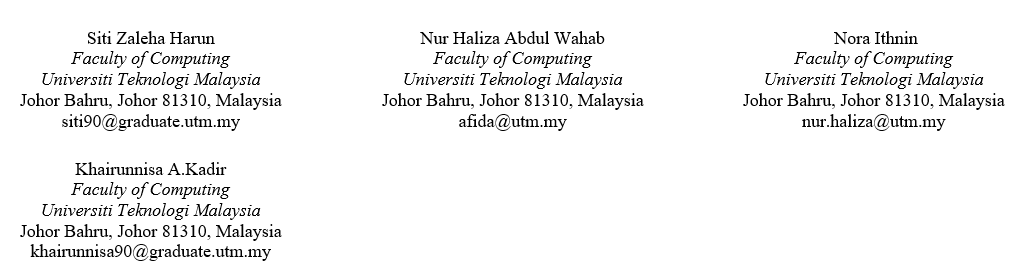
Title: Blockchain Meets Artificial Intelligence: A Comprehensive Review of Synergizing Futures.



ABSTRACT

The rapid evolution of Artificial Intelligence (AI) and Blockchain technology has paved the way for transformative changes across multiple sectors, promising enhanced security, transparency, and efficiency. This comprehensive literature review delves into the synergistic potential of merging AI with Blockchain technology, examining the breadth of research and development efforts documented in leading academic and industry publications from IEEE and Springer between 2016 and 2023. By systematically analysing the convergence of these two revolutionary technologies, our review highlights key advancements, practical applications, challenges, and future directions. We explore the integration of Blockchain's immutable ledger with AI's predictive capabilities to foster innovative solutions in areas such as supply chain management, healthcare, and privacy-preserving data sharing. Additionally, this review addresses the technical, ethical, and regulatory challenges encountered in the integration process, offering insights into how these hurdles are being overcome. Through a critical evaluation of existing literature, this paper aims to provide scholars, practitioners, and policymakers with a thorough understanding of the current landscape, encouraging informed decision-making and inspiring future research at the intersection of AI and Blockchain technology.

Keywords—Blockchain, Artificial Intelligence, Merging Technology, BAI

INTRODUCTION

Artificial Intelligence (AI) and Blockchain technology have been two revolutionary forces that have drastically changed the technical landscape in the previous ten years. Originally the term AI was introduced by John McCarthy in 1956 [1] to proposed a summer research project to explore ideas surrounding "thinking machines" and the possibility of creating machines capable of intelligent behaviour. While the term of Blockchain was introduced by Satoshi Nakamoto in 2008 in the white paper titled "Bitcoin: A Peer-to-Peer Electronic Cash System." to proposed as a core component of the Bitcoin cryptocurrency system, describing a decentralized ledger technology for recording transactions securely and immutably [2]. In the realm of historical integration, blockchain emerges as a relatively nascent concept, introduced by visionaries Nakamoto and Wright in 2008 [3]. Nonetheless, the synergistic fusion of artificial intelligence and blockchain is rapidly gaining traction across diverse domains, notably in healthcare and pharmaceuticals. This symbiotic relationship presents novel avenues, fostering heightened trust and bolstered efficiency. By 2030, there will be an estimated that blockchain and AI will converge to create a new paradigm of decentralized, trustworthy, and intelligent systems. Blockchain will provide the infrastructure for data sharing, verification, and governance, while AI will enable data analysis, optimization, and automation. Together, they will enable new applications and services that are more efficient, transparent, and fair [3] and McKinsey Global Institute, for example, predicted that the AI market will grow to 13 trillion dollars by 2030.

Blockchain and artificial intelligence (AI) are two emerging technologies that have the potential to transform various domains and industries. However, they also face several challenges and risks that could compromise their security, reliability, and performance. Some of the factors that contribute to the vulnerability of blockchain and AI are: Lack of standards and regulations, Human errors and malicious attacks, Scalability and efficiency issues, Interoperability and compatibility challenges. Blockchain and AI are lack of standards and regulations because these technologies still relatively new and evolving fields, and there is no clear consensus on the best practices, guidelines, and policies for their development and deployment. This could lead to inconsistent, incompatible, and unethical applications that could harm users, stakeholders, and society [4, 5]. Other than that, Human errors and malicious attacks is one of vulnerability in Blockchain and AI because these technologies rely on human inputs, such as data, code, and parameters, which could be erroneous, incomplete, or manipulated. Moreover, both technologies are susceptible to various types of cyberattacks, such as denial-of-service, 51% attack, Sybil attack, adversarial examples, and backdoor attacks, that could compromise their integrity, availability, and confidentiality [6]. On the other hand, the Scalability and efficiency issues in Blockchain and AI require significant computational resources and energy consumption to operate, which could limit their scalability and efficiency. For instance, blockchain networks use a consensus mechanism, such as proof-of-work or proof-of-stake, to validate transactions and maintain security, which could be slow, costly, and wasteful. Similarly, AI models, such as deep neural networks, require large amounts of data and processing power to train and infer, which could be time-consuming and expensive [5]. Other than that, Interoperability and compatibility challenges in these technologies is one of the vulnerabilities in these technologies. Blockchain and AI are often used in combination with other technologies, such as cloud computing, internet of things, and big data, to create complex and integrated systems. However, these technologies may not be fully compatible or interoperable with each other, which could cause technical difficulties, communication errors, and performance degradation.

Review studies have been conducted in the area of the basic of blockchain technologies, fundamental of AI and the emerging of these technologies. Review studies have been conducted in the area of the basic of blockchain technologies, fundamental of AI and the emerging of these technologies. These studies provide a comprehensive overview of the current state-of-the-art, challenges, and opportunities of blockchain and AI integration. However, there is still a lack of empirical and practical research that demonstrates the real-world applications and impacts of blockchain and AI convergence[7]. Therefore, this paper aims to fill this gap by presenting a systematic review of the existing blockchain and AI applications in various domains and industries, such as finance, health care, supply chain, energy, and education. We also identify the common benefits, limitations, and requirements of these applications, and propose a conceptual framework for designing and evaluating blockchain and AI solutions [8].

