available to the public. Users can purchase virtual products identified by NFTs in a digital world but will receive real products in the real world by integrating DeFi (including basic and professional services) into the metaverse. In addition, users can gain profit using the DeFi ecosystem, which allows them to lend, borrow, mine, and stake cryptocurrencies. The XAI-based mechanisms of a decentralized exchange will allow users to provide liquidity to the liquidity pool and earn incentives in return.

D. Real Estate

Individuals and businesses alike have contributed a lot of money into the metaverse's real estate market [22]. There are currently available metaverses where users may purchase, sell, and trade goods, including real estate (plots of land and virtual dwellings), such as the Axie Infinity for virtual games and Sandbox, Upland, and Decentraland for virtual real estate. These virtual residential properties, typically accompanied by non-fungible tokens (NFTs), have a finite number in circulation, which serves to protect their scarcity-based prices over time. The real estate in the metaverse can serve as a venue for online gatherings (like art shows and fashion shows) or for housing virtual buildings (like homes and workplaces). In addition, the metaverse offers an affordable method for real estate firms to show potential buyers around their properties before they commit to anything. Customers can get a feel for the entire space, from every aspect of the furnishings to the big picture of the building itself, with the use of VR experiences and dynamic inspections.

E. Agriculture

The agricultural metaverse (AgriVerse) mainly aims to optimize the production chain by reducing costs and increasing efficiency in view of sustainable agriculture. It can be regarded as the convergence of techniques of AI, blockchain, knowledge automation, intelligent machinery with the goal of providing reliable services to various stakeholders [23]. AgriVerse is still in its infancy, so more applications than the current services for virtual farms, agricultural teaching systems or agricultural product traceability systems are expected [23]. In particular, it is expected to have an impact on Agriculture 4.0, which is still a hot research topic dealing with IoT, AI, big data. In such a context, explainability and interpretability have already been discussed (e.g. see [24] and references therein), and they can easily influence the Agriverse.

F. Gaming

The gaming sector has always served as a primary usage throughout the metaverse, and now machine learning (ML) and deep learning (DL) are transforming and altering it across consoles, mobile devices, and personal computers [25]. It discusses how ML and DL can transform game development and how the metaverse can help build a new generation of games. Video game development has been greatly impacted by ML in the past decade. Games developers and studios are increasingly using machine learning to help systems and nonplayer characters (NPCs) respond to players' actions in a dynamic and reasonable manner. It helps create more realistic worlds with attractive challenges and unique stories.

The Bayesian method has been used for modelling three levels of abstraction in real-time strategy games, including StarCraft: strategy, tactics, and micromanagement [26]. These Bayesian learning algorithms were able to direct reactive forces, derive goals from operational data, and estimate an opponent's moves by applying their strategic intelligence. Multiple game developers have used XAI to investigate jobs during the design and development phases to get closer to a human-like intelligent response system. An artificial chess game with a large number of moving strategies was controlled using metamorphic testing [27]. To reveal metamorphic relationships, a decision tree model proved effective at determining the optimal move among all possible moves.

V. Integration Challenges and future directions

This section discusses the integration challenges of XAI with the metaverse and the related future directions.

A. Transparency and interpretability

XAI aims to make AI models more transparent and interpretable to humans. However, the complex nature of the metaverse, which involves multiple virtual environments, user interactions, and AI systems, makes it difficult to achieve transparency and interpretability. The future direction involves developing XAI systems that are specifically designed for the metaverse and can operate in real-time while providing transparent and interpretable explanations. XAI improves the transparency of AI by detailing the reasoning behind an algorithm's decision-making conclusion. The main objective of XAI approach is to transform AI systems' decision-making mechanism more transparent and explicable to humans, which may be immensely useful in a wide range of practical situations. Several features of XAI contribute to the transparency of AI: **Model visualization:** Users of XAI can decide to make use of visualisation tools to learn more about an AI model's decision-making process. This may include revealing the model's inner working, such as how it handles data and the relative importance of various inputs. **Feature importance analysis:** Decision-making elements or parameters might get prioritised with the use of XAI. Humans can learn about the AI model's internal functions by discovering which characteristics are most influential in making its final decision. **Natural language explanations:** XAI can create human-readable justifications for an AI model's outcome. It might assist in making decisions that people can comprehend and interpret.

Overall, XAI methods might contribute to greater transparency in AI by providing explanations and understanding that aid in the comprehension of how AI models arrive at their decisions. It has the potential to enhance human-AI interactions by increasing trust in and responsibility for AI systems.

