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Blockchain and Artificial Intelligence integration in Supply Chains: A systematic review

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***Abstract*— Artificial intelligence and blockchain are among the most popular technologies. Combining the two technologies also harbors manifold potentials. For instance, blockchain can help address specific AI-related difficulties, and vice versa, AI offers opportunities to improve the blockchain's mining process or smart contracts. The fusion of blockchain and artificial intelligence (AI) marks a paradigm shift in supply chain, ensuring data privacy and facilitating secure data transmission. This study, through a systematic literature review, examines the interplay between artificial intelligence and blockchain and then provides a comprehensive analysis of the integration of blockchain and artificial intelligence in supply chains, highlighting their role in enhancing security and transparency in the field of supply chain management. In particular, the supply chain is the area that has been shown to benefit tremendously from blockchain and AI, by enhancing information and process resilience, enabling faster and more cost-efficient product delivery, and augmenting product traceability. This research aims to review the current studies on the integration of blockchain and AI in the supply chain. Our analysis of 30 English-language articles published between 2018 and 2024 identifies a number of research challenges and opportunities.**

***Key words*: Artificial intelligence, Blockchain, Supply Chain.**

I. INTRODUCTION

Among the various disruptive technologies of the 21st century, blockchain and artificial intelligence are those that stand out in terms of the attention and hype they have received [1]. However, combining AI and blockchain is a combination of two distinct technologies. The connecting AI and blockchain harbors a great deal of potential. The blockchain can increase the transparency of AI systems, which often have the character of a black box [2]. Therefore, the blockchain can provide new potential for increasing transparency [3,4]. Additionally, AI can overcome some challenges that the blockchain, as a new technology, still struggles with. An example is the blockchain's energy-intensive mining process, which results in substantial energy consumption [5]. However, AI offers the potential for improvements, such as predicting transaction confirmation times or developing new consensus procedures [7]. In turn, the blockchain can serve as a database to encourage more people to share personal data [8]. This data can be highly valuable for companies as a source of data for their AI systems. Now, let's investigate the potential advantages of combining blockchain technology with artificial intelligence.

II. LITERATURE REVIEW

A. Blockchain

The term "blockchain" refers to an increasing list of data structures called blocks [9]. It is a type of data-driven network that combines decentralized transactional processes with extra data management tools [10]. In a literature review on blockchain technology, we found that: Diffie & Hellman already formulated digital signature and public key

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cryptography ideas in 1976. They were also the first to recognize the necessity of hash functions for digital signatures [11]. The first works on analysis of hash functions and construction were published at the end of the 1970s by Merkle (1979) and Rabin (1978) [12].

Further developments in blockchain have resulted in recognizing the problem of digital documents being easy to modify. Based on hash functions, Haber and Stornetta proposed solutions for digital time-stamping documents, so that they cannot be forged [9]. Atoshi Nakamoto combined the ideas for group signature schemes and ring signature schemes with today's blockchain in 2008 [13]. Currently, the blockchain has been widely adopted in various fields, and according to Iansiti and Lakhani (2017), as well as Casey and Wong (2017), five basic principles underlie the blockchain technology [14,15].

1. Distributed Database

   The whole database and its complete history are available for each blockchain party. No single party controls the data and information, and all parties can verify transactions without using an intermediary.

2. Peer-to-peer transmission

   The network peers can communicate with one another without a central node. This includes the storing and forwarding of information to all other peers.

3. Transparency

   Transactions and their associated values are visible to everyone within a blockchain network. The single nodes on a blockchain have an alphanumeric address as a clear identifier. Transactions occur between these blockchain addresses.

4. Irreversibility of records

   Once a transaction is part of the blockchain, it cannot be altered or changed. Because the transaction is linked to each transaction carried out beforehand. Various approaches and algorithms ensure permanence and the correct order of transactions.

5. Computational logic

   The blockchain's computational logic can be programmed on the blockchain. Users can set up algorithms and rules that automatically trigger transactions between nodes.

