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Review

Blockchain Technology and Artificial Intelligence Together: A Critical Review on Applications

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Abstract: It is undeniable that the adoption of blockchain- and artificial intelligence (AI)-based paradigms is proceeding at lightning speed. Both paradigms provide something new to the market, but the degree of novelty and complexity of each is different. In the age of digital money, blockchains may automate installments to allow for the safe, decentralized exchange of personal data, information, and logs. AI and blockchains are two of the most talked about technologies right now. Using a decentralized, secure, and trustworthy system, blockchain technology can automate bitcoin payments and provide users access to a shared ledger of records, transactions, and data. Through the use of smart contracts, a blockchain may also regulate user interactions without the need for a central authority. As an alternative, AI provides robots with the ability to reason and make decisions and human-level intellect. This revelation led to a thorough assessment of the AI and blockchain combo created between 2012 and 2022. This critical review contains 121 articles from the recent decade that investigate the present situation and rationale of the AI and blockchain combination. The integration's practical application is the emphasis of this overview's meatiest portion. In addition, the gaps and problems of this combination in the linked literature have been studied, with a focus on the constraints.

Keywords: blockchain technology; artificial intelligence; AI; critical review; AI applications

Citation: Taherdoost, H. Blockchain Technology and Artificial Intelligence Together: A Critical Review on Applications. *Appl. Sci.* **2022**, *12*, 12948. https://doi.org/10.3390/app122412948

Academic Editor: Christos Bouras

Received: 22 November 2022
Accepted: 11 December 2022
Published: 16 December 2022

1. Introduction

It is not a secret that there are many new technologies being promoted right now, but among them, the blockchain has been gaining a lot of traction as a decentralized ledger system that can be used in a variety of settings [1,2]. Since its inception in the 1920s, blockchain has persisted as a potentially disruptive innovation that will affect the ways of working together, automating payments, monitoring markets, and recording transactions [3]. Blockchain technology has the potential to be very useful in eliminating the need for a central authority figure to oversee and verify transactions and agreements between many parties [4]. Each transaction in the blockchain is cryptographically hashed and verified by all mining nodes [5]. It creates immutable, secure, and accessible timestamped records that can be accessed by all parties involved [6]. Artificial intelligence (AI), which gives machines the ability to learn from data and make decisions based on what they haveve learned, is another very visible area that is gaining a lot of traction. Ongoing statistical polling predicts that by 2030, the AI sector will be worth as much as USD 13 trillion [7].

While numerous competing innovations aim to make information in smart homes impervious to attacks, this is not yet the case. When it comes to protecting the home network from command and control attacks on encrypted data and providing a secure platform for all the devices in the network to connect, the development of blockchain technology is seen as among the most promising [8]. The consensus reached among the nodes in a blockchain ensures that all transactions are recorded permanently [9]. Control attacks on transmitted or stored information are therefore impossible through a single trad. Instead, the preponderance of hubs must be compromised for the attack to succeed [10].

Recent years have seen progress toward the concept of decentralized AI. A combination of these two technologies is the basis for decentralized AI (blockchains and AI) [11]. In a distributed and intermediary-free manner, it allows for the execution and storage of trustworthy, carefully tagged, and shared data on the blockchain [12]. The blockchain is now anticipated as a trusted platform to preserve such information, and simulated intelligence is described to work with massive amounts of data [13]. Blockchains may be programmed with smart contracts, allowing trusted third parties to monitor data access and sharing between users [14]. After being exposed to an autonomous system, a machine, and several scenarios, they may adapt and learn, yielding accurate and reliable decision-making outcomes that are unanimously sanctioned by all blockchain mining nodes [15,16].

As a result, everyone with a vested interest may trust and endorse such decisions. AI procedures using blockchains may provide decentralized deduction of how to promote security and trust in information sharing and choice outcomes across countless independent operators, which can contribute, arrange, and vote on future choices [17].

The convergence of AI and blockchain technology has produced several practical benefits [18]. Blockchain technology allows for the safe keeping of patient records in the healthcare industry. If they are permitted access, medical practitioners may learn valuable lessons from the patterns mined by AI in this data. Remarkably, their combined use has enabled the healthcare sector to deal with the COVID-19 pandemic [19]. One forward-thinking example is BurstIQ, a blockchain-based startup that offers data solutions for the healthcare sector and offers a health wallet using blockchain technology, AI, and big data to handle patient data. Medical providers may access patient health data via the wallet whenever needed [20]. Increased transaction speeds and mutual trust are two ways in which merging these two technologies is revolutionizing the financial services sector [21].

As can be seen in Figure 1, there are notable differences between blockchains and AI from a technological standpoint, yet these two technologies can be combined to address each other's weaknesses. Integrating AI with a blockchain has been claimed to have far-reaching implications in fields as diverse as 6G networks, smart cities, banking, and driverless cars [22]. Estimates suggest several potential benefits of combining AI with a blockchain. Without relying on a centralized authority or intermediaries, this enables the safe and reliable distribution of large data sets for analysis, learning, and decision making among many parties [23]. Several new and useful large-scale applications may potentially emerge as a result [24]. As a consequence of a blockchain's capacity to ensure the veracity of data, it may be used to store both the inputs and outputs of AI systems [25]. This article discusses the advantages of merging blockchain technology with AI. This overview's most substantial portion focuses on the integration's practical use. The difficulties are also highlighted before the conclusion.

The objective of this study is to examine the state of the AI and blockchain combo literature in a manner that will help emerging researchers catch up on the evolution of the field and provide advice for improving the quality of future research. The structure of the current study is as follows. The research approach used to find, filter, and choose the literature is covered in depth in the second part. In the third section, the literature on AI and blockchain integration is covered. The most popular articles are presented, their applicability is discussed, and some of the key problems are highlighted. The last section of the study discusses the conclusion.

