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Does Blockchain Matter in Industry 4.0? A Key Driver of Industry

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Abstract

The Internet of Things (IoT) has become a fundamental element of Industry 4.0 and is increasingly applied across multiple industrial domains. Nevertheless, reliance on cloud-based storage, computation, and communication introduces several drawbacks, including latency in data transfer, vulnerability to single points of failure, and risks of privacy breaches. In addition, centralized access control limits both the scalability and availability of IoT systems. Blockchain, as a decentralized, immutable, transparent, and tamper-resistant ledger, offers potential solutions to these challenges. The convergence of Blockchain with IoT has enabled the development of diverse distributed applications, ranging from smart healthcare, finance, and supply chains to smart cities, manufacturing, governance, agriculture, transportation, education, e-commerce, and energy grids. To fully address the demands of digital transformation within Industry 4.0, Blockchain integration with enabling technologies such as 5G and artificial intelligence is considered essential.

Keywords: industry 4.0, internet of things (iot), blockchain, 5g, artificial intelligence (ai)

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1. Introduction

Blockchain technology originated with Bitcoin, the first and most successful cryptocurrency. Since the introduction of digital currency in 1983, the expansion of the Internet has created diverse opportunities for its use. At the core of digital currency lies the question of whether encryption should be applied to secure transactions and regulate currency issuance. Blockchain represents a decentralized, tamper-resistant ledger that operates as a distributed network rather than through centralized authority. It combines anonymity, cryptographic techniques, consensus protocols, smart contracts, and reputation

mechanisms into a unified framework capable of providing accurate, secure, and traceable services at lower cost while minimizing reliance on intermediaries. With these attributes, blockchain offers businesses distinctive advantages, such as decentralization, stronger security, immutability, and support for strategic decision-making, making its practical application in information systems a crucial issue beyond mere theoretical discourse (Casino et al., 2019).

The accelerated advancement of blockchain has drawn significant attention from researchers. Academic studies increasingly examine its technical foundations, operating models, and potential challenges. However, research into blockchain's role within the field of information systems remains limited. Much of the existing literature has been descriptive in nature, emphasizing blockchain-enabled service provision and technology applications. This reflects a growing trend toward examining blockchain adoption, diffusion, and value creation. Current research spans not only finance and economics but also sociology, management, psychology, and related disciplines, demonstrating blockchain's expanding interdisciplinary relevance.

Industry 4.0, first conceptualized by the German government in 2011, represents a paradigm shift aimed at transforming the manufacturing sector (Javaid et al., 2021; Khan & Javaid, 2021; Li, 2018; Roblek et al., 2016; Vogel-Heuser & Hess, 2016; Xu et al., 2018b). The initiative is driven by technological advancements such as Cyber-Physical Systems (CPS), the Internet of Things (IoT), Internet of Services, Cloud Computing, Big Data, Machine Learning, Mobile Internet, Semantic Web, and virtualization (Li et al., 2015, 2018; Mabkhot et al., 2018; Wang et al., 2017; Whitmore et al., 2015; Xu et al., 2014). Its foundation rests on four essential dimensions: devices, connectivity, tailored services, and optimized data utilization (Aceto et al., 2020; Bellini et al., 2021; de la Peña et al., 2020; Harrison et al., 2016). By promoting decentralized production and integrating shared facilities within a global network, Industry 4.0 seeks to reconfigure value chains and digitalize traditional processes (Brettel et al., 2017; Haleem & Javaid, 2019; Lasi et al., 2014). This digital transformation connects the physical and virtual worlds, generating unprecedented opportunities for industrial growth and innovation (Viriyasitavat et al., 2019; Zhang et al., 2021b).

Viewed historically, Industry 4.0 follows three earlier industrial revolutions. The first was defined by steam and water power, enabling mechanical production and transportation. The second introduced electricity, which replaced steam and facilitated mass mechanization. The third brought about automation through electronics and information technology, significantly improving production efficiency and accuracy. Building upon these stages, Industry 4.0 leverages CPS as its central concept (Xu & Duan, 2019; Xu, 2020a, 2020b). CPS integrates data analytics, communication, and precise control, allowing it to analyze information, generate predictions, and dynamically link virtual and physical processes.