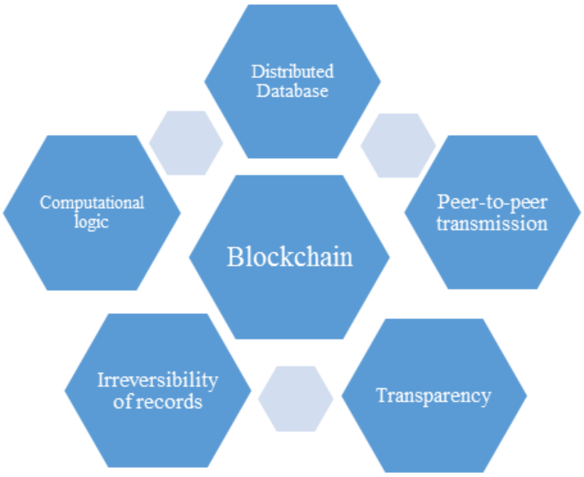

Fig. 1. Fundamentals of Blockchain Technology

The blockchain can also be interpreted as a chain of blocks, with each block connected to the previous blocks by a hash. Until recently, the blockchain was used in connection with Bitcoin, being the best-known project based on the blockchain [16].

a) Smart contract

A smart contract is another often-mentioned term in connection with blockchain. This refers to software that imitates the behavior or logic of contracts, allowing companies to automate the terms and conditions of contracts. A smart contract can refer to data fields contained in the blockchain [17].

b) Internet of Things (IoT)

The Internet of Things marks a significant innovation in information technology. IoT is regarded as the most cutting-edge technology for enabling ubiquitous and universal data exchange by connecting everything to the Internet [18].

This revolution is the result of the continuous evolution of the Internet, technological advancements, improved software, communication protocols, and increasingly sophisticated sensors embedded in devices. As a result, these objects are capable of providing information and perceiving their environments in real time [19].

B. Artificial Intelligence

The term "Artificial Intelligence" (AI) was first coined in 1956 [20]. In recent years, there has been increased interest in applying AI in various settings to inform decision-making and facilitate predictive analytics. McKinsey Global Institute, for example, has predicted that the AI market will grow to 13 trillion dollars by 2030 [21].
The research of AI covers a wide range of topics, including machine learning, computer vision, and natural language processing. Importantly, machine learning is an essential technology allowing AI to imitate human thought and behavior, and most current AI programs are based on it [22].

a) Machine Learning (ML)

Samuel, in 1959, defined machine learning as “the field of study that gives computers the ability to learn without being explicitly programmed. Machine learning (ML) technology powers many aspects of modern society, from web searches to content filtering on social networks to recommendations on e-commerce websites, and it is increasingly present in consumer products, such as cameras and smartphones [23]. Machine learning has been developed over a long period; now it is a relatively complete technical framework with mature algorithms, and has developed techniques such as deep learning, reinforcement learning, and federated learning [22].

b) Deep Learning (DL)

Deep learning was introduced by Hinton et al. (2006) [24]. Deep learning was based on the concept of an artificial neural network (ANN). In terms of working domain, deep learning (DL), a branch of machine learning (ML) and artificial intelligence (AI), is nowadays considered a core technology of the Fourth Industrial Revolution (Industry 4.0) [25]. Deep learning is among the current trending technologies and has seen tremendous growth over the last years.
This area of study has led to a resurgence in neural network research, often referred to as "new-generation neural networks." When properly trained, deep networks have achieved remarkable success in various classification and regression tasks. [26] Deep learning (DL) differs from traditional machine learning in terms of efficiency, particularly as the volume of data increases. DL technology employs multiple layers to represent the abstractions of data, thereby constructing computational models. Although deep learning requires a significant amount of time to train a model due to the large number of parameters, it requires much less time to execute during testing compared to other machine learning algorithms [27].

c) Federated Learning

The model training of machine learning employs a large amount of sensitive data, and data privacy is a critical issue. At the same time, data is distributed in different organizations. These decentralized data are usually heterogeneous and unbalanced; therefore, it is difficult to combine them.
In 2016, Google introduced federated learning, which merges machine learning with distributed computing. In federated learning, participants only need to share their own training model parameters rather than their original data, thereby enhancing data privacy to a certain extent. As a result, federated learning represents an innovative method in the field of machine learning.