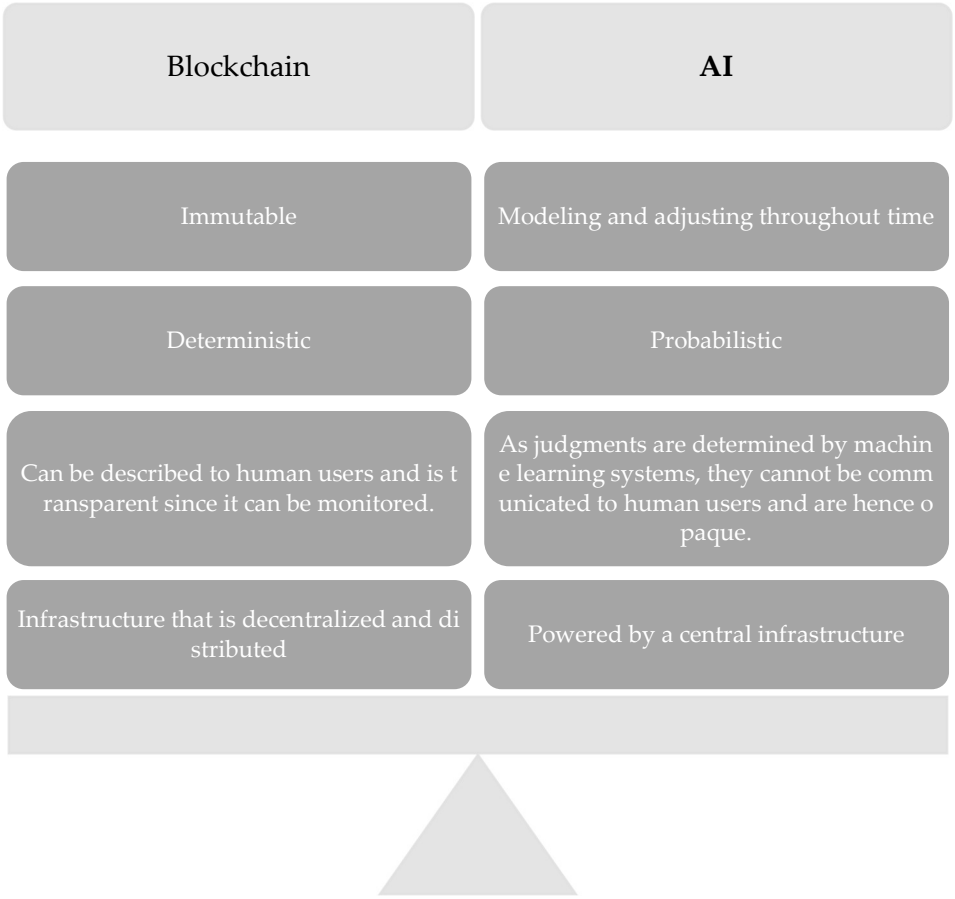


Figure 1. Properties of AI and blockchain.

2. Research Methodology

2.1. Planning the Review

The goal of this critical study was to evaluate the current state of blockchain technology with AI. With the utmost seriousness, all the recent pertinent literature was carefully reviewed for this inquiry. The review strategy made extensive use of structured research questions (RQs), the Scopus database, and methods for finding and analyzing information. A specific subset of the required reporting components for critical reviews was chosen to provide a complete and concise evaluation of the research topics. The RQs' details are as follows:

RQ1: How is the field of research doing now?
RQ2: What sectors can benefit from the combination of blockchains and AI?
RQ3: What applications do blockchains and AI have together?
RQ4: What are the challenges in combining blockchains with AI?

2.2. Research Strategy

A holistic review of the literature necessitated an inclusive perspective. Throughout the study, Scopus sources were examined. Relevant databases were thoroughly searched to make sure the data supplied here were complete. For several reasons, not all outstanding pieces of literature were included in the search criteria. A thorough literature search was conducted to reach this objective. Up to now, 353 Scopus results have been analyzed. About 121 were considered important (Figure 2). The formulation of the search string was influenced by the study domain and research subjects. By searching "Artificial intelligence" OR "AI" AND "blockchain", relevant content was located and compiled:

- Inclusion criteria (ICs).
  - The publication of research may occur at any time between 2012 and 2022.
  - The paper must combine blockchain technology and AI.
  - The scope of the study is limited to the journal.
- Exclusion criteria (EC).
  - The deletion of articles in the press.
  - Articles not written in English.
  - Exclusion of book chapters, dissertations, conference proceedings, interview-based works, and reviews.

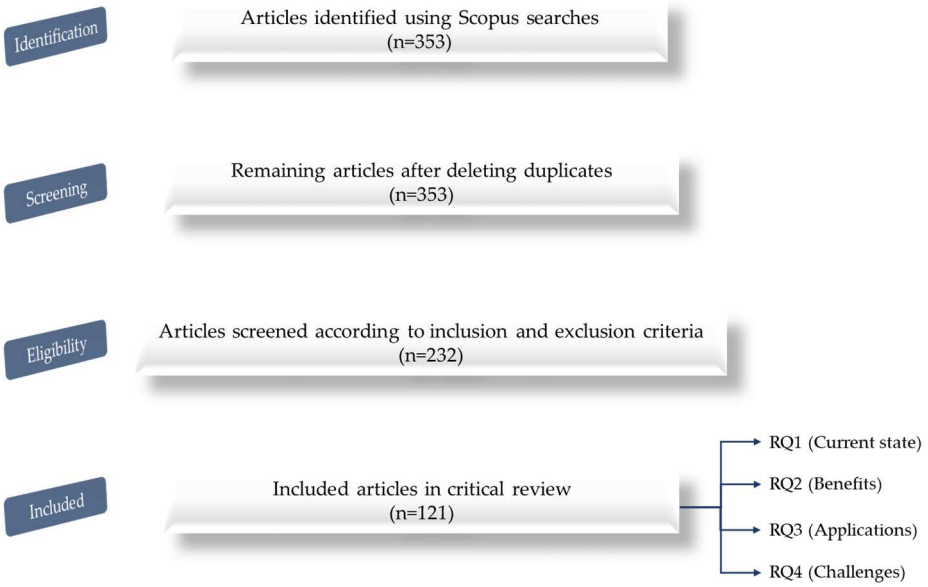


Figure 2. Diagram of research method.

3. Blockchain and Artificial Intelligence

The results of answering the RQs given in the preceding critical review follow. This study seems to substantially advance the use of the AI and blockchain combination. This section describes the AI and blockchain combination and its foundations, variations, development teams, platforms, and consensus procedures. The importance and applications of employing the AI and blockchain combination will be discussed in further detail in the future. The responses to the RQs from the critical review that came before are included here. This research seems to significantly enhance the application of blockchain technology and AI together. This section explains the foundations, variants, development teams, platforms, and consensus mechanisms for the AI and blockchain combo.

Selection Results

In total, 353 items were generated by this search, and 232 of them were inspected. There are 121 articles in this critical review. The publications that were selected are listed below, along with an explanation of the overall classification results.

RQ1: How is the field of research doing now?

This critical study looks at the descriptive data that were gathered on the various papers that are published every year, the publishing source, and the yearly average amount of citations that research publications receive. This critical analysis concludes the study of research papers combining AI and blockchains that were released between 2012 and 2022. The IEEE Access magazine had the most papers on this subject (10 articles).

Figure 3 displays the number of articles created for each subject area from 2012 to 2022. Computer science (84 articles) and engineering were the primary topics (52 articles). In addition, there were articles on mathematics (15 articles), materials science (12

articles), social sciences (10 articles), decision sciences (9 articles), medicine (9 articles), business, management, and accounting (8 articles), energy (8 articles), health professions (7 articles), economics, econometrics and finance (4 articles), neuroscience (4 articles), biochemistry, genetics, and molecular biology (3 articles), physics and astronomy (3 articles), agricultural and biological sciences (2 articles), environmental science (2 articles), nursing (2 articles), arts and humanities (1 article), chemical engineering (1 article), chemistry (1 article), dentistry (1 article), and multidisciplinary (1 article). Nearly 35% of the research was in computer science, which is fundamental and the inherent nature of blockchains and AI. The next category is engineering, which may usefully include all of these topics.