Each has individually brought about significant transformations in the ways that data is handled, protected, and used in a variety of contexts. But the combination of AI and Blockchain promises to have much more of an impact, bringing in a new era of creativity and productivity. The goal of this research review journal is to examine in detail how blockchain technology and artificial intelligence work together to create novel opportunities for growth across several industries. Artificial intelligence has found uses in everything from driverless cars to healthcare diagnostics. Its capabilities include learning from data, making judgements, and predicting results. Blockchain technology, on the other hand, provides a decentralised and tamper-evident ledger system that guarantees security and transparency in digital transactions. Blockchain technology is most renowned for being the foundation of cryptocurrencies like Bitcoin. Combining these technologies improves their already-existing capabilities and opens up new, previously unreachable applications [9].

This paper aims to give a thorough overview of the academic and industry developments in the fusion of blockchain technology and artificial intelligence from 2016 to 2023. Through a comprehensive review of a wide range of literature from reputable sources such as IEEE and Springer, the purpose of this paper is to determine the present status of this integration, identify significant accomplishments, and talk about future prospects and problems. By means of this investigation, "Blockchain Meets Artificial Intelligence: A Comprehensive Review of Synergizing Futures" aims to provide readers with a sophisticated comprehension of how the amalgamation of AI and Blockchain is laying the foundation for a future in which intelligent automation and digital trust will push the frontiers of technology. The assessment will lay the groundwork for future research and development in this fascinating interdisciplinary topic by critically analysing the technologies' effects across a range of industries and charting their evolution.

The structure of this study is as follows: Section 1 delves into the Literature Review, offering an in-depth exploration of relevant scholarly works. Section 2 highlights emerging technologies, elucidating their current applications across various industries. The findings and discussions, encompassing responses to research inquiries, are articulated in Section 3. Finally, Section 4 offers Conclusions and outlines potential avenues for future research.

1. LITERATURE REVIEW

Artificial Intelligence (AI) and Blockchain, two of the 21st century's most revolutionary technologies, have seen unprecedented progress over the last ten years. These technologies, each with its own uses and a persistent quest to push the limits of technological capability, have developed from fledgling ideas to cornerstones of contemporary digital infrastructure. This section examines how AI and blockchain have developed independently, as well as key turning points and the theoretical foundations that have prepared the way for their combination [10].

1. Artificial Intelligence: Significant Advances and Practical Uses; From the creation of fundamental machine learning algorithms to the emergence of deep learning, which has greatly increased AI's capabilities and applications, artificial intelligence has experienced an amazing journey. The development of deep learning algorithms, like Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), was a turning point in the evolution of AI. These algorithms have made it possible for machines to process and interpret complex data structures, like images and sequential data, with previously unheard-of accuracy.

Science fiction applications have now found real-world use thanks to these breakthroughs. AI algorithms are currently used in healthcare to help diagnose illnesses more accurately than human doctors in certain situations. Artificial Intelligence (AI) powers autonomous cars in the automotive sector, sifting through enormous volumes of sensor data to make navigational decisions in real time. Furthermore, artificial intelligence (AI) has transformed how companies engage with their clientele by creating complex natural language processing (NLP) models that allow chatbots and conversational agents to offer customized customer support.

1. Blockchain: From Digital Assets to Worldwide Internet Infrastructure; Originally envisioned as the foundation for cryptocurrencies such as Bitcoin, blockchain technology has expanded far beyond its application in finance. Across many industries, its distinct value proposition of decentralized, transparent, and safe record-keeping has been acknowledged. Blockchain has been used in supply chain management to produce tamper-proof product trip records, improving accountability and transparency. It provides solutions for the safe and unchangeable storage of patient data in the healthcare industry, enabling improved data sharing while protecting patient privacy.

Smart contracts, self-executing contracts with the conditions of the agreement directly put into lines of code, have also been developed as a result of Blockchain’s expansion. This development has increased the potential for automating complicated contracts without the need for middlemen, broadening the range of industries in which Blockchain can be used.

1. Theoretical Suggestions for Blockchain and AI Integration

Researchers and developers realized that blockchain and AI have complementary strengths, which is when the notion to combine the two started to take shape. Blockchain technology was first offered as a solution to some of the biggest issues facing AI, such as data security, privacy, and the requirement for open decision-making procedures. To increase confidence in AI systems, Blockchain's immutable ledger, for example, might offer a verifiable record of AI choices.

On the other hand, artificial intelligence (AI) might improve blockchain technology by streamlining consensus processes, boosting security against fraud, and leveraging predictive analytics to improve smart contract functionality. Important academic studies from this era discussed frameworks for decentralized AI marketplaces on the Blockchain, where data could be exchanged without jeopardizing privacy and algorithms could be bought and traded safely. These articles lay the foundation for practical integration.

At the nexus of AI and blockchain, a new interdisciplinary discipline arose as these theoretical claims started to come to pass. In addition to addressing the intrinsic difficulties presented by each technology, this sector promises to foster synergistic relationships that may result in previously unthinkable advancements. An important turning point in the development of digital technologies has been reached with the investigation of AI and Blockchain integration, paving the way for a time when these technologies will propel advancement in a world that is becoming more digitally connected and networked by the day.

## Basics of Blockchain Technology

Blockchain technology provides a decentralized, transparent, and safe means of recording transactions over a network of computers. It is hailed as the cornerstone of contemporary digital innovation. This portion of the literature analysis dives into the fundamentals of blockchain technology, examining its types, fundamental ideas, and innate characteristics that have made it a disruptive force in a number of industries.

The fundamental idea behind distributed ledger technology is the maintenance of transaction records across multiple computers as opposed to one central location. The security and resilience of the data kept on the Blockchain are greatly increased by this decentralization, which makes sure that no one party has control over the whole database. There are several transactions in each block of the chain, and each time a new transaction takes place, a record of that transaction is recorded to the ledger of each participant.