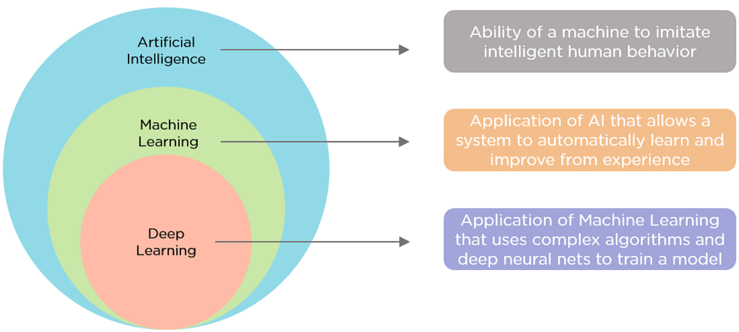

Fig. 2. Differences between artificial intelligence, machine learning, and deep learning

C. Supply chain challenges

Geographically dispersed supply chains have always posed management challenges. The complexity of supply chains stems from various factors, and ensuring their long-term viability requires effective maintenance, repair, and operations management, among other considerations [29]. In today’s business environment, traceability is becoming a necessity and a competitive advantage in many supply chain industries. Without transparency in the supply chain, stake holders cannot properly assess and validate the true value of items. The cost of dealing with intermediaries, as well as their dependability and transparency, make managing supply chain traceability even more difficult, leading to strategic and reputational competitive issues [30].

There are different issues with today’s supply chains because they rely so heavily on central, sometimes disparate, and stand-alone systems of information management, such as enterprise resource planning systems [30]. The single point failure of centralized information systems is a drawback of such systems, which in turn makes the entire system vulnerable to error, hacking, corruption, or attack [31]. Maintaining strong trust is crucial for supply chain entities sharing sensitive data with a central organization [32]. Furthermore, supply chains face increasing pressure to certify their sustainability, encompassing environmental, social, and business aspects in alignment with the triple-bottom-line concept [33].

It is necessary to examine existing supply chain information systems to determine if they can provide the secure, transparent, and reliable data needed to track the timely origin of goods and services.

Samanta et al. (2024) also explain that traditional supply chain management systems often struggle with issues such as data silos, lack of real-time visibility, and difficulties in tracing the provenance of goods. And these challenges can result in inefficiencies, increased costs, and diminished trust among stakeholders. For instance, tracking the origin of products and verifying their authenticity can be arduous tasks in conventional systems, resulting in potential fraud and compliance issues [34]. The key to resolving these complicated matters is to improve supply chain security, transparency, long-term viability, and process integrity. Blockchain technology could be the solution to this problem. Its decentralized 'trustless' database characteristics can facilitate global-scale transactions and process disintermediation and decentralization among various stakeholders [30,35]. As Saberi et al. (2019) noted, although the number of blockchain use cases has grown over time, blockchain, like any potentially disruptive system or technology, faces many challenges and barriers in terms of adoption and implementation by supply chain networks. Because blockchain is still in its early stages of development, it poses various challenges in terms of behavioral, organizational, technological, and policy-related issues. Artificial intelligence (AI) will be able to solve some of the above-mentioned problems. In fact, the integration of blockchain and AI is estimated to bring many significant advantages [36]. With such integration, parties can share massive amounts of data for analysis, learning, and decision-making without the need for a central authority or third-party intermediaries. By automating the entire workflow, the use of AI technology in the blockchain system has the potential to redefine the supply chain.

III. Research Method

In this article, we used an SLR, which is a means of evaluating and interpreting all available research relevant to a particular research question, topic area, or phenomenon of interest. An SLR has the capacity to present a fair evaluation of a research topic by using a trustworthy, rigorous, and auditable methodology. Therefore, we adopted SLR guidelines that follow transparent and widely accepted procedures, minimize potential bias (researchers), and support reproducibility [37].