This unified system combines production, logistics, and services to enable real-time monitoring and management. CPS not only supplies relevant information instantly within value chains but also supports optimization of costs, resource allocation, and operational continuity. Through IoT and cloud computing, CPS establishes real-time interaction and cooperation between humans and machines, creating interconnected and adaptive smart factories. These factories are capable of monitoring physical processes, producing virtual counterparts, and making autonomous decisions to improve efficiency and flexibility. Industry 4.0 therefore enables dynamic, self-organizing networks that span organizations and enhance value creation.

The proliferation of connected IoT devices and the unprecedented data they produce present major challenges in terms of security and scalability for Industry 4.0 applications (Mohanta et al., 2020; Wu et al., 2020). Blockchain technology has been proposed as an effective approach to overcome these challenges by enabling tamper-resistant data

sharing and secure communications across IoT systems (Alhejazi & Mohammad, 2021; Cagigas et al., 2021; Carvalho et al., 2021; Guo et al., 2021; He et al., 2020).

Blockchain, considered one of the foundational technologies of Industry 4.0, is characterized as a decentralized, transparent, immutable, and append-only ledger (Carvalho et al., 2021; Guo et al., 2021). It essentially acts as a distributed public record that stores transactions in sequential blocks, resistant to faults and malicious attacks (Chen et al., 2021b; Xu et al., 2021). Its design ensures properties such as transparency, fairness, anonymity, and traceability, making it applicable to financial transactions as well as broader value exchange scenarios (Jamil et al., 2021; Nanayakkara et al., 2021).

Different architectures of Blockchain exist, namely permissionless/public and permissioned/private, supported by diverse consensus algorithms like proof-of-work, proof-of-stake, and proof-of-authority (Gourisetti et al., 2019; Viriyasitavat et al., 2019a–2019d). Consensus protocols ensure that all participants maintain a consistent state of the ledger without depending on a central authority (Nerurkar et al., 2021). Encryption, digital signatures, and cryptographic hash functions safeguard integrity and authenticity, while each node keeps a complete copy of the ledger to validate new transactions autonomously (Cocîrlea et al., 2020; Zhang et al., 2021a).

By adopting a peer-to-peer network, Blockchain removes the reliance on intermediaries and enables decentralized governance. This facilitates trust, accountability, and transparency in multi-party systems, such as IoT networks (Alhejazi & Mohammad, 2021; Bouras et al., 2021). Features like smart contracts, tokenization, and distributed consensus add further layers of automation and efficiency, making Blockchain a suitable foundation for self-managing and autonomous IoT ecosystems (Upadhyay et al., 2021).

Moreover, Blockchain contributes significantly to improving privacy, scalability, and interoperability in digital infrastructures. It enables secure value transfer, ensures confidentiality in control systems, and supports cross-boundary trust between different agents and organizations (Song et al., 2021; Rathee et al., 2021). The convergence of Blockchain with edge computing and artificial intelligence further strengthens its potential by reducing latency, securing sensitive data exchanges, and supporting computation-intensive services in IoT and 5G environments (Gu et al., 2020; Haro-Olmo et al., 2021; Yang et al., 2020). Thus, Blockchain not only addresses the limitations of conventional IoT frameworks but also provides a secure, transparent, and decentralized infrastructure for building next-generation Industry 4.0 solutions.

2. Materials and Methods

In Industry 4.0, Blockchain acts as a catalyst for transformation by providing secure mechanisms for authentication, asset management, smart contract deployment, and data exchange (ElMamy et al., 2020). While its earliest applications were concentrated on cryptocurrency transactions, the introduction of Ethereum, which enabled smart contract creation and automated execution, opened the door to broader innovations outside the cryptocurrency sphere (Alwabel & Kwon, 2021; Lone & Naaz, 2021