One key component of Blockchain security is the integration of cryptographic hash algorithms. An immutable chain of blocks is produced by each block having a distinct hash of the previous block, making it nearly impossible to change without being noticed. Because it guarantees that a transaction cannot be altered after it has been recorded in the Blockchain, immutability is essential for fostering confidence in the system.

Another essential component of Blockchain technology are smart contracts, which are self-executing agreements with the conditions of the contract encoded directly into the code. These contracts operate automatically, without the need for middlemen, to implement and enforce its terms in accordance with predetermined regulations. This breakthrough has created a plethora of opportunities for the transparent and conflict-free automation of intricate agreements and processes.

Three primary forms of blockchain networks may be distinguished: consortium, private, and public blockchains. Each type caters to distinct requirements and provides variable degrees of privacy and access control.

1) Public Blockchain:

Public Blockchain like Ethereum and Bitcoin, are totally accessible to anyone who wants to sign up and take part in the network. These fully decentralized blockchains provide great levels of security and transparency, but frequently at the expense of speed and scalability.

2) Private Blockchain:

Private blockchains are only available to particular companies or groups, and access and permissions are strictly regulated. These blockchains are more scalable and efficient, which makes them a good fit for companies that need to conduct transactions quickly and privately but at the expense of increased centralization.

3) Public Blockchain:

Consortium blockchains, which are run by several organizations as opposed to just one, offer a compromise. They offer a middle ground between the increased control and efficiency of private blockchains and the high security and openness of public blockchains.

Blockchain technology is now used for much more than just virtual currencies. Because of its characteristics, which provide transparency and traceability throughout the goods' path from production to delivery, supply chain management improvements have been made possible. Blockchain technology makes it possible to store patient records in an encrypted and unchangeable manner, which promotes effective data sharing between healthcare providers while protecting patient privacy. Blockchain has also revolutionized the financial industry by enabling safer, faster transactions while cutting costs and fraud.

Blockchain technology has limitations despite its potential, such as scalability problems, energy consumption (particularly in proof-of-work consensus techniques), and regulatory uncertainty. Since the size of the ledger increases and the network's capacity to handle a finite number of transactions per second, scalability is still a major challenge for public blockchains. Furthermore, mining-related energy usage has sparked worries about the environment, especially in networks that employ proof-of-work consensus procedures [11].

To sum up, blockchain technology signifies a major change in the way a variety of sectors record and execute transactions and maintain data. It is an effective instrument for innovation because of its decentralized structure as well as the security and transparency it provides. For it to continue to be used and evolve, it is imperative that the issues of scalability, energy consumption, and regulatory compliance be resolved. The studied literature emphasizes how Blockchain technology is dynamic and ever-evolving, with the ability to completely transform businesses by providing secure, transparent, and effective solutions.

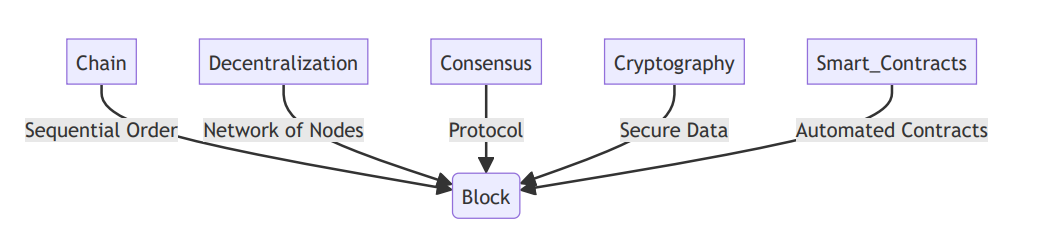


Figure 1: Basic elements in blockchain technology

Figure 1 shows the foundational elements of blockchain technology. At its core lies the concept of "Blocks," each representing a container of data containing transactional information. These blocks are sequentially linked together to form a "Chain," symbolizing the chronological order of transactions. The principle of "Decentralization" is illustrated by a network of interconnected nodes, signifying the distribution of the blockchain across multiple participants. This decentralization ensures redundancy and enhances security by eliminating a single point of failure. The "Consensus Mechanism" node represents the protocol governing how nodes agree on the validity of transactions and add new blocks to the blockchain. Cryptographic techniques, denoted by the "Cryptography" node, are employed to secure the data within each block, ensuring tamper-proof integrity. Additionally, the diagram includes "Smart Contracts," which are self-executing contracts encoded within the blockchain, automating transactional processes and enhancing trust. Together, these elements define the structure and functionality of blockchain technology, enabling decentralized, secure, and immutable transactional systems.

B. Fundamentals of Artificial Intelligence

With the use of artificial intelligence (AI), computers can now accomplish activities that would normally need human intelligence, marking a paradigm change in computational capabilities. This part on literature review explores the foundations of artificial intelligence (AI), detailing its development, essential ideas, methods, and the significant influence it has had on numerous industries.

The first neural network models and the Turing Test, which Alan Turing suggested as a gauge of machine intelligence, marked the beginning of artificial intelligence (AI) in the middle of the 20th century. Artificial intelligence development has fluctuated throughout the years, with spurts of activity interspersed by "AI winters," or times when advancements appeared to halt. But in the twenty-first century, huge data, more processing power, and improvements in machine learning algorithms have brought to a resurgence of AI research and applications.

Several fundamental ideas and methods that have aided in the development of AI are at its core: A branch of artificial intelligence called machine learning (ML) is concerned with creating algorithms that can analyse, interpret, and generate predictions from data. Rather than requiring explicit programming for every decision, machine learning enables models to adapt and get better with further data exposure.

1) Deep Learning:

Using multiple-layered artificial neural networks (deep networks), deep learning is an advanced subset of machine learning that model’s intricate patterns in data. In domains including natural language processing, autonomous cars, and image and audio recognition, deep learning approaches have proved essential to obtaining cutting-edge outcomes.

2) Natural Language Processing (NLP):

Natural Language Processing (NLP): This branch of artificial intelligence studies natural language communication between computers and people. Chatbots, machine translation, and sentiment analysis are made possible by natural language processing (NLP), which gives machines the ability to comprehend, interpret, and produce human language.

