

Artificial Intelligence and Blockchain in the Metaverse

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Abstract—The Metaverse emerges as a completely virtual reality offering diverse possibilities through the immersive use of technology. Currently, artificial intelligence and blockchain have proven to be highly valuable in the ongoing technological revolution, with artificial intelligence providing automation, personalization, prediction and numerous other functionalities, and blockchain ensuring security through decentralization. Therefore, analyzing the integration of these two technologies within the Metaverse is crucial to understanding how they can be applied together effectively. However, there is a shortage of academic studies that address both artificial intelligence and blockchain within the Metaverse, indicating a significant gap in the literature. To address this issue, we conducted a systematic review covering publications from 2019 to 2023 in the IEEE Xplore, Scopus, and ACM databases. Our findings aim to fill this gap by providing insights into the current state of research, highlighting areas for future study and discussing how it can be applied to improving security and data in the Internet of Things.

Index Terms—Artificial Intelligence, Blockchain, Metaverse

I. INTRODUCTION

The Metaverse is a shared virtual space combining enhanced physical reality with persistent virtual environments. It offers an immersive platform where users, represented by avatars, engage in social interactions, commerce, entertainment, and collaboration. Blockchain technology enhances the Metaverse by providing decentralized security, transparency, efficiency, and traceabil-

ity. Artificial Intelligence (AI) enables systems to perform tasks requiring human intelligence, such as natural language processing, object recognition, and predictions.

Integrating blockchain and AI effectively addresses various challenges in the Metaverse. To explore this integration, we conducted a systematic literature review, identifying a gap as no prior reviews existed on this specific topic, likely due to the Metaverse's recent emergence.

This article fills this gap by mapping the literature on AI and blockchain in the Metaverse. It provides an overview of their integration and identifies areas for future research.

The article is organized as follows: Section 2: Methodology for the review; Section 3: Research questions and results; Section 4: Applications in the Internet of Things (IoT); Section 5: Final considerations

II. METHODOLOGY

This study utilized the Systematic Literature Mapping (SLM) method to categorize and provide an overview of the research area, encompassing three stages: planning, conducting, and publishing [1].

Planning Stage: Defined the objectives, research questions, search strategy, search string, selection criteria, and data extraction model.

Conducting Stage: Executed the search using the defined string, applied selection criteria, thoroughly read selected studies, completed the extraction model, and

analyzed the data to answer the research questions. Tools used included Parsif.al for planning and extraction, and Google Sheets for article analysis and graph generation.

Objective: To select primary studies and understand how blockchain and AI are integrated in the Metaverse, focusing on applications, use cases, and algorithms. Three research questions were established:

- 1) **RQ1:** Which country and when have the primary studies been published?
- 2) **RQ2:** How are blockchain and AI applied together in the Metaverse?
- 3) **RQ3:** What algorithms are used in Metaverse solutions?

Search Strategy: Searched on ACM Digital Library, IEEE Xplore, and Scopus using the following string:

Abstract: (("Artificial Intelligence" OR "AI" OR "Deep Learning" OR "Machine Learning") AND "Blockchain" AND ("Metaverse" OR "Virtual World")) AND Keywords: "Blockchain"

Inclusion Criteria (IC): Case studies that include blockchain and AI and relate them within the Metaverse.

Exclusion Criteria (EC): Articles deviating from the research objective, published outside 2019-2023, among others. The initial search returned 147 articles. After removing 39 duplicates, 108 articles remained. Applying IC and EC resulted in 16 articles after full-text review.

Data Extraction: From the 16 selected articles, relevant information was extracted, including the application objectives in the Metaverse, general areas, operation summaries, blockchain-AI relationships, AI models used, blockchain mechanisms, publication details, year, and the first author's country. This information selection was based on the protocol defined in the planning stage of the SLM.

This structured approach provided a comprehensive understanding of the current integration of AI and blockchain in the Metaverse, guiding future research and applications.

III. DISCUSSION AND RESULTS

In this section, we will cover the analysis of the articles found. These results will answer the research questions, as shown below.