B. Data quality and privacy

XAI systems require large amounts of data to learn and provide explanations. However, ensuring the quality and privacy of data in the metaverse is a major challenge. Data privacy concerns arise due to the nature of the data collected in the metaverse, which includes personal information, behavioral patterns, and preferences. The future direction involves incorporating privacy-preserving techniques, such as differential privacy, into XAI systems to ensure that user data is protected.

C. Bias and fairness

XAI systems need to be designed to ensure that they are free from bias and treat all users fairly. However, integrating XAI with the metaverse is challenging due to the complexity of the system and the large amount of data involved. The future direction involves addressing bias and fairness by designing XAI systems that are robust and incorporate fairness.

D. Real-time explanations

The metaverse operates in real-time, and users expect immediate feedback and responses. Integrating XAI with the metaverse requires systems that can provide real-time explanations without causing any delays or disruptions. The future direction involves exploring new ways to provide real-time explanations in the metaverse, such as using natural language or by using a Generative Pre-trained Transformers.

E. User experience

The user experience is crucial in the metaverse, and any disruptions or delays caused by XAI systems can have a significant impact on the user experience. Integrating XAI with the metaverse requires systems that are designed to enhance the user experience. The future direction involves conducting user studies to understand how XAI systems can be designed to enhance the user experience in the metaverse.

VI. Conclusion

In order to establish trust, transparency, and user empowerment in this immersive digital domain, XAI must be incorporated into the metaverse. XAI techniques enable users to understand the decision-making processes of AI systems, empowering them to confidently navigate through the metaverse. While there exist several challenges when integrating XAI with the metaverse, such as scalability and privacy considerations, ongoing research and development efforts hold promise in overcoming these obstacles. Hence, the future research directions include further exploration of interpretable AI models tailored to the metaverse's unique characteristics, the development of user-friendly XAI interfaces, and the establishment of ethical guidelines for XAI implementation in virtual environments. As the metaverse continues to evolve, the fusion of XAI and this virtual ecosystem will shape a future where users actively participate and navigate the digital landscape with confidence and ethical awareness, unlocking the full potential of this transformative technology.

References

[1] T. Huynh-The, T. R. Gadekallu, W. Wang, G. Yenduri, P. Ranaweera, Q.-V. Pham, D. B. da Costa, and M. Liyanage, "Blockchain for the metaverse: A review," *Future Generation Computer Systems*, 2023.

[2] 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," *arXiv preprint arXiv:2301.03386*, 2022.

[3] G. Srivastava, R. H. Jhaveri, S. Bhattacharya, S. Pandya, P. K. R. Maddikunta, G. Yenduri, J. G. Hall, M. Alazab, T. R. Gadekallu *et al.*, "Xai for cybersecurity: state of the art, challenges, open issues and future directions," *arXiv preprint arXiv:2206.03585*, 2022.

[4] M. Weinberger, "What is metaverse?—a definition based on qualitative meta-synthesis," *Future Internet*, vol. 14, no. 11, p. 310, 2022.

[5] S. Mystakidis, "Metaverse," *Encyclopedia*, vol. 2, no. 1, pp. 486–497, 2022.

[6] 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," *Engineering Applications of Artificial Intelligence*, vol. 117, p. 105581, 2023.

[7] A. Koohang, J. H. Nord, K.-B. Ooi, G. W.-H. Tan, M. Al-Emran, E. C.-X. Aw, A. M. Baabdullah, D. Buhalis, T.-H. Cham, C. Dennis *et al.*, "Shaping the metaverse into reality: a holistic multidisciplinary understanding of opportunities, challenges, and avenues for future investigation," *Journal of Computer Information Systems*, pp. 1–31, 2023.

[8] M. Brahma, M. A. Rejula, B. Srinivasan, S. Kumar, W. A. Banu, K. Malarvizhi, S. S. Priya, and A. Kumar, "Learning impact of recent ict advances based on virtual reality iot sensors in a metaverse environment," *Measurement: Sensors*, p. 100754, 2023.

[9] 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," *Integrative Medicine Research*, vol. 12, no. 1, p. 100917, 2023.

[10] T. Wischgoll, A. Stork, H. Schilling, and G. Scheuermann, "Metaverse: Technologies for virtual worlds," *IEEE Computer Graphics and Applications*, vol. 43, no. 02, pp. 11–12, 2023.