3) Reinforcement Learning:

Reinforcement learning is a kind of machine learning in which an algorithm gains decision-making skills by acting in a given environment and getting feedback in the form of incentives or penalties. This method has been applied to create systems that perform well in settings requiring complicated decision-making, such gaming and robotics.

AI has a wide range of revolutionary applications that affect almost every aspect of life. AI systems are used in healthcare to help with disease diagnosis, patient outcome prediction, and treatment plan personalisation. AI in finance helps with fraud detection, trading strategy automation, and chatbot client support. Artificial Intelligence (AI) is the foundation of autonomous vehicle technology in the automobile industry, allowing cars to safely navigate complicated situations.

Artificial intelligence's ethical and sociological ramifications are becoming increasingly visible as technology is incorporated into everyday life. Important issues include privacy, prejudice in AI systems, and the loss of jobs to automation. The literature emphasises how crucial it is to create AI responsibly, with a focus on responsibility, openness, and fairness.

AI still has a long way to go before it can fully explain judgements made by it. Some of these obstacles include algorithmic bias, data availability and quality issues, and explainability. In the future, research will concentrate on resolving these issues, enhancing the generalizability of AI, and investigating novel frameworks like explainable AI (XAI) and ethical AI.

In summary, the principles of artificial intelligence cover a wide range of ideas, methods, and uses that have completely changed how work is done in a variety of fields. The studied literature emphasises how AI has the ability to spur innovation going forward and stresses the significance of tackling the ethical and societal issues raised by this quickly developing technology.

1. EMERGING TECHNOLOGIES

Supply chain management, healthcare, and data sharing that protects privacy are undergoing a transformation because to the combination of blockchain technology and artificial intelligence (AI). The emerging technologies at the nexus of blockchain and artificial intelligence are examined in this section of the literature review, with an emphasis on how they can revolutionise these two vital industries and solve present problems.

programming for every decision, machine learning enables models to adapt and get better with further data exposure.

1) Supply Chain:

In recent years, the convergence of blockchain technology and artificial intelligence (AI) has sparked significant advancements in the realm of supply chain management, revolutionizing the way businesses handle logistics, inventory management, and transparency within their supply networks. The synergy between these two cutting-edge technologies has paved the way for the creation of robust, transparent, and efficient supply chains, offering unparalleled benefits to stakeholders across various industries. One of the primary areas where the integration of blockchain and AI has yielded transformative outcomes is in demand prediction. AI algorithms analyze vast volumes of historical data and real-time information to forecast demand with unprecedented accuracy. By leveraging predictive analytics, businesses can anticipate fluctuations in demand, optimize inventory levels, and minimize stockouts or overstock situations, thereby enhancing operational efficiency and reducing costs.

Furthermore, AI-driven logistics optimization has emerged as a game-changer in supply chain management. Advanced algorithms optimize routes, vehicle scheduling, and warehouse operations, leading to streamlined transportation processes and reduced delivery times. By harnessing AI-powered logistics solutions, businesses can minimize transportation costs, improve delivery accuracy, and enhance customer satisfaction. Blockchain technology complements AI's capabilities by providing a secure and immutable ledger for recording transactions and ensuring the integrity of supply chain data. The decentralized nature of blockchain networks eliminates the risk of data tampering or fraud, enhancing trust and transparency among supply chain participants. Moreover, blockchain facilitates end-to-end traceability of products, allowing stakeholders to track the journey of goods from manufacturing facilities to end consumers. This transparency enables rapid identification of inefficiencies, mitigation of risks, and adherence to regulatory compliance standards.

An emerging trend in supply chain management is the concept of creating a "digital twin" for products using blockchain technology. A digital twin is a virtual representation of a physical product, equipped with sensors and data points that capture real-time information about its status, location, and condition. By leveraging blockchain technology, businesses can track the movement and provenance of products throughout the supply chain, enabling enhanced visibility and accountability. This real-time tracking capability empowers stakeholders to optimize routing, minimize waste, and proactively address supply chain disruptions. Additionally, smart contracts play a pivotal role in streamlining supply chain operations and automating contractual agreements. These self-executing contracts are encoded on the blockchain and automatically execute predefined actions when specific conditions are met. Smart contracts enable seamless execution of payment transactions, enforcement of contractual terms, and resolution of disputes, thereby reducing administrative overhead and enhancing operational efficiency. Overall, the integration of blockchain technology and artificial intelligence holds immense potential to revolutionize supply chain management, driving innovation, efficiency, and transparency across the entire supply network. As research in this field continues to evolve, businesses can expect to witness further advancements in supply chain optimization, risk mitigation, and value creation through the synergistic application of blockchain and AI technologies [12].

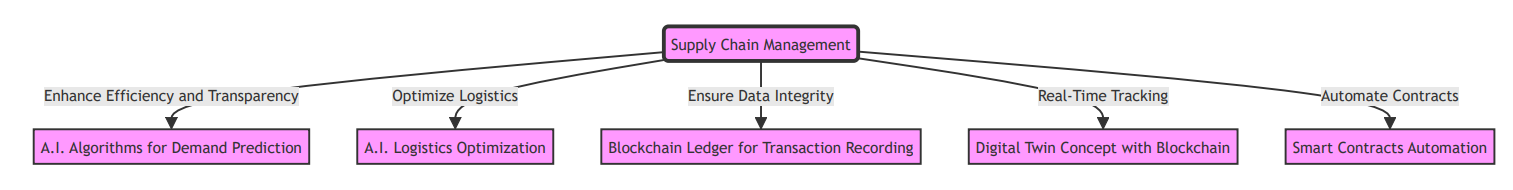


Figure 2: Supply Management

Figure 2 illustrates the key components of the integration of blockchain technology and artificial intelligence (AI) in supply chain management. Each component, including A.I. algorithms for demand prediction, A.I. logistics optimization, blockchain ledger for transaction recording, digital twin concept with blockchain, and smart contracts automation, plays a crucial role in enhancing efficiency, transparency, and automation within the supply chain ecosystem.