A. Article Collection

Several procedures were followed to ensure a high-quality review of the literature. A comprehensive search of peer-reviewed articles was conducted from January 2025 (short papers, posters, dissertations, and reports were excluded), and publications were selected from 2018 onwards based on a relatively inclusive range of key terms:

Blockchain & Smart Contract, Blockchain & Transparency, Artificial Intelligence (AI) & Machine Learning, Artificial Intelligence (AI) & Deep learning, Artificial Intelligence (AI) & Federated Learning, Blockchain & Supply chain, Artificial Intelligence (AI) & Supply chain. A wide variety of databases were searched, including Emerald Insight, ProQuest, Science Direct, SpringerLink, and Google Scholar:

1. Emerald Insight (https://www.emerald.com/insight/)
2. ProQuest (https://www.proquest.com/)
3. Science Direct (https://www.sciencedirect.com/)
4. SpringerLink (https://link.springer.com/)
5. Google Scholar (https://scholar.google.com/)

The selected databases were aligned with the SLR guidelines.[37], and the search process uncovered 1,769 peer-reviewed articles.

B. Inclusion and Exclusion Criteria

The selection phase determines the overall validity of the literature review. Therefore, it is critical to define specific inclusion and exclusion criteria.

As Dybå and Dingsøyr (2008) specified, the quality criteria should encompass three main issues – namely, rigor, credibility, and relevance – that need to be considered when evaluating the quality of the selected studies. We applied eight quality criteria informed by the proposed Critical Appraisal Skills Programme (CASP) and related works [38]. Table 1 presents these criteria.

Table 1. Quality Criteria

1	Does the study clearly address the research problem?
2	Is there a clear statement of the aims of the research?
3	Is there an adequate description of the context in which the research was carried out?
4	Was the research design appropriate to address the aims of the research?
5	Does the study clearly determine the research methods (subjects, instruments, data collection, data analysis)?
6	Was the data analysis sufficiently rigorous?
7	Is there a clear statement of findings?
8	Is the study of value for research or practice?

The mentioned criteria were applied in stages 2, 3, and 4 of the selection process (see Fig. 3), when we assessed the papers based on their titles and abstracts, and read the full papers.

C. Analysis

Each collected study was analyzed based on the following elements: study design (e.g., experiment, case study), area (e.g., supply chain), technology (e.g., Blockchain, Artificial intelligence), population (e.g., managers, employees), sample size, unit of analysis (individual, firm), data collections (e.g., surveys, interviews), research method, data analysis, and the main research objective of the study.

Although this process did not provide reliability indices (e.g., Cohen's kappa), it did provide certain reliability in terms of consistency of the coding and what Krippendorff (2018) [39]. stated as the reliability of "the degree to which members of a designated community concur on the readings, interpretations, responses to, or uses of given texts or data", which is considered acceptable research practice [40].

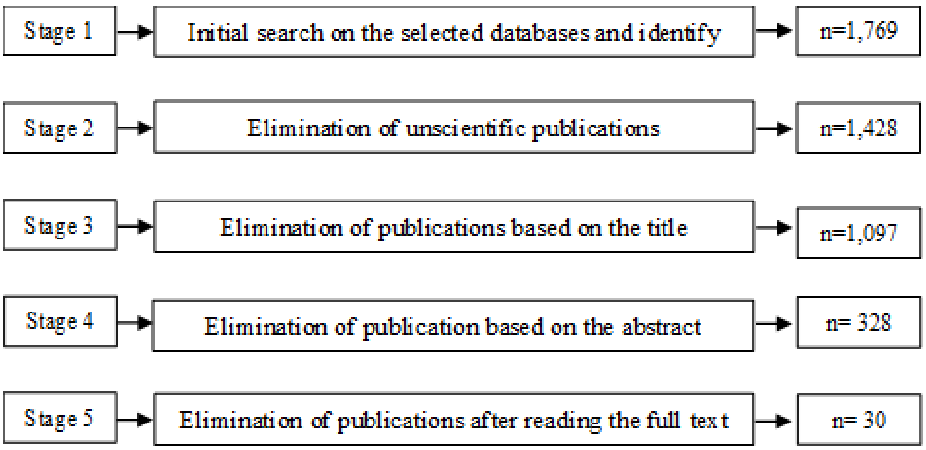

Fig. 3. Illustration of the elimination criteria and the resulting number of publications

IV. Findings

A. Combining blockchain and AI

The identified combination applications can be divided into two main groups. The first group includes use cases and applications that use blockchain and AI to support or enhance each other's functions. The second group comprises applications and platforms that combine AI and blockchain without emphasizing one technology supporting or leveraging the other.