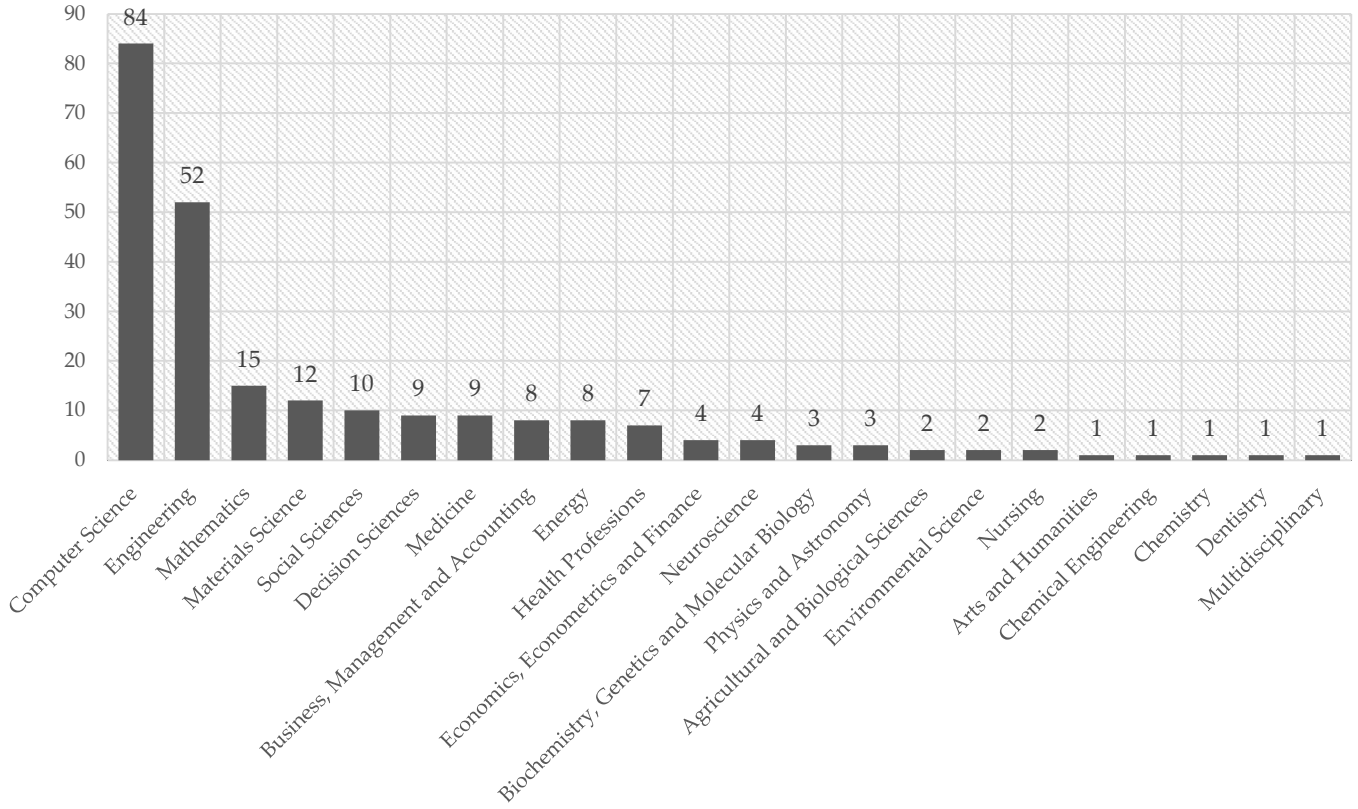


Figure 3. The number of articles published on the topic between 2012 and 2022.

Figure 4 illustrates the number of papers produced in each year from 2012 to 2022. There was no content available between 2012 and 2017. Here, 2018 witnessed the publication of four publications. In 2019, 2020, and 2021, 13, 21, and 36 papers were published, respectively. The increasing pace of article publication was followed by 47 articles published in 2022. The concept of merging blockchain and AI technology has been forming and expanding over the last 5 years.

Moreover, the main keywords (repeated $\geq$10 times) employed in the articles were "Blockchain", "Artificial Intelligence", "Block-chain", " Internet of Things", "Big Data", "Deep Learning", "Deep Learning", "Deep Learning Security", "AI", "Health Care", "Smart Contract", "Digital Storage", and "Machine Learning", as shown in Figure 5. As can be seen, "Blockchain" was the most repeatable keyword, followed by "Artificial Intelligence". Blockchain and artificial intelligence had the greatest repetition. Table 1 presents the top ten papers published between 2012 and 2022 in terms of citations.

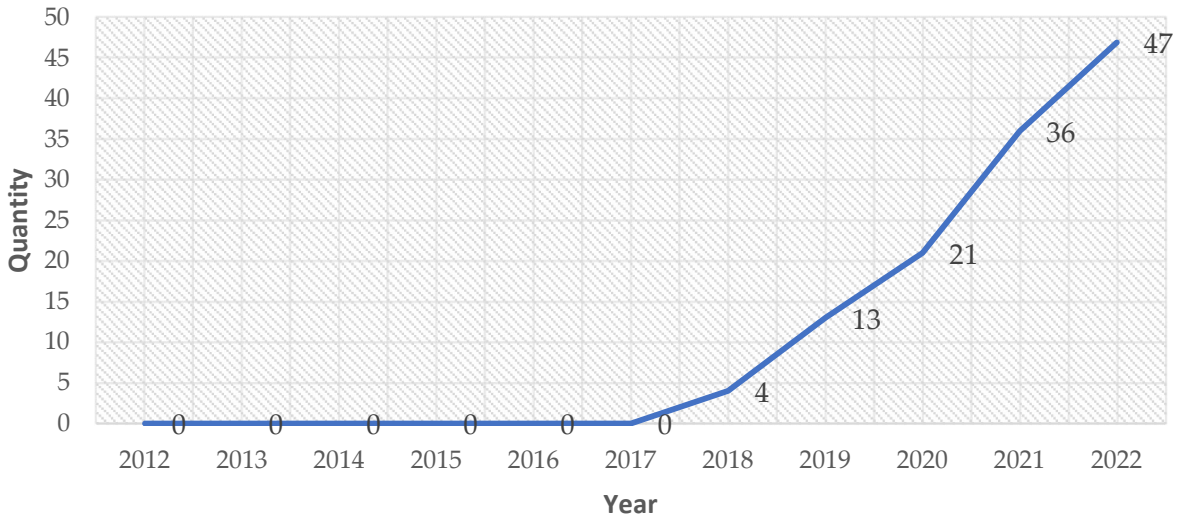


Figure 4. The number of annual publications between 2012 and 2022.

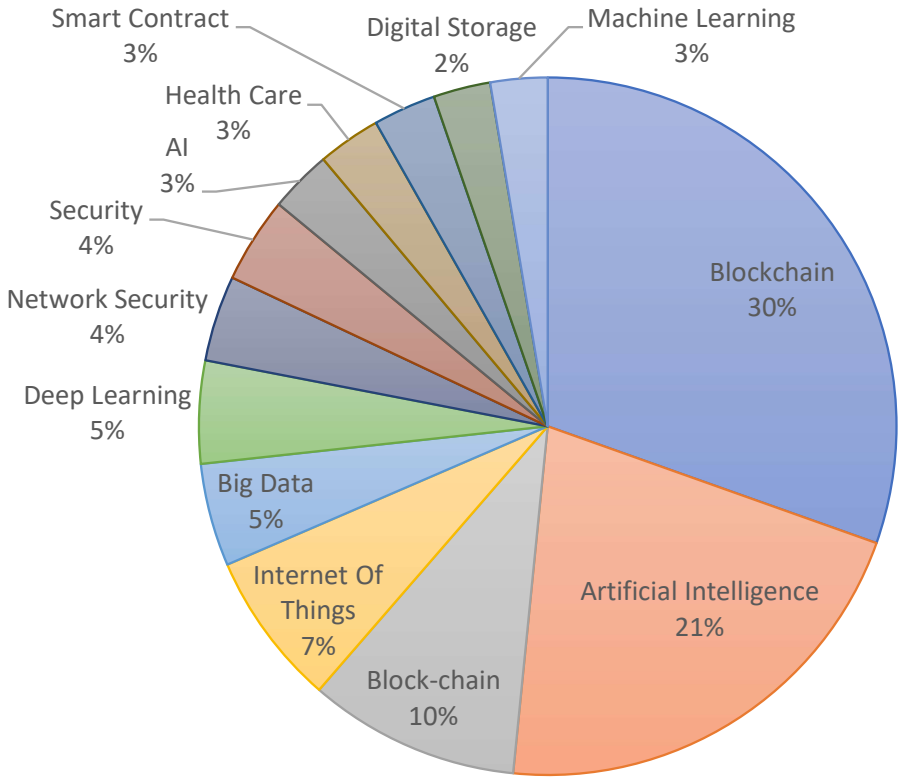


Figure 5. The articles' primary keywords.