2) Healthcare:

In recent years, the convergence of blockchain technology and artificial intelligence (AI) has significantly transformed the landscape of healthcare, ushering in a new era of secure, individualized patient care and innovative healthcare solutions. The synergy between these two cutting-edge technologies holds immense promise for revolutionizing various aspects of healthcare delivery, from diagnosis and treatment planning to data security and interoperability. One of the primary areas where the integration of blockchain and AI has demonstrated remarkable potential is in leveraging AI's capabilities to analyze vast datasets for enhanced outcome prediction, treatment planning, and diagnosis. AI algorithms can sift through large volumes of patient data, including electronic health records (EHRs), medical imaging scans, and genetic information, to identify patterns, predict disease progression, and recommend personalized treatment regimens. By harnessing the power of AI-driven analytics, healthcare providers can optimize clinical decision-making, improve patient outcomes, and deliver more tailored care interventions.

Meanwhile, blockchain technology addresses critical challenges related to data security, privacy, and interoperability in healthcare. By establishing a secure, decentralized ledger for storing and sharing patient health information, blockchain ensures the integrity and confidentiality of sensitive medical data. Blockchain-based health information exchanges (HIEs) enable seamless and secure data exchange between healthcare providers, facilitating better care coordination, reduced medical errors, and improved patient outcomes. Moreover, blockchain's cryptographic techniques and consensus mechanisms safeguard patient privacy and protect against unauthorized access or tampering of medical records.The combination of blockchain-based HIEs and AI-driven analytics holds immense potential for advancing population health management and disease prevention efforts. By securely sharing patient data across disparate healthcare systems, blockchain-powered HIEs enable AI algorithms to analyze comprehensive datasets for early detection of disease outbreaks, identification of health trends, and prediction of public health emergencies. This proactive approach to healthcare surveillance and monitoring empowers healthcare organizations and public health agencies to implement targeted interventions, allocate resources more efficiently, and mitigate health risks within communities.

Furthermore, blockchain's immutability ensures the integrity and trustworthiness of AI-generated health data, fostering confidence in AI-driven healthcare solutions among healthcare providers, patients, and regulatory authorities. The transparent and auditable nature of blockchain transactions enhances accountability and traceability, allowing stakeholders to verify the provenance and accuracy of medical insights derived from AI algorithms. In conclusion, the integration of blockchain technology and artificial intelligence represents a paradigm shift in healthcare delivery, offering unprecedented opportunities to enhance patient care, improve clinical outcomes, and optimize healthcare operations. As research in this field continues to evolve, stakeholders can expect to witness further advancements in personalized medicine, predictive analytics, and healthcare innovation driven by the synergistic application of blockchain and AI technologies [13].

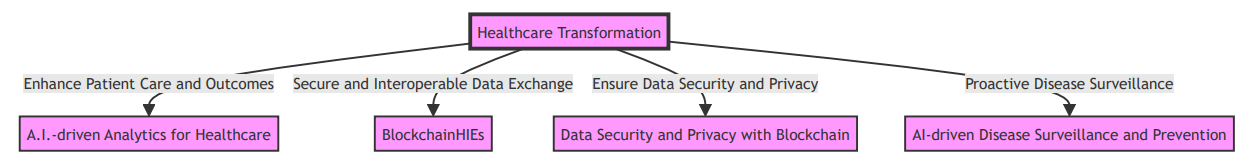


Figure 3: Healthcare Transformation

Figure 3 illustrates the key components of the integration of blockchain technology and artificial intelligence (AI) in healthcare. The diagram highlights how AI-driven analytics enhance patient care and outcomes, while blockchain-enabled health information exchanges (HIEs) ensure secure and interoperable data exchange. Additionally, blockchain technology enhances data security and privacy, while AI-driven disease surveillance and prevention efforts enable proactive healthcare interventions. Together, these technologies transform healthcare delivery, promoting personalized, efficient, and secure patient care.

3) Privacy-Preserving Data Sharing:

The convergence of blockchain technology and artificial intelligence (AI) has opened up new avenues for privacy-preserving data sharing, addressing critical concerns surrounding data privacy and security in various industries. This synergy offers innovative solutions for sharing and analyzing data without compromising individual privacy, particularly in sensitive sectors such as finance and healthcare. One notable advancement in privacy-preserving data sharing is the utilization of federated learning in conjunction with blockchain technology. Federated learning is a distributed machine learning approach that enables AI models to be trained across multiple decentralized servers or devices without the need to transfer raw data. Instead, model updates are exchanged between the devices or servers, allowing the AI model to learn from the collective knowledge of the distributed network while preserving the privacy of individual data.

Blockchain technology enhances the security and transparency of federated learning by providing a decentralized and immutable ledger for recording model updates and training processes. By leveraging blockchain, federated learning ensures the auditability and integrity of the learning process, making it resistant to tampering or unauthorized access. This transparent and secure foundation instills confidence in cooperative AI development efforts, enabling stakeholders to collaborate on AI model training without compromising data privacy. The application of blockchain and AI in privacy-preserving data sharing is particularly significant in industries where data privacy is paramount, such as finance and healthcare. In the financial sector, for example, blockchain-enabled federated learning can facilitate collaborative analysis of sensitive financial data across multiple institutions while safeguarding customer privacy and confidentiality. Similarly, in healthcare, blockchain-based federated learning enables healthcare organizations to collaborate on medical research and analysis while ensuring compliance with strict patient privacy regulations, such as the Health Insurance Portability and Accountability Act (HIPAA).

Furthermore, the integration of blockchain and AI in privacy-preserving data sharing extends beyond traditional industries to emerging sectors such as digital identity management and supply chain transparency. Blockchain-based decentralized identity solutions combined with AI-powered privacy-preserving algorithms offer a secure and user-centric approach to identity verification and authentication, reducing reliance on centralized databases and minimizing the risk of data breaches. In conclusion, the emerging research in the integration of blockchain technology and artificial intelligence for privacy-preserving data sharing holds significant promise for addressing the growing concerns surrounding data privacy and security. By leveraging federated learning and blockchain technology, stakeholders can collaborate on data-driven initiatives while preserving individual privacy rights and maintaining data integrity. As research in this field continues to evolve, we can expect to see further innovations and applications that enhance privacy-preserving data sharing across various industries [14].