A. RQ1: Which country and when have the primary studies been published?

In Fig. 1, we highlight China and, notably Canada, which is ahead of reference countries such as the USA, with articles originating from the University of Quebec

[2],[3] and Polytechnique Montreal [4], [5]. We also notice the variety of countries researching the topic and the continental diversity in which they are present.

Regarding the years of publication, we can see how recent the study in this field is in Fig.2, mainly because the great fame of the metaverse came recently with Meta and its applications.

B. RQ2: How blockchain and AI are being applied together in the metaverse?

In Fig. 3, we can see that almost half of the articles are focused on the area of artificial intelligence and the articles are concerned with ensuring the security of AI through the use of blockchain, from training to the operation and output of the AI. Regarding AI training, the focus is on the use of decentralized methods, as shown in Fig. 4 with Federated and Swarm Learning. This phenomenon can be explained by the decentralization characteristic of blockchain and the training of AIs locally to avoid loss or theft of user data in the Metaverse. The other three categories in Fig. 4 are related to the security of the AI result/output, a constant concern due to the criticality of this problem.

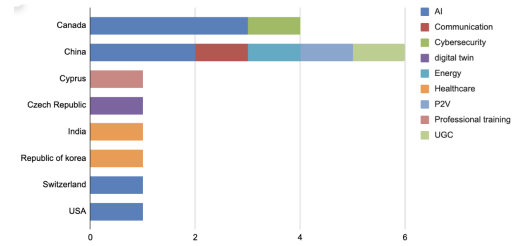


Fig. 1. General Area and Country of the Article

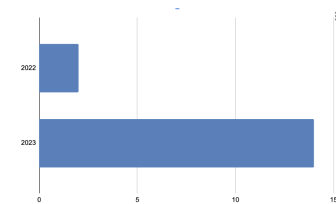


Fig. 2. Year Published

Fig. 5 shows the diversity of the purposes of other applications that do not have AI development as their ultimate goal. The use of AI in smart contracts stands out in the article [6] as a particularly interesting application, because it's a combination of enhanced security and practicality. However, it would benefit from further development to support more robust algorithms.

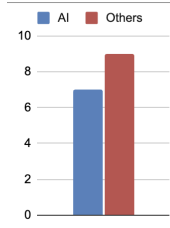


Fig. 3. Purpose of the application

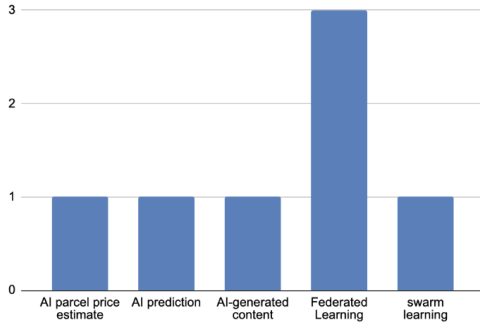


Fig. 4. Purpose of the application in the AI Area

In Fig. 6, we can see more directly the importance of using AI and blockchain in the Metaverse. We can see, based on Fig. 6, that in most articles that do not have something related to AI as their final objective, the use of blockchain together with AI is to secure the data that will be used.

C. RQ3: What algorithms are used in the solutions for the metaverse?

Fig. 7 shows that neural networks are the most commonly used models due to their versatility and diverse architectures. Three articles ([4], [5], [7]) did not specify an AI type as they discuss training methods applicable