The proportion of writers by nationality is shown in Figure 6. It is evident that China had the most writers. Australia and India came next. The populations of various nations may be relevant to this situation.

Table 1. Top 10 publications between 2012 and 2022 in terms of citations. The high citation rate indicates that the combination of AI and blockchains is significant and progressing.

	Objective	Year	Cited by	Source
1	An in-depth analysis of the COVID-19 pandemic and its management impact using 5G, blockchain, AI, drones, and IoT (Internet of Things)	2020	540	[26]
2	Blockchain for AI: Look at it and come up with a new research problem	2019	349	[27]
3	Decentralizing and accelerating biomedical research and healthcare via the convergence of blockchain and next-generation AI	2018	234	[28]
4	BlockIoTIntelligence: Bringing AI to the IoT with blockchain	2020	180	[11]
5	AI and blockchain coming together in an IoT network to create a sustainable smart city	2020	165	[29]
6	Knowledge trading in edge-AI powered IoT: a consortium-based incentive and effective approach	2019	104	[30]
7	The convergence of blockchain, AI, and 3D printing has the potential to revolutionize how humanitarian supply chains are run.	2020	80	[31]
8	Problems, strategies, and future trends of energy cloud management with blockchain and AI	2020	67	[32]
9	Business transformation via digital innovations: use of cloud, data analytics, blockchain, AI, and other technologies	2022	58	[33]
10	How might AI powered by many sensors and blockchain change the cyclic economy of plastic waste from garbage to cash?	2020	42	[34]

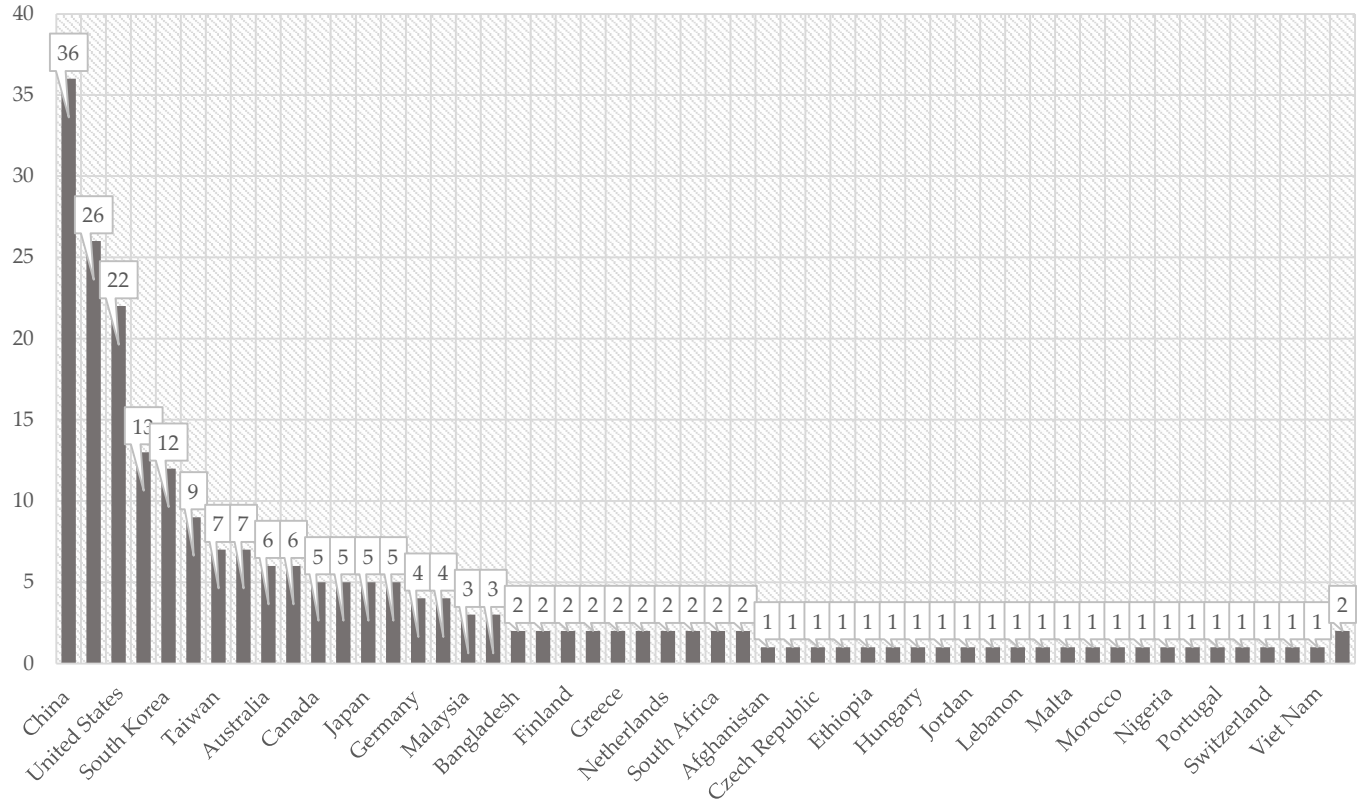


Figure 6. Distribution of authors by country.

4. Benefits of Blockchains and AI Together

4.1. Automation

AI, automation, and blockchains may provide value to multi-party business processes by decreasing the need for human intervention, boosting throughput, and facilitating better data integrity. AI models incorporated in smart contracts implemented on a blockchain could suggest recalling expired products, reordering, paying, or purchasing stock based on predetermined thresholds and events, resolving disputes, and choosing the most environmentally friendly shipping option, among other things. The goal of the research article by Rajagopal et al. [35] was to examine the effects of AI and blockchain technology on an automation service. To obtain pertinent data and information on the study subject, the researcher chose a secondary data gathering approach. Similar to this, the resources employed quantitative techniques to make the data easier to interpret. Additionally, this research will aid readers in comprehending the proper efficacy of AI in managing automation activity.

4.2. Augmentation

AI can read, analyze, and correlate data with lightning speed and depth, giving blockchain-based business networks a competitive edge. Blockchain enables AI to expand by enabling access to enormous amounts of data from inside and outside the company, allowing for more actionable insights, better management of data consumption and model sharing, and a more transparent and trustworthy data market. By leveraging third parties, or oracles, to process data, Lopes et al. [36] suggested an architecture that makes use of blockchain technology as smart contract technology and a ledger for robotic control. They demonstrated how to securely record events, how smart contracts may be used to drive robots, and how to interact with outside AI systems for picture analysis. Since the suggested architecture is simple to integrate, modify, maintain, and expand to other domains, it may be utilized in a variety of settings including manufacturing, network management, and robot control.