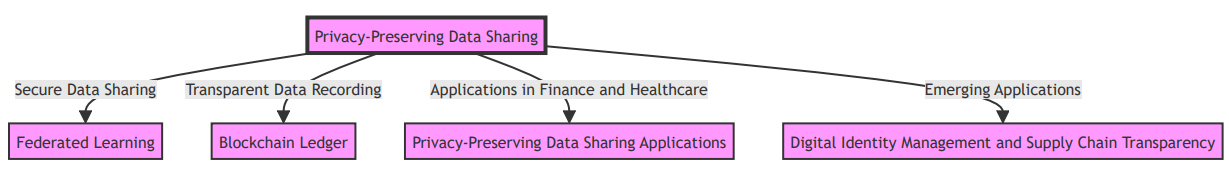


Figure 4Privacy-Preserving Data Sharing with Blockchain and AI

This figure illustrates the concept of privacy-preserving data sharing using blockchain technology and artificial intelligence (AI). The diagram depicts how federated learning enables secure data sharing across decentralized networks, while blockchain ledger ensures transparent and immutable recording of data transactions. Various applications of privacy-preserving data sharing in finance, healthcare, digital identity management, and supply chain transparency are highlighted, showcasing the transformative potential of blockchain and AI technologies in safeguarding individual privacy and promoting secure data exchange across industries.

Furthermore, Blockchain-enabled zero-knowledge proofs (ZKPs) provide a way for participants to validate a claim without disclosing the supporting information. With this technique, data sharing can be done while protecting privacy, enabling AI algorithms to access and learn from data without ever disclosing the original data.

Blockchain technology and artificial intelligence are combining to create new solutions that have the potential to transform healthcare, supply chain management, and data sharing while protecting privacy. Through the integration of AI's analytical capabilities with Blockchain's security and transparency, these industries may surmount current obstacles and provide enhanced, individualised, and secure services. The future of these vital industries will probably change as a result of the integration of these rapidly evolving technologies, which will probably open up new possibilities and paradigms. Several related research on performance scalability optimization schemes is shown in TABLE I.

Table 1 performance scalability optimization schemes for consortium blockchains

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Ref** | **Paper Title** | **Area of Study** | **Method Used** | **Advantages** | **Disadvantages** |
| [4] | “A critical analysis of the integration of blockchain and AI for supply chain” | Supply chain management | State-of-the-art review | Enhanced information and process resilience, faster and cost-efficient product delivery, improved traceability | Scalability challenges, energy consumption concerns, regulatory uncertainties |
| [15] | “Artificial Intelligence and Blockchain Integration in Business: Trends from a Bibliometric-Content Analysis” | Bibliometric analysis | Citation analysis | Insights into popular research trends, identification of influential papers, understanding research impact | Limited to existing literature, may not capture emerging trends |
| [16] | “Blockchain and artificial intelligence technology in e-Health” | Healthcare | Machine learning on medical records | Secure patient data sharing, improved diagnostics, fraud detection | Privacy concerns, data interoperability challenges |
| [17] | “Implementation of Smart Contract Technology in Financial Services Institutions” | Finance | Smart contracts | Transparent transactions, reduced intermediaries, automated compliance | Regulatory hurdles, scalability limitations |
| [18] | “The Potential of Blockchain Technology and Smart Contracts in the Energy Sector: A Review” | Energy | Decentralized energy trading | Peer-to-peer energy exchange, grid stability, renewable energy integration | Technical complexity, market adoption challenges |
| [19] | “A patent registration and trading system based on blockchain” | Intellectual property | Blockchain-based patent management | Immutable patent records, enhanced patent tracking, reduced patent disputes | Legal and regulatory uncertainties, patent trolls |
| [20] | “Traceability in a food supply chain: Safety and quality perspectives” | Agriculture | Supply chain traceability | Authenticity verification, food safety assurance, fair trade practices | Adoption barriers in rural areas, data entry challenges |

Table 1 provides valuable insights into the integration of blockchain and artificial intelligence (AI) across various industries. The study "A critical analysis of the integration of blockchain and AI for supply chain" underscores the benefits of enhanced information resilience, faster product delivery, and improved traceability in supply chain management. However, it also highlights challenges such as scalability issues, energy consumption concerns, and regulatory uncertainties. Meanwhile, "Artificial Intelligence and Blockchain Integration in Business: Trends from a Bibliometric-Content Analysis" offers insights into research trends and influential papers but may overlook emerging trends due to its reliance on existing literature. In healthcare, "Blockchain and artificial intelligence technology in e-Health" showcases secure patient data sharing and improved diagnostics, yet faces challenges related to privacy and data interoperability. Similarly, "Implementation of Smart Contract Technology in Financial Services Institutions" reveals advantages like transparent transactions but faces regulatory hurdles and scalability limitations. In the energy sector, "The Potential of Blockchain Technology and Smart Contracts in the Energy Sector: A Review" presents benefits such as peer-to-peer energy exchange but confronts technical complexity and market adoption challenges. Furthermore, "A patent registration and trading system based on blockchain" emphasizes immutable patent records but contends with legal uncertainties and patent trolls. Lastly, "Traceability in a food supply chain: Safety and quality perspectives" discusses benefits like authenticity verification but encounters challenges in rural adoption and data entry. These analyses collectively highlight the multifaceted nature of integrating blockchain and AI, underscoring both the potential benefits and obstacles across diverse industries.

This chapter is essentially an in-depth investigation of the various performance scalability problems that consortium chains, particularly ones that depend on PBFT face. It explores a number of potential solutions, such as improvements in consensus algorithms and the thoughtful fusion of cryptographic methods like as VRF and BLS. The ultimate goal is to give a thorough overview of the strategies used to solve the crucial performance scalability issue, opening the door for the creation of consortium blockchain networks that are both highly scalable and effective, satisfying the requirements of contemporary high-performance applications.