1. AI and Blockchain include

Blockchain is gaining wide attention due to its secure and decentralized resource-sharing approach. However, existing blockchain systems also face several challenges in operational maintenance, smart contract quality assurance, and detection of malicious blockchain data behavior. At the same time, recent advances in artificial intelligence offer opportunities to address these challenges. The first part discusses scientific works related to supporting or enhancing blockchain through AI methods. This topic is known by different names: Panetta (2019) refers to the combination of blockchain with other technologies like AI or the internet of things as enhanced blockchain solutions [41]. (Panetta, 2019) Garimella and Fingar (2018) use the term Blockchain 4.0 for intelligent blockchain applications [42]. Zheng et al. (2020) describe the intelligent capabilities provided to the blockchain ecosystem by AI as blockchain intelligence [43]. Based on the existing literature, we categorize the studies into two groups: improving smart contracts with AI to make them smarter, and enhancing the mining process.

- **improving smart contracts**
  AI potential is specifically noted in the context of smart contracts. An AI system could act as a recommendation tool during contract negotiations in supply chains, analyzing past smart contracts to understand previous negotiation patterns and suggest suitable language and clauses likely to lead to agreement among involved parties. AI can also review past contracts to identify overlooked factors and incorporate them into future agreements. Additionally, within smart contracts, AI could be programmed to negotiate different conditions affecting the price or quality of goods. Using supervised or unsupervised learning techniques, AI could determine the best time to trigger or execute a smart contract. Moreover, AI can assist in case of contract failure by dynamically identifying alternative solutions tailored to the parties' needs [45].
- **Enhancing the mining process**
  Singh and Hafid (2020) explore using machine learning to predict Ethereum blockchain transaction confirmation times. As transaction volume increases, they highlight the need for users to know if their transaction will be accepted and how long it will take, proposing three models to predict this confirmation time. Chen et al. (2018) critique current immature consensus mechanisms in blockchains and propose a new one called Proof of Artificial Intelligence (PoAI). In this approach, all nodes are ranked by a CNN based on criteria like computing power or security. Only the top nodes, forming a mining pool, perform mining, selected through a rotation mechanism. This method eliminates the need for competitive computing power, saving electricity while promoting fairness and decentralization. Initial experiments with this algorithm show promising results [7].

a) Application of blockchain in AI

This category consists of use-cases and applications that use the blockchain to support or enhance existing AI applications. In other words, consists of use cases that aim to support AI methods and techniques by means of the blockchain and it can be divided into the following subcategories:

- Blockchain-based data management
- Blockchain-based data marketplaces
- Blockchain-based AI architectures
- Blockchain-enhanced swarm systems
- Increase of transparency through the blockchain

- **Blockchain-based data management**
  The vast amount of available data is a key driver of the current AI revolution. The integration of blockchain technology for storing, managing, and sharing data offers several advantages and potential benefits for AI and machine learning (ML) systems. According to Salah et al., centralized data storage solutions, such as cloud services, data centers, and clusters, are becoming significant bottlenecks in the development of highly secure AI applications that prioritize data protection. Additionally, there are various methods to manipulate the training data and models used in AI systems. Utilizing blockchain to acquire and store learning data for AI and ML systems presents promising opportunities to address the challenges and risks mentioned earlier. It highlights that secure storage and provisioning of data through blockchain technology directly benefit AI and ML systems.
- **Blockchain-based data marketplaces**
  According to Subramanian (2017) in a decentralized marketplace, a network of nodes replaces the company responsible for the marketplace's proper functioning. This network is responsible for matching buyers and sellers, enabling transactions. And for the infrastructure, the network of nodes provides the same functionality independently as a centralized marketplace would. And the final [47].
  - Such decentralized marketplaces minimize transaction costs, as they do not require intermediaries, and buyers can pay sellers directly.
  - owing to the fast network validation, transactions occur immediately, and payment modalities do not delay them.
  - Here are also gains in security, as transaction details can be encrypted, network manipulation is extremely difficult and cost-intensive, and identities do not need to be revealed on the marketplace [47]. According to some authors, blockchain's decentralized architecture will lead to greater security.