4.3. Authenticity

Using the digital record provided by blockchain technology, the AI's underlying structure and the data source it is drawing from can be better understood, thus overcoming the problem of explainable AI. Trust in data and, by extension, AI-generated suggestions is bolstered as a result. Data security may be improved when a blockchain distributes and stores AI models, particularly when combined with AI. Li et al. [37] suggested a blockchain-based data security system for AI in 6G networks. After that, they talked about two 6G-related, AI-enabled applications: autonomous vehicles and indoor positioning. They illustrated the efficiency of blockchains in data security via a case study of an indoor navigation system. Blockchain and AI integration is being developed to assess and improve the level of intelligent service.

5. AI and Blockchain Use Cases

Introducing AI into blockchains creates new possibilities in a wide range of industries.

5.1. Supply Chain

AI and blockchains are revolutionizing supply chains across sectors by adding automation and intelligence to perform transactions, making the data trustworthy and shareable, and digitizing a formerly paper-based process. Carbon emissions data can be tracked, for instance, at the product or component level, giving manufacturers more precision and insight into their decarbonization efforts.

5.2. Financial Services

The introduction of trust, the elimination of friction in multi-party transactions, and the acceleration of transaction speeds are just a few ways AI and blockchains are revolution-

izing the financial services business. Take the procedure of obtaining a loan for example. Applicants agree to allow blockchain access to their data. Faster closings and higher customer satisfaction may be achieved via a combination of data trust and automated application evaluation procedures.

5.3. Life Sciences

The use of AI and blockchains in the pharmaceutical business has the potential to greatly increase the success rate of clinical trials while also boosting transparency and traceability across the medication supply chain. The integrity of data, automation of trial participation and data collecting, monitoring of patients, management of permission, and openness of data are all made possible by combining powerful data analysis with a decentralized framework for clinical trials.

5.4. Healthcare

AI may assist in improving almost every aspect of healthcare, from bringing to light therapeutic findings and supporting user demands to recognizing insights from uncovering trends and patient data. Blockchain technology allows for the safe sharing of sensitive patient information such as electronic health records (EHR) across healthcare providers.

5.5. Social Network Analysis

Only a relatively small amount of research considered the inherent social networking properties of the blockchain [38]. In order to forecast personality, multiple works conducted psychological analyses. Based on the findings, various researchers developed various models that enabled recognizing the characteristics of individuals that characterize their personalities. These models make it feasible to understand the connections that underlie personality and psychiatric disorders [39], work performance and satisfaction [40], and even interpersonal interactions. Social networks are a good source for personality research of a certain group due to the abundance of information they contain and the millions of members they have. The interactions between blockchain users are really quite important for uncovering previously undiscovered patterns and for opening up fresh perspectives for examining this speculative bubble. To examine the connections in the blockchain network, social network analysis concepts might be of significant assistance. In this exercise, it makes sense to picture a social network where each node represents a user, identified by blockchain address, and where each arc represents a user-to-user transaction. In order to uncover patterns of user behavior throughout a cryptocurrency speculative bubble and gather information about it, Bonifazi et al. [38] developed a social network analysis-based technique. Their method is all-encompassing and can be used to analyze any cryptocurrency speculative bubble, whether it exists now or in the future. They demonstrated that their technique includes the capacity to help the search for speculators and that this capability can include past, current, and future bubbles.

6. Why Combine AI with Blockchains

The corporate world and bespoke software development services will see significant adoption of these two technologies over the next 5–10 years. Industry executives that are both forward-thinking and tech-savvy still see the immense potential of combining blockchains with AI. Let us take a look at how one may use AI and blockchains for his or her business.

6.1. Understanding How AI Thinks

However advanced AI may be, it will never replace human judgment and hence will never be widely adopted by the public. The inability to account for the computer's actions is one of the problems that has slowed the widespread use of AI. The public will quickly come to trust AI if its decision-making processes can be recorded.

Incorporating blockchain technology with AI has the potential to reveal previously hidden processes inside computers. Every AI decision may be recorded and made accessible in a distributed ledger. The information on a blockchain cannot be altered once it has been recorded, making it ideal for auditing and other security-sensitive applications.

6.2. Security Improvement

Blockchains include built-in encryption that makes the data very secure. Storing private and sensitive information such as medical records or individual recommendations on a blockchain makes a lot of sense. Continuous and massive amounts of data are essential for AI. AI algorithms that can safely process encrypted data are now the focus of intensive research and development.

In any case, there is a supplementary viewpoint regarding the enhancement of security. There is a high level of security in the blockchain itself, but any extra layers or applications are not bulletproof. In the banking sector, machine learning will speed up the rollout of blockchain applications and allow for the prediction of potential system breaches.

6.3. Gaining Entry to and Control over the Data Market

This is inextricably linked to better safety measures. With the ability to store massive quantities of encrypted data on a distributed ledger and have AI efficiently manage it, fresh use cases emerge. Blockchain technology makes it possible to keep sensitive information, such as medical records, and even benefit from providing others with access to it. That is why there are now markets for data, models, and AI.

Enhancing the data management processes is another advantage of integrating AI with a blockchain. To decipher encrypted data, computers go through possible character permutations until they find the one that matches the original message. A hacking AI is like a person in that it improves with practice. AI, however, will not need a human lifetime to achieve the same level of expertise. This may be accomplished fairly rapidly with sufficient training data.

6.4. Smart Contract Enhancement

Certain vulnerabilities in the blockchain's underlying technology provide a risk for malicious actors. This was very recently shown. To put it another way, smart contracts are not that smart yet. Once certain triggers are reached, they will automatically release and transfer the monies. This can only be accomplished after the blockchain community has reached a unified decision. Since the code for a smart contract is openly available, anybody may take their time to carefully examine it for vulnerabilities. The use of AI aids in the validation of smart contracts and the forecasting of exploitable flaws. Li et al. [41] created Astraea, a private smart contract-based, secure, anonymous, and decentralized auditing platform for contribution systems. In particular, they combined a Distribute Smart Contract (DiSC) with an SGX Enclave to distribute contributions, demonstrate the accuracy of the gift number (intention), and protect the anonymity of donors. They created a donation smart contract by using a DiSC to reimburse deposits and protect against theft and collusion attacks from nefarious collectors and transponders. They used security reduction to explicitly describe and demonstrate Astraea's security and privacy. To carry out an in-depth performance study, they constructed a prototype of Astraea. Astraea is efficient in terms of both computing and communication, according to experimental data.

6.5. Maximizing Energy Efficiency

Energy consumption is high while data mining. This is a huge problem in the contemporary world, but Google has shown that machine learning can solve it. By feeding the DeepMind AI historical data from hundreds of sensors inside a data center, Google has enabled cutting down on the amount of energy needed to keep its data center at a comfortable temperature by 40 percent. Using this similar concept, mining hardware costs may be reduced.

7. AI Applications Powered by a Blockchain

This section presents research published in the literature on the application of blockchain technology and AI to better manage and protect data and algorithms and answer RQ3: What applications do blockchains and AI have together?

7.1. Smart Grid

Everybody contributes to the energy supply in a smart grid, which is part of the energy Internet [42,43]. Smart grids are currently following a trend toward distributed energy trading, but this model is incompatible with the centralization of traditional grids. Therefore, the smart blockchain's distributed nature can greatly aid in facilitating the shift from centralized to distributed power in smart grids [44]. The smart blockchain's decentralized nature allows for the elimination of information silos and the realization of trustless data exchange between multiple parties [45]. In addition to lowering the price of keeping smart grids running, blockchain technology can also increase market participation and reduce associated operating expenses [46]. The research by Wang et al. [47] suggests an AEBIS, or AI-enabled electric vehicle integration system, for power management in a platform for smart grids. An electric vehicle fleet is used as both a consumer and a supplier of electrical energy within a virtual power plant (VPP) platform in the system, which is built on an artificial neural network and federated learning methodologies. The suggested system generates dependable and timely service to deliver additional electricity from the vehicular network, reducing the level of power fluctuation with the correct prediction of power use. Additionally, the use of AI chips provides cost-effective performance. At the expense of a manageable memory and latency cost, adding a blockchain to the system further delivers a safe and transparent service. Figure 7 depicts the graph of incorporating blockchains and AI into smart grids.