1. METHODOLOGY

In order to give a clear framework for the examination of scalability solutions inside consortium chains, this review paper outlines the scope of its research. It focuses on pertinent advances that have occurred between 2018 and 2023. The scope includes important areas of interest such as the use of BLS cryptography, the Practical Byzantine Fault Tolerance (PBFT) consensus algorithm, and the Verifiable Random Function (VRF), especially in relation to consortium blockchains. Consortium chains are a unique architectural paradigm in the blockchain space, and this review's comprehension of their scaling issues and remedies is crucial. The review guarantees that it includes the most recent developments and conversations in the area by defining a temporal window that runs from 2018 to 2023. This gives readers an understanding of the state of scalability solutions inside consortium chains at the moment. This method helps to provide a thorough and current analysis by bringing the evaluation into line with the changing field of consortium chain scalability research.

A. Data Sources

In the quest for relevant data, it is imperative to select scholarly databases with a proven track record for their robust coverage of both blockchain technology and artificial intelligence (AI) research. Databases such as IEEE Xplore, SpringerLink, and Elsevier's ScienceDirect stand out for their expansive repositories of academic articles and are thus highly recommended sources. Ensuring the chosen databases encompass a wide array of research articles spanning blockchain, AI, and their intersections is crucial to upholding the integrity and credibility of the research endeavor. By relying on scholarly sources, the study aims to uphold academic standards and enhance the reliability of its findings.

Moreover, the research narrows its focus to specific domains within the convergence of blockchain and AI, including consensus algorithms, cryptography, decentralized applications, and their real-world implementations. By honing in on these core areas, the study endeavors to provide a nuanced exploration of the intricate relationship between blockchain and AI technologies. This targeted approach facilitates the extraction of pertinent data and insights essential for a thorough analysis of the subject matter. Ultimately, such a focused investigation contributes to a deeper understanding of how blockchain and AI intersect and can be effectively integrated across various sectors and applications.

Through the strategic selection of reputable databases and a deliberate focus on key areas of inquiry, the research seeks to shed light on the complexities and potentials inherent in the integration of blockchain and AI. By synthesizing insights from diverse scholarly sources and conducting a meticulous analysis, the study aims to offer valuable contributions to the burgeoning field of blockchain-AI integration. Additionally, the findings are poised to inform future research endeavors and practical applications, paving the way for innovative solutions and advancements in this rapidly evolving domain.

B. Search Strategy

In formulating the search strategy, the study emphasizes the strategic use of keywords tailored to the domains of blockchain and artificial intelligence (AI). Targeted keywords encompass a range of relevant topics, including consensus algorithms, cryptographic techniques, decentralized applications, and emerging trends in both fields. By utilizing these specific keywords, the research aims to optimize the retrieval of pertinent literature and enhance the relevance of the search results. Additionally, the employment of Boolean operators further refines search queries, allowing for the precise combination of keywords to retrieve research papers that address the intersections of blockchain and AI. This strategic use of Boolean operators enables the study to capture a comprehensive array of scholarly works that delve into the complex relationship between the two technologies.

Moreover, the search strategy adopts a broad yet focused approach to ensure inclusivity while maintaining relevance to the research objectives. While the search encompasses a wide range of publications, the focus remains directed towards publications directly connected to the main topics of interest, such as consensus mechanisms, cryptographic advancements, and decentralized applications. This balance between breadth and focus enables the study to gather a diverse range of literature while ensuring that the retrieved publications align closely with the research themes. By adopting such a nuanced search strategy, the research aims to uncover valuable insights into the integration of blockchain and AI, shedding light on emerging trends and advancements in this rapidly evolving field.

C. Inclusion and Exclusion Criteria

In establishing inclusion and exclusion criteria, the study employs a systematic approach guided by three primary considerations: Firstly, relevance to research topics serves as a fundamental criterion for inclusion. Research papers are selected based on their direct contributions to advancing knowledge in the integration of blockchain and AI. Specifically, publications addressing key areas such as consensus algorithms, cryptographic techniques, and decentralized applications are prioritized for inclusion. By focusing on papers that directly align with the research objectives, the study ensures the quality and relevance of the literature reviewed.

Secondly, the publication period is carefully considered to capture the most recent advancements and discussions in the field of blockchain and AI. Research papers published within a specified timeframe are included to provide insights into the latest developments and emerging trends. This temporal restriction allows the study to remain current and comprehensive, offering a nuanced understanding of the contemporary landscape of blockchain-AI integration.

Lastly, the exclusion of irrelevant studies is essential to maintaining the focus and relevance of the review. Research papers that do not align with the specified research topics or fall outside the designated publication period are excluded from consideration. By applying stringent exclusion criteria, the study ensures that the literature reviewed remains cohesive and directly contributes to the research objectives. This selective approach enhances the rigor and validity of the review, enabling a more insightful analysis of the integration of blockchain and AI.

D. Screening and Selection

The process of conducting a systematic literature review, or SLR, is designed to include stringent screening and selection phases. These steps are carefully crafted to find and select research articles that closely fit the specified parameters of the study. The following steps are sequential in the screening and selection process:

* First Screening:

Review of Titles and Abstracts: Research paper titles and abstracts get a thorough examination at the first screening stage. The purpose of this preliminary evaluation is to determine how each publication relates to the defined scope of the research. Papers that demonstrate a strong fit with the research goals and thematic areas advance to the following phase.

* Whole-Text Examination:

Detailed Evaluation: Selected papers move on to the full-text screening phase after the first screening. Here, every manuscript is carefully assessed in-depth to ensure that it is appropriate for inclusion in the review. This extensive evaluation includes a close look at the paper's methods, conclusions, and applicability to the designated study fields. Papers that fulfil the specified requirements for inclusion move on to the next round.