- **Blockchain-based AI architectures**
  Deep Ring is an architecture proposed by Akhil Goel et al. (2019) that aims to protect deep neural networks using blockchain technology. In this system, the individual blocks of convolutional neural networks (CNNs) are arranged randomly and contain information about the nearest legitimate blocks. One of the key advantages of Deep Ring is its ability to register and detect all attacks on CNNs. If tampering occurs at any point, it alters the hash value of the affected block as well as all subsequent blocks, making any changes or attacks quickly and easily identifiable. This mechanism enhances the transparency of the entire network as well as that of individual

blocks. The authors conducted experiments demonstrating that the synergy between blockchain and deep neural networks can produce tamper-proof models. In addition to simply exchanging data, AI agents should be capable of requesting tasks or providing results via smart contracts. The ability to quickly and dynamically connect or combine different AI systems or agents is also critically important. Moreover, smart contracts facilitate interaction among AI agents, enable external customers to engage with them, and assist in requesting various tasks or data, along with managing payments for these services [49].

- **Blockchain-enhanced swarm systems**

The integration of blockchain technology within the context of artificial swarm intelligence offers several potential advantages and enhancements. Blockchain could enhance safety, support distributed decision-making, and differentiate between the behavior of individual robots. It has long been believed that swarm systems are robust and that the failure of individual robots has little effect on a swarm's overall collective behavior and security [50]. Bjerknes and Winfield (2013) demonstrated that the latter is not correct, and that the overall system's reliability decreases with increasing swarm size [51]. Higgins et al. (2009) define various potential security gaps and dangers that can arise in the context of swarm systems. For example, security threats can emerge from insecure communication channels or from manipulated swarm members [52].

According to Ferrer (2018) the blockchain can provide a reliable peer-to-peer communication channel for each agent in a swarm, therefore counteracting potential threats, vulnerabilities, and attacks. In the case of swarm robotics, public-key cryptography allows robots to share their public keys with other robots for communication purposes. Consequently, each robot in the network can send information to specific robot addresses by ensuring that only the robot with an appropriate private key can read the message. The blockchain can also prevent third-party robots from decrypting information, even if they use the same communication channel. Similarly, a message's authorship can be clearly proven when robots use their own private key to encrypt messages [53]. In the context of swarm robotics, Ferrer (2018) suggests using blockchain technology to enhance decision-making and consensus among robots. This approach enables rapid, secure, and verifiable agreements through mechanisms like majority rule, allowing all robots to monitor the balance of addresses involved in the voting process. However, as the number of transactions increases, the blockchain requires more storage of data. Beyond a specific size, it becomes increasingly difficult to download or maintain a copy of the blockchain. This issue, known as "bloating," can pose significant challenges in swarm systems. If a large number of robots operate continuously over time, the blockchain will expand to such an extent that the robots cannot retain a complete copy of the entire transaction ledger [53].

Nishida et al. (2018) address this issue. These authors also see the continuously increasing blockchain as a challenge for its use in the swarm systems environment. They proposed an approach that can reduce the blockchain's size and growth. This proposal only encompasses the storage of hash values in the blockchain, which are generated from the target data to be exchanged. Therefore, the size of the transactions contained in the blockchain remains unchanged with no dependence on the shared size of information [54].

- **Increase of transparency through the blockchain**

According to Salah et al., if consumers or users find the decisions made by AI systems difficult to understand, those decisions may lose their value [1]. A clear audit trail can not only improve the data and the trustworthiness of the model, but also provide a transparent way of tracking the process through which the AI system came to its decision [55].