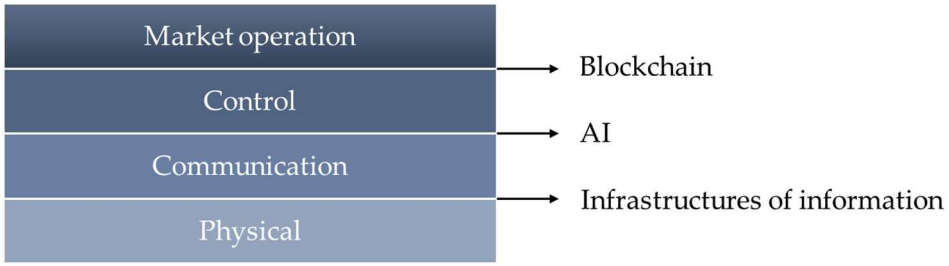


Figure 7. Blockchain applications in smart grids.

7.2. Agriculture Aspects

Understanding blockchain technology and its implications for agrifood is the primary goal of the PPP project titled "Blockchain for Agrifood". This project is focusing on the specific aspects of SCM and the necessity of applying blockchains in agrifood chains [48]. According to Markets and Markets, the global blockchain in the agricultural and food supply chain market is expected to extend to USD 429.7 million by 2023, expanding at a CAGR of 47.8% (2019). In agriculture, blockchain-based data management can improve the integration of supply chain resources [49]. Figure 8 summarizes the applications of blockchains in smart agriculture. The traceability of food from the farm to the dinner table can be confirmed by using the blockchain to develop a digital identity for the actual product or service. Using IoT-based smart devices, an AI engine provides proactive assistance to farmers on sowing, pest control, harvesting, etc. as well as alerts to the farmers. Future food safety catastrophes, such as the *E. coli* outbreak that sickened people in 25 states due to contaminated lettuce, can be better managed with the use of blockchain technology. Using blockchains, AI, and the IoT might boost productivity, cut expenses, and increase revenue for businesses. Case studies focusing on Chinese pork and Mexican mangoes show that Walmart and Kroger were among the first corporations to hold blockchains and use the technology in their supply chains [50].

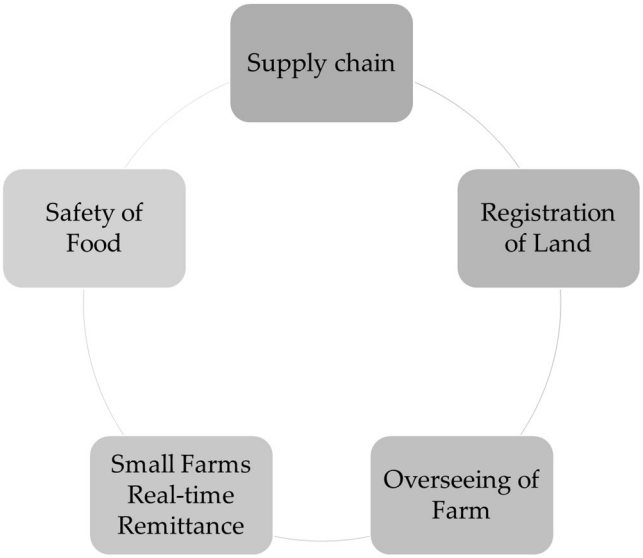


Figure 8. Blockchain applications in smart agriculture.

The agriculture industry is becoming more intelligent, predictive, trackable, and transparent as AI and blockchains are increasingly integrated. To guarantee openness in their food supply chains, the food and dairy industries have adopted blockchain technology platforms. Table 2 summarizes some of the important findings from the literature.

Table 2. Agriculture using blockchains and AI.

Number	Objective	Reference
1	Blockchain-based agriculture 4.0 strategy	[51]
2	Investigating supply chain management using blockchains, AI, and the IoT	[52]
3	Using blockchains to focus on Food Industry 4.0	[53]

7.3. Supply Chain

Due to its decentralization, high dependability, and immutability, the blockchain has become a significant technological way to overcome the development restrictions of conventional supply chains [54]. Information asymmetry between downstream and upstream firms in the supply chain may be successfully resolved via the use of the blockchain network to publish the data held in the database, therefore facilitating the accurate and speedy exchange and cooperation of logistical data [55].

Applying AI to the blockchain system has the potential to completely automate the supply chain, hence redefining its very nature. Integrating with the blockchain allows the AI platform to learn from historical purchase data, point-of-sale sales data, etc., allowing for the identification of data characteristics and the implementation of predictive analysis such as demand forecasting, sales model forecasting, route planning, and network management (Figure 9) [56]. The solution D'souza et al. [57] suggested in their study for the secure distribution of pharmaceuticals throughout the whole supply chain leverages a blockchain and AI. Using an event request-response method, each product within the chain may be moved between chain members who have been verified. Smart contracts are used to record all transactions between entities onto the blockchain, allowing a product to be tracked back to its original source. The results of the experiments demonstrate that our technique is workable and somewhat more secure than current solutions.

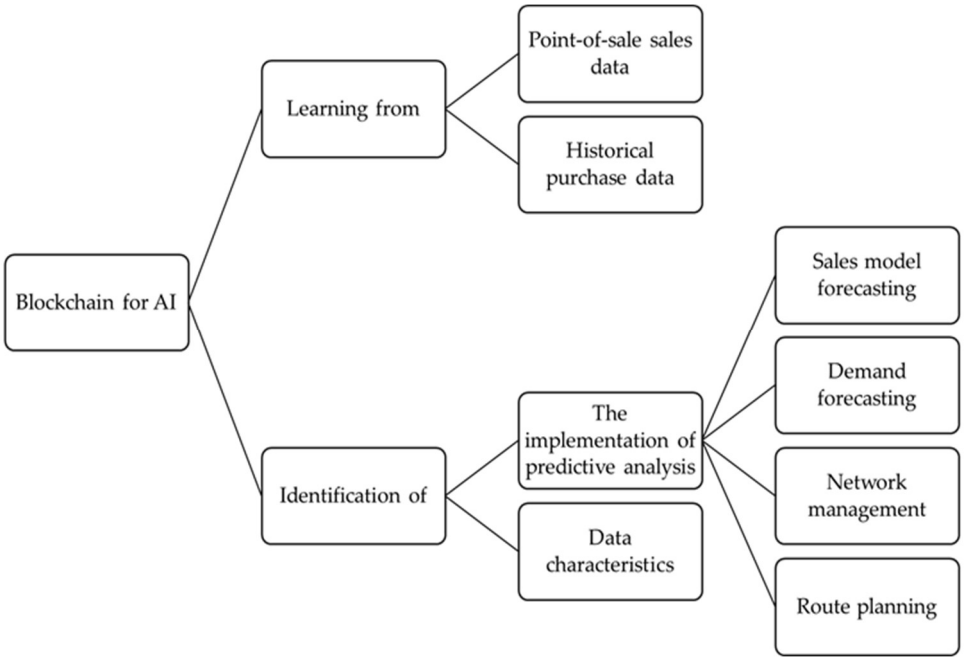
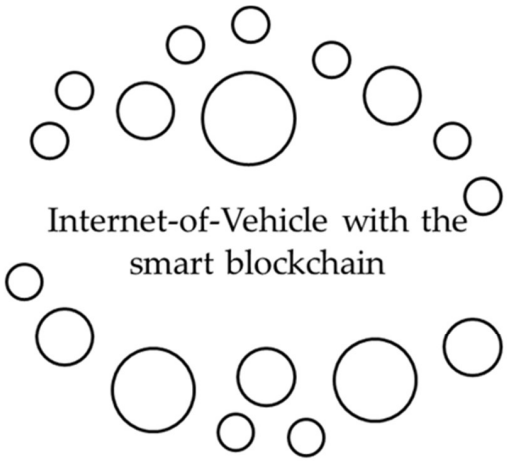


Figure 9. The applications of integrating AI and blockchains in supply chain.