* Evaluation of Quality:

Evaluating Credibility and Scholarliness: The chosen articles are subjected to a comprehensive analysis of their quality and rigour during the quality assessment step. The purpose of this evaluation is to guarantee that reliable, academic sources are included in the review. This grading takes into account various factors, including study technique, data integrity, citation sources, and general academic rigour. Merely those documents exhibiting an exceptional calibre of academic writing are kept for the thorough examination.

A careful and methodical approach characterizes the screening and selection procedure used in this SLR. This method is intended to preserve the review's integrity by making sure that the final selection of research papers closely follows the goals and scope of the study as defined. The study attempts to offer a thorough and academic analysis of the chosen literature by utilising these stringent screening and selection phases.

E. Data Extraction and Analysis

The methodical extraction of pertinent data is the following step after the selection of research articles is complete. This procedure is essential to extracting important data, conclusions, and insights from the chosen papers. The following are the essential phases in data extraction and analysis:

Data Extraction: Careful data extraction is applied to a selection of research papers. Research methods, empirical results, theoretical contributions, and noteworthy insights into the scalability of consortium chains are collected in a systematic manner, together with other pertinent material.

The gathered data is then rigorously subjected to thematic analysis. It is possible to identify recurring themes, new trends, and significant contributions in the field of consortium chain scalability with this analytical technique. A thorough grasp of the study landscape is attained by classifying and arranging the retrieved material into relevant themes.

F. Synthesis and Review Composition

The review article's composition is carefully organised to provide a logical summary of the chosen research publications. This synthesis is structured around a number of important components, such as:

The review article's thematic organization is based on topics that were found during the examination of a few research publications. Every subject is associated with a particular facet of consortium chain scalability, allowing readers to effortlessly peruse related content.

Methodological Insights: This page offers an analysis of the approaches taken in the chosen studies. Offering a thorough overview of the research landscape, it emphasizes the different study approaches and methodology utilized by academics to investigate consortium chain scalability.

Presenting the major conclusions and ramifications drawn from the chosen research publications is a primary goal of the review. The paper provides insightful information about the present status of performance scalability in consortium chains by summarizing important research findings.

G. Conclusion

The evaluation concludes with a strong summary of the main lessons learned from the examined research publications. The following goals are fulfilled by the conclusion:

* Key Takeaways Synopsis: It offers a succinct synopsis of the major discoveries and contributions that were emphasized during the evaluation. Readers can clearly grasp the ideas obtained from the chosen research by reading this summary.
* Future Implications: The concluding section delves into the more extensive consequences of the examined studies for the scalability of consortium chains in the future. It explores possible ramifications for scholars, politicians, and industry practitioners.
* Future Research Directions: The review indicates possible directions for further study and advancement in the area of consortium chain scalability. It advances the body of knowledge in the topic by highlighting areas that need more research.

With an emphasis on the PBFT consensus algorithm, the review paper seeks to offer a thorough and enlightening investigation of consortium chain scalability by adhering to this systematic methodology for data extraction, analysis, synthesis, and conclusion.

1. RESULT AND DISCUSSION

Table presents a comprehensive analysis of journal publications by four prominent publishers—IEEE, Science Direct, Springer Link, and Taylor and Francis—over the period from 2016 to 2023. Overarching trends indicate a consistent rise in the number of journals released annually by each publisher throughout the period. Notably, Science Direct consistently leads in the number of publications, followed closely by Springer Link, while IEEE and Taylor and Francis show slightly lower figures but still demonstrate steady growth over the years. The most substantial increases in publications occur between 2018 and 2020 across all publishers, suggesting a period of accelerated scholarly output during this time frame. Looking ahead, it is anticipated that this upward trajectory will continue, with Science Direct and Springer Link likely maintaining their positions as the leading publishers in terms of journal releases, while IEEE and Taylor and Francis are poised for continued moderate growth. Overall, these findings underscore a robust and expanding landscape for scholarly journal publications, reflecting ongoing advancements and contributions to academic research across diverse fields.

Table 2 Number of journals published annually by four major publishers (IEEE, Science Direct, Springer Link, and Taylor and Francis) from 2016 to 2023.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Publisher | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
| Journals | Journals | Journals | Journals | Journals | Journals | Journals | Journals |
| IEEE | 0 | 2 | 12 | 51 | 106 | 166 | 233 | 324 |
| Science Direct | 1 | 10 | 60 | 203 | 472 | 883 | 1352 | 1962 |
| Springer Link | 3 | 28 | 84 | 159 | 382 | 686 | 1074 | 2000 |
| Taylor and Francis | 4 | 22 | 57 | 114 | 199 | 330 | 435 | 553 |

Figure 5 Area of studies with number of citations

1. CONCLUSION AND FUTURE DIRECTIONS

To provide a comprehensive framework for exploring scalability solutions within the intersection of blockchain and artificial intelligence (AI), it's essential to recognize their significance as two groundbreaking technologies shaping innovation across diverse sectors. Their integration holds immense promise, offering synergistic advantages that bolster efficiency, security, and explainability while addressing inherent constraints. By amalgamating the capabilities of blockchain and AI, a myriad of benefits and applications emerge, facilitating transformative advancements across industries: Blockchain serves as an immutable ledger, ensuring transparent and secure transactions, while AI enhances decision-making processes with its predictive and analytical capabilities. Together, they bolster data integrity, accountability, and trustworthiness within complex ecosystems.

Moreover, the fusion of blockchain and AI augments automation, enabling intelligent, self-executing contracts and streamlined workflows. This synergy optimizes resource allocation, expedites processes, and fosters innovation in supply chain management, financial services, healthcare, and beyond. Furthermore, the integration empowers organizations to harness vast troves of data stored on blockchain networks, unlocking actionable insights and facilitating informed decision-making. AI-driven analytics enhance efficiency, uncover patterns, and drive business intelligence, fueling competitive advantage and sustainable growth. In essence, the convergence of blockchain and AI presents a transformative paradigm for scalable and sustainable solutions across industries. By leveraging their complementary strengths and mitigating inherent limitations, organizations can unlock new avenues for innovation, efficiency, and value creation in the digital era.

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