Dillenberger et al. (2019) assumed that the blockchain can increase trust in and the transparency of AI systems. The authors highlight the growing importance of trust in data, models, training processes, and outcomes as these systems become more integrated into everyday life and critical business processes. Blockchain can help track and illustrate a specific AI process at different granularity levels. Blockchain can also provide a fair evaluation of stakeholders' contributions by capturing the parties' interactions and activities [3].

2- AI with blockchain

The second category consists of applications and platforms that integrate AI and blockchain together without focusing on AI, support of blockchain, or enhancement by other technologies. In other words, AI and blockchain coexist side by side, and their combination creates completely new applications.

Markopoulos et al. describe a method that utilizes both AI and blockchain within the realm of human resource management. The method starts with the Democratic Teaming Model (DTM) for the selection of project personnel democratically. By including expert systems, the organization can obtain recommendations on how teams should be composed. The expert system can utilize various types of employee data, including their interests, experiences, or past activities. The blockchain can support this further by securing the data feed and transactions to optimize the analytical output [56].

Keršič et al. (2020) developed a platform for global employability based on AI and blockchain. Their goal was to create a platform that allowed an automatic search and recruitment process. Blockchain was used to ensure data integrity and to automate business logic through smart contracts. In Keršič et al.'s approach, ML, as a part of AI, was used to analyze large amounts of data. ML could find a suitable employee for a given task, avoiding the manual screening of applicants and job offers [57].

Arora et al. (2020) proposed a combination of deep learning or AI and blockchain to make collaborative recommender systems safer. The goal of this approach was to make simple control of one's own data possible. The mentioned authors believed that the combination of these technologies would be appropriate for those industries in which data privacy is important [58].

Ladia (2020) addresses the challenge companies face in sharing data due to privacy concerns. This limitation is a huge disadvantage, because machine learning models benefit from additional training data. The author presents a blockchain-based solution that enables the training of machine learning models without compromising privacy [59].

Li et al. (2019) also presented an approach based on blockchain and automated machine learning (Auto ML) for an open and automated customer service. The starting point here is data collected by IoT devices during customer service. Then, the data can be traded in an open, but secure, way with the blockchain. The blockchain can also be used to ensure that the data remains unchanged or unmanipulated. Auto ML performs analysis to reduce reliance on human experts. The authors believe that their approach can be useful in small and medium-sized enterprises (SMEs) because the necessary resources are not available. Auto ML, in combination with blockchain, should permit this process to be automated and more accessible [60].

B. Combining blockchain and AI in supply chain

The integration between blockchain and artificial intelligence can promote security, efficiency, and productivity of applications in business environments characterized by volatility, uncertainty, complexity, and ambiguity. In particular, the supply chain is the area that has been shown to benefit tremendously from blockchain and AI, by enhancing information and process resilience, enabling faster and more cost-efficient delivery, and augmenting the traceability of products [61].

Samanta et al. (2024) present an approach based on blockchain and artificial intelligence for supply chain management. Here, the integration of blockchain technology and artificial intelligence (AI) is revolutionizing supply chain management by enhancing transparency, efficiency, and trust across global networks. In fact, blockchain's immutable ledger offers a secure and decentralized platform for recording transactions, ensuring data integrity and traceability throughout the supply chain. AI also complements this by providing advanced analytics, predictive insights, and automation capabilities that optimize operations and decision-making processes [34].

Together, these technologies address key challenges in supply chain management, such as fraud, counterfeiting, and inefficiencies, by creating a more transparent and accountable ecosystem. Their research revealed that this synergy between blockchain and AI not only streamlines processes but also empowers stakeholders with real-time, reliable data, fostering collaboration and resilience in supply chains [34].

In this regard, Tsolakis et al. (2023) explored the joint implementation of Artificial Intelligence (AI) and Blockchain Technology (BCT) in supply chains for extending operations performance boundaries and fostering sustainable development and data monetization [62]. They first mapped the business processes and the system-level interactions to understand the governing material, data, and information flows that could be facilitated through the combined implementation of AI and BCT in the respective supply chain. The mapping results illustrate the central role of AI and BCT in digital supply chains' management, while the associated sustainability and data monetization impact depends on the parameters and objectives set by the involved system stakeholders. Finally, they proposed a unified framework that captures the key data elements that need to be digitally handled in AI and BCT-enabled food supply chains for driving value delivery [62]. In addition, delivering the finest products to consumers at the optimal time, in the perfect location, at the right price, and with the highest quality- these are well-known requirements for logistics and transportation. However, in a highly dynamic logistics market and the complexity of supply chains, it is not simple to fulfil these needs, and requires new methods and services.

Idrissi et al. (2024) also addresses the issue of how traditional supply chains can be transformed into smart ones through the integration of new technologies, especially Blockchain and the Internet of Things (IoT), and artificial intelligence (AI). In other words, the impact of blockchain technology can be amplified by integrating it with IoT and AI, particularly in the context of supply chains. This integration offers the potential to create more transparent, efficient, and secure logistics operations [63].

Because IoT devices have limited computational and storage capabilities, and user-sensitive logistics data are typically stored in a centralized cloud facility, which is readily a source of privacy leakage [64]. So, the integration of blockchain, artificial intelligence (AI), and the Internet of Things (IoT) in logistics represents a transformative synergy, offering unprecedented efficiency, transparency, and security. Blockchain's immutable ledger technology, when combined with IoT's real-time data collection capabilities and AI's data processing power, creates a robust system for logistics management [63]. For instance, Wong et al. discuss how IBM and Maersk's TradeLens platform leverages blockchain to provide an end-to-end supply chain solution, ensuring transparency and reducing fraud. IoT sensors attached to shipping containers monitor conditions such as temperature and humidity in real-time, feeding this data into AI algorithms that predict potential issues before they arise, thereby preventing spoilage of perishable goods [65]. Another example is highlighted by Bai and Li, where DHL and Accenture collaborate to use blockchain to track pharmaceutical shipments. While IoT devices ensure the integrity of the supply chain by monitoring the conditions under which drugs are transported. AI processes this data to optimize routes and improve delivery times [66].

V. Conclusion

This systematic review clarifies and underscores the nascent yet promising role of blockchain and Artificial Intelligence (AI) in revolutionizing the supply chain. The majority of the studies found are conceptual or in initial experimental phases, indicating that the use of these technologies is still in its infancy. However, within the scope of the smart supply chain, significant potential areas for development include enhancing operational logistics processes, transparency of supply chain processes, identification and tracking methods, etc. The integration of blockchain and artificial intelligence (AI) into supply chain management represents a transformative shift toward greater transparency, efficiency, and security. The findings reveal that when blockchain is combined with AI's real-time analytics capabilities:

1. Significantly enhances the transparency of supply chain operations.
2. This integration provides stakeholders with a reliable and tamper-proof record of transactions, fostering trust among participants.
3. The ability to track goods in real-time provides unparalleled visibility into the movement and condition of products. It not only improves operational efficiency but also reduces the risk of delays, losses, and damage.
4. The automation of processes through smart contracts further streamlines operations, reduces costs, and minimizes the need for manual intervention, leading to more efficient and cost-effective supply chain management.
5. The enhanced security provided by blockchain's cryptographic techniques and AI's real-time threat detection contributes to the integrity and protection of supply chain data. It mitigates risks associated with data breaches and fraud, ensuring that sensitive information remains secure and trustworthy.

In addition, the impact of blockchain technology can be amplified by integrating it with IoT and AI, particularly in the context of supply chains. This integration offers the potential to create more transparent, efficient, and secure logistics operations, aiming to enhance areas such as real-time tracking, automated decision-making, and predictive maintenance. As a result, blockchain and AI technologies not only enable new roles in supply chains but also revolutionize the history of supply chain management. They are setting the pace of innovation and introducing a radical shift in almost every industry. On their own, blockchain and AI are cutting-edge technologies; however, when combined, they can be truly revolutionary, each with the potential to enhance the other's capabilities, allowing for better oversight and accountability.

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