7.4. Internet of Vehicles

The Internet of Vehicles (IoV) has become more significant in the field of intelligent transportation as a result of the proliferation of communication technologies [58,59]. Although vehicle-to-vehicle communication through the IoV has the potential to ameliorate current traffic and road safety issues, there is a risk of a trust crisis and other safety concerns arising from the technology's use [60,61]. The development of Internet of Vehicle technology may be hastened with the help of a smart blockchain, which can offer trust assurances, trustworthy data security, and efficient incentive systems (Figure 10). Blockchain technology adds new participants (vehicles, people, and service providers) to the chain. Through its openness, anonymity, and immutability, it facilitates data information exchange, increases the security of stored data, and fosters trust between various components [62].



- Trust assurances
- Trustworthy data security
- Efficient incentive systems

Figure 10. Effects of smart blockchain on IoV.

In dispersed vehicle networks, standard AI-based algorithms are also ineffective. The research by Chai et al. [63] proposed a hierarchical blockchain architecture and a hierarchical federated learning algorithm for knowledge sharing, wherein cars learn environmental data using machine learning techniques and share the learning information with one another. Large-scale automotive networks may use the suggested hierarchical blockchain system. The distributed privacy and pattern requirements of IoVs are met by the hierarchical federated learning method. To encourage sharing behaviors, knowledge sharing is then represented as a trading market process, and the trading process is framed as a multi-player and multi-leader game. The suggested hierarchical method may boost sharing effectiveness and learning quality, according to simulation findings. Additionally, the blockchain-enabled system has good defenses against certain harmful assaults.

7.5. Healthcare Aspect

The foundation of conventional EHR systems is a centralized architecture which gives one organization overall responsibility for system oversight, coordination, and management. AI has the computing heft to handle large volumes of patient data and the speed to quickly assess them. Despite AI's impressive capabilities, which have shown that it can perform many dynamic and cognitive functions quicker than a person, some doctors are still reluctant to use AI to affect a patient's health [64,65]. Healthcare applications of blockchains and AI are shown in Figure 11.

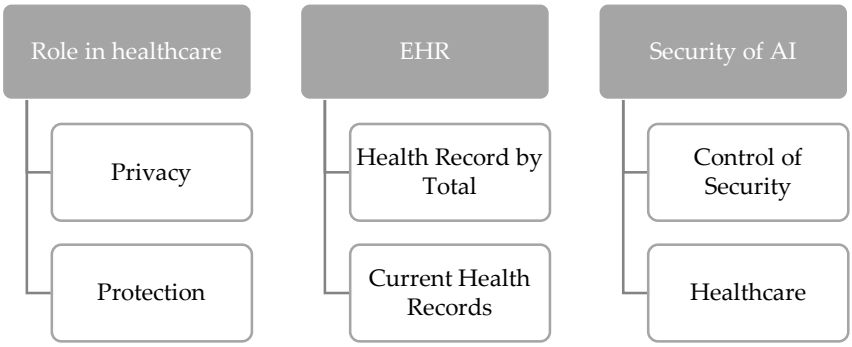


Figure 11. Healthcare applications of AI and blockchains.

Recent research [66,67] also shows that distance has a negative correlation with people using health care. Thus far, blockchains and AI are the two technologies that have shown the most promise for improving healthcare delivery. Interest from the academic community has been shown in the area of using these methods in EHR data processing. On the other hand, blockchain technology has been expanding its presence in the healthcare sector. To prevent the malicious modification and exploitation of patient data, it addresses the interoperability problems of existing EHR systems [68]. Live AI solutions for clinical decision support systems and public health management are used by several EHR-based software platforms, including Epic, to forecast hospital readmissions, patient risk levels, death, and deterioration. Similarly, patients may now use a blockchain-based system called MedRec. Scholars have used a variety of strategies based on blockchain technology and AI technologies to study the aforementioned conclusions. Several features allow the health business to conduct comprehensive assessments of data without sacrificing data security or the ability for specialists to obtain data within a predetermined time frame [9]. Using a focus on AI and the IoT, which have not been combined before [69], this inquiry analyzes the impacts, suggests a study topic, and explores the utilization of blockchains in food, agriculture, and health. In addition, modern technologies are better equipped to analyze big data sets in real time, which paves the way for quicker illness diagnosis and detection as well as automated therapy possibilities and comparisons [70]. In addition to enhancing trust and communication between healthcare providers and their patients, blockchain

technology also facilitates more transparency in the healthcare industry. Table 3 provides a summary of the key results from the literature.

Table 3. Healthcare using blockchains and AI.

Number	Objective	Reference
1	To solve the difficult challenge of data exchange in healthcare	[71]
2	Using the IoT and blockchains to provide a novel approach for enhancing biomedical research to benefit from patient information	[28]
3	Integrating blockchains, big data, AI, and the IoT for better health and in other industries	[25]
4	Security and reliability of blockchain technology for use in healthcare predictive modeling that protects individual privacy	[72]
5	Blockchain technology's potential and possible pitfalls in the healthcare industry	[73]
6	Blockchain-enabled IoT intelligence architecture (BlockIoTIntelligence)	[11]
7	Data integration with AI and blockchains	[74]
8	Using AI and blockchains to focus on PHR	[75]

8. Challenges

This section points out the problems and challenges in the integration of blockchains and AI and answers RQ4: What are the challenges with combining blockchains with AI?

8.1. Privacy and Security

Among the obstacles of blockchain application, privacy, security, and landing protection are major concerns [76]. Due to its role as the backbone of the Internet of Value, the blockchain's inter-node communications are public and transparent, but they may also include sensitive data that users would like to keep secret. Therefore, the key to whether or not blockchain applications can be deployed on a big scale is how to safeguard user privacy. Typical blockchain privacy protection strategies include information concealment and identity confusion. Using privacy-protecting signature technologies such as ring signatures and group signatures to muddle the identities of both participants in a transaction, identity obfuscation technology makes it hard to match the true user to their blockchain transaction. The supervisor's private key allows the supervisor to access user data as required, protecting users' identities.

The user's transaction privacy is successfully protected by information concealing, which employs technologies such as secure multiparty computing and zero-knowledge proof to complete transactions without disclosing any private information and to guarantee the credibility of the findings. The increased complexity of the calculations, however, results in a less effective system, and therefore more work has to be carried out to boost its usefulness in real-world contexts. It is not easy to figure out how to apply AI algorithms sensibly to boost inefficient performance. Furthermore, the current AI algorithm has to be redesigned to be applied to a distributed context.