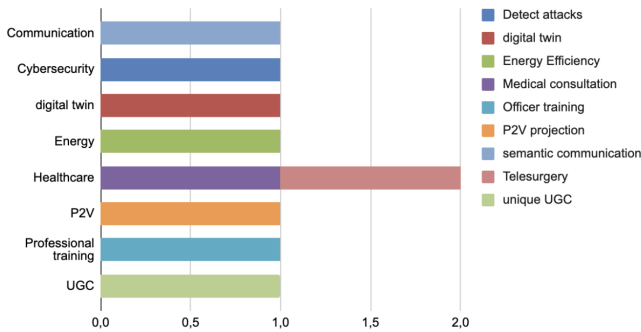


Fig. 5. Purpose of the application in many areas

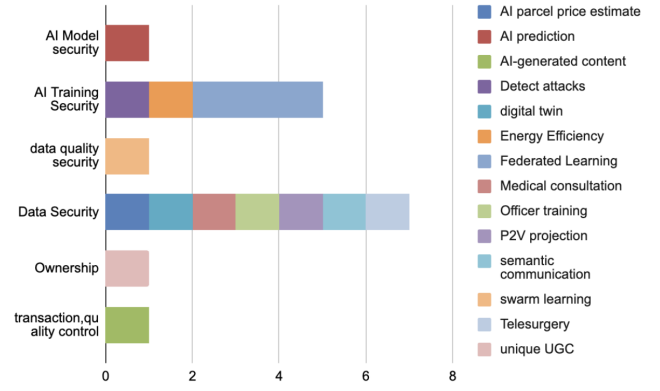


Fig. 6. Relationship between blockchain and AI and objective of the application

to various models. Specifically, [4] and [5] focus on federated learning, while [7] addresses energy efficiency through distributed learning in the metaverse. Some neural network models were not utilized, indicating that the proposed methods target multiple models within the category. Additionally, xAI appears in two studies ([8], [9]), aiming to explain neural network actions and support human-AI decision-making, such as doctors using AI to predict diseases.

In Fig. 8, Ethereum, smart contracts, Proof of Authority (PoA) and IPFS are frequently highlighted for their vital roles in the decentralized metaverse. Ethereum enables the creation and registration of digital assets and identities, while smart contracts automate transactions and governance, supporting a trustless economy. PoA provides an efficient consensus mechanism for high-performance subnetworks, and IPFS stores large data like 3D models, ensuring distributed and accessible visuals. Together, these technologies create a secure and scalable infrastructure, explaining their prominence in studies. Additionally, BFT ensures network reliability in the metaverse, protecting millions of users and digital assets from failures and malicious behavior, and safeguarding identities and transactions from fraud.

IV. INTERNET OF THINGS

These findings on AI-blockchain integration in the Metaverse also apply to the Internet of Things (IoT). IoT devices can generate data for real-world applications, like using cameras with object detection like in [14]. Federated Learning offers strong potential for decentralized AI, allowing local data processing and reducing leakage risks. Meanwhile, blockchain-based protocols

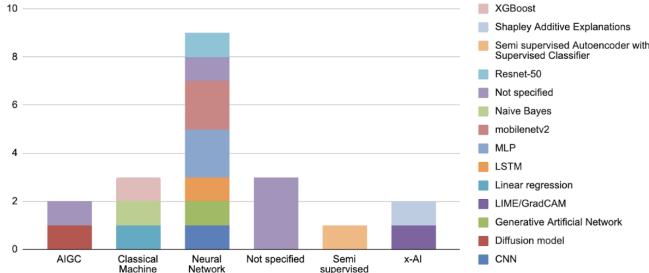


Fig. 7. AI models

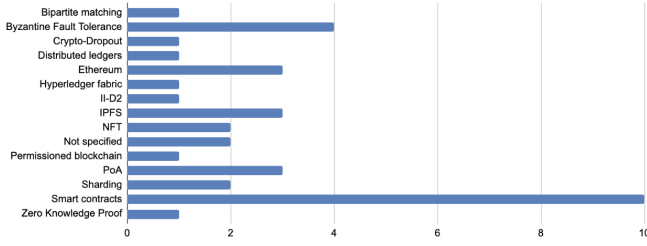


Fig. 8. Protocols and mechanisms for blockchain operation

ensure traceability, efficiency, decentralization, and security when recording and storing IoT data.

V. CONCLUSION

Our review of 2019–2023 publications reveals a growing global interest in combining AI and blockchain, with strong potential to boost security, privacy, scalability, and user experience in virtual spaces. Although various aspects have been studied, more research is needed to tap AI's powerful capabilities in fields like healthcare, virtual training, finance, and education. Continued investigation, interdisciplinary collaboration, and addressing current challenges can unlock the full potential of these technologies, enhancing the Metaverse and benefitting society.

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