[11] A. K. Bashir, N. Victor, S. Bhattacharya, T. Huynh-The, R. Chengoden, G. Yenduri, P. K. R. Maddikunta, Q.-V. Pham, T. R. Gadekallu, and M. Liyanage, "A survey on federated learning for the healthcare metaverse: Concepts, applications, challenges, and future directions," *arXiv preprint arXiv:2304.00524*, 2023.

[12] Q.-V. Pham, X.-Q. Pham, T. T. Nguyen, Z. Han, D.-S. Kim *et al.*, "Artificial intelligence for the metaverse: A survey," *arXiv e-prints*, pp. arXiv–2202, 2022.

[13] M. Yunis, C. Markarian, and A. El-Kassar, "A conceptual model for sustainable adoption of ehealth: Role of digital transformation culture and healthcare provider's readiness," *Proceedings of the IMCIC*, 2020.

[14] O. Banos, J. Bang, T. Hur, M. H. Siddiqi, H.-T. Thien, L.-B. Vui, W. A. Khan, T. Ali, C. Villalonga, and S. Lee, "Mining human behavior for health promotion," in *2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE, 2015, pp. 5062–5065.

[15] T. Huynh-The, C.-H. Hua, N. A. Tu, and D.-S. Kim, "Physical activity recognition with statistical-deep fusion model using multiple sensory data for smart health," *IEEE Internet of Things Journal*, vol. 8, no. 3, pp. 1533–1543, 2020.

[16] T. Hur, J. Bang, T. Huynh-The, J. Lee, J.-I. Kim, and S. Lee, "Iss2image: A novel signal-encoding technique for cnn-based human activity recognition," *Sensors*, vol. 18, no. 11, p. 3910, 2018.

[17] X. Qian, H. Chen, H. Jiang, J. Green, H. Cheng, and M.-C. Huang, "Wearable computing with distributed deep learning hierarchy: a study of fall detection," *IEEE Sensors Journal*, vol. 20, no. 16, pp. 9408–9416, 2020.

[18] H. Li, A. Shrestha, H. Heidari, J. Le Kernec, and F. Fioranelli, "Bi-lstm network for multimodal continuous human activity recognition and fall detection," *IEEE Sensors Journal*, vol. 20, no. 3, pp. 1191–1201, 2019.

[19] M. C. Enache, "Metaverse opportunities for businesses." *Annals of the University Dunarea de Jos of Galati: Fascicle: I, Economics & Applied Informatics*, vol. 28, no. 1, 2022.

[20] M. Arafeh, P. Ceravolo, A. Mourad, E. Damiani, and E. Bellini, "Ontology based recommender system using social network data," *Future Generation Computer Systems*, vol. 115, pp. 769–779, 2021.

[21] S. Arsi, K. Guesmi, and E. Bouri, "Herding behavior and liquidity in the cryptocurrency market," *Asia-Pacific Journal of Operational Research*, vol. 39, no. 04, p. 2140021, 2022.

[22] S. Ammous, "Can cryptocurrencies fulfil the functions of money?" *The Quarterly Review of Economics and Finance*, vol. 70, pp. 38–51, 2018.

[23] M. Kang, X. Wang, H. Wang, J. Hua, P. d. Reffye, and F.-Y. Wang, "The development of agriverse: Past, present, and future," *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, vol. 53, no. 6, pp. 3718–3727, 2023.

[24] M. Uzair, S. Tomasiello, and E. Loit, "Interpretable approaches to predict evapotranspiration," in *Proceedings of the 14th International Conference on Soft Computing and Pattern Recognition (SoCPaR 2022)*. Cham: Springer Nature Switzerland, 2023, pp. 275–284.

[25] M. Chalhoub, A. Khazzaka, R. Sarkis, and Z. Sleiman, "The role of smartphone game applications in improving laparoscopic skills," *Advances in Medical Education and Practice*, pp. 541–547, 2018.

[26] G. Synnaeve and P. Bessiere, "Multiscale bayesian modeling for rts games: An application to starcraft ai," *IEEE Transactions on Computational intelligence and AI in Games*, vol. 8, no. 4, pp. 338–350, 2015.

[27] A. Liaqat, M. A. Sindhu, and G. F. Siddiqui, "Metamorphic testing of an artificially intelligent chess game," *IEEE Access*, vol. 8, pp. 174 179–174 190, 2020.