Private AI, which combines AI and encryption methods to solve the data security problem, was recently developed, but prior research has demonstrated that model inversion attacks may be used to reverse-engineer the model parameters to create pictures [77]. In this context, Khowaja et al. [78] suggested an industrial IoT environment-specific federated learning and encryption-based private (FLEP) AI system that offers two-tier security for data and model parameters. They provided a hypothetical approach to protect the model parameters together with a three-layer encryption mechanism for data security. The suggested approach, according to experimental data, produces improved encryption quality at the cost of a somewhat longer execution time. By applying a trust-based protection mechanism, Corradini et al. [77] suggested a two-tier blockchain architecture to improve the security and independence of smart items in the IoT. Smart items are appropriately

categorized into communities in this architecture. The first-tier blockchain is local and is only used to record probing transactions carried out to assess the confidence of an item in another one of a different community or of a same community, which reduces the complexity of the solution. These transactions are periodically aggregated after a time interval, and the resulting values are kept on the secondary blockchain. In particular, the stored values are each object's standing within its community and each community's confidence in the other communities inside the framework.

Moreover, the blockchain and federated learning integration method has drawn a lot of interest as a new trustworthy data-sharing pattern with privacy protection. Generally speaking, this approach bypasses the supervision of the computing process and federated learning model in favor of using blockchain technology to oversee the original data and computation outcomes [14]. In order to create a new data privacy sharing paradigm using blockchains and federated learning, Guo et al. [14] presented the ideas of the sandbox and state channel. They primarily addressed issues with data privacy sharing in federated learning and the deterioration of system performance brought on by poor data quality. The simulation results demonstrate that the suggested strategy outperforms and is more effective than the conventional data exchange method.

8.2. Credible Oracles

Blockchain players may trigger the execution of a smart contract by triggering an external event or calling a third-party function. Event or data retrieval automation is not a primary focus of smart contract design. To rephrase, the contracts are unable to obtain information from the real world. The contracts need to be "pushed" data and events. To address these issues, it is recommended to employ trustworthy oracles, which are essentially trusted external parties or nodes, to transmit events and data to smart contracts. When it comes to maintaining trust, oracles provide a new layer of complexity and potential security risks, as a previously decentralized system becomes centered on a set of oracles that must be relied upon. Usually, the agreement is reached by a vote among reliable oracles [79].

8.3. Concerning the Security of Smart Contracts and the Implications of Their Deterministic Execution

The success of a smart contract relies on its implementation being safe against hacks and errors. Code and data on the network should be protected against intrusion wherever possible. For instance, in 2016, hackers exploited a critical flaw in the coding of the Ethereum platform used to create the smart contract for the DAO. There was a loss of 3.6 million Ethers as a consequence of this. This problem, introduced by smart contract programming and other blockchain-based applications, calls for blockchain engineering [80]. Problems with security in smart contracts may be traced back to careless coding in the languages used to create them. The relevance of vulnerability testing for smart contracts has grown, and as a result, several tools have been created to evaluate the safety of a contract's source code [81,82]. Moreover, as it stands right now, there is no such thing as a probabilistic result for the execution of a smart contract. When AI and machine learning-based decision-making algorithms are implemented as smart contracts by the mining nodes, the execution output is typically not deterministic but rather random, unpredictable, and approximative [83]. This may be a significant difficulty for decentralized AI. With data input that might be rapidly changing as much as that of IoT and sensory readings, this calls for a unique approach to deal with approximation computation and to design consensus protocols for mining nodes for agreeing on outputs with a certain degree of confidence, accuracy, or precision.

8.4. Scalability

The key to the successful rollout of smart blockchain applications is in solving the scalability problem [84]. Blockchain decentralized applications need the underlying blockchain platform to function. If the scalability and performance of the system are inadequate, it cannot be deployed as a large-scale application. The blockchain's scaling concerns may be

broken down into three primary categories: consistency problems, network latency, and performance constraints. Most nodes need to agree on the transaction data to guarantee the blockchain's security. The blockchain will split if the need for consistency in the distributed network is neglected in favor of faster growth. Due to its decentralized nature, blockchain's scalability is limited by the time it takes for data to travel between nodes in the network. This is particularly true for longer delays. The key problem that prevents the widespread use of blockchain applications is the impact of transaction performance on scalability [85]. To maintain security and ultimate consistency, blockchain transactions cannot be completed in parallel, which makes it impossible to boost transaction throughput.

8.5. Off-Chain and On-Chain Storage Data Cooperation

Blockchain technologies and conventional information storage methods both have advantages and disadvantages. Both conventional information systems and blockchains require off-chain storage and compute infrastructure to boost performance. To accomplish this, it is necessary to combine blockchain technology with conventional information systems, with the most important consideration being to guarantee the accuracy and consistency of both the data on the chain and the data that are stored in conventional databases. More importantly, data are essential to the advancement of AI. There are still several obstacles to the widespread use of AI, such as issues with data quality, data monopolization, and data abuse. The introduction of blockchain technology opens up new avenues for solving these issues. The marriage of blockchains and AI is only useful in the real economy if the data on the chain are properly combined with the data off the chain [86].

In order to enable model sharing and ensure a fair model-money exchanging process between independent developers and ML-as-a-service (MLaaS) providers, Weng et al. [87] developed a model marketplace dubbed Golden Grain. To encourage the loyal contributions of well-trained models, they implemented the swapping process on the blockchain and subsequently created a blockchain-enabled model benchmarking procedure for openly deciding the model values in accordance with their real-world performances. Their marketplace carefully offloads the laborious computation and designs a protected off-chain on-chain interaction protocol based on a trusted execution environment (TEE), for guaranteeing both the integrity and authenticity of benchmarking, particularly to reduce the blockchain overhead for model benchmarking. In order to show the realistically inexpensive performance of their architecture, they deployed a prototype of Golden Grain on the Ethereum blockchain and carry out comprehensive testing using common benchmark datasets.

9. Conclusions

There is no denying the rapid pace at which blockchain- and AI-based concepts are being adopted. However, although both paradigms bring something new to the table, the level of originality and complexity varies widely. Because of the prevalence of digital currency in today's society, blockchain technology may one day automate payments and facilitate the secure, distributed transfer of sensitive data, information, and transaction records. Both blockchains and AI have been in the spotlight recently. Blockchain technology automates bitcoin payments and gives users access to a shared ledger of records, transactions, and data using a decentralized, secure, and trustworthy system. A central authority may not be necessary for blockchain technology's smart contracts to govern user interactions. AI, on the other hand, gives machines reasoning and decision-making capabilities on par with humans. However, combining these two technologies might cause a dramatic change in the market. Both technologies are state-of-the-art, but by combining them, work might be completed more quickly and with less effort. This realization led to the investigation of a rigorous assessment of blockchain and AI combination publications written between 2012 and 2022. This presentation examined the current state of blockchain and AI combinations, their applications, and the possible revolutionary effects of their unique traits. There were 121 distinct publications on this topic that were considered for

this assessment in total. The belief in the potential of AI and blockchains is gaining more and more acceptance. The benefits of combining AI with blockchain technology are covered in this essay. The bulk of this analysis is devoted to the use cases for integration, including supply chains, financial services, healthcare, life sciences, smart grids, agriculture, and the IoV. Before concluding, issues including privacy and security, credible oracles, the security of smart contracts, and the consequences of their deterministic execution, scalability, and collaboration between off-chain and on-chain data storage were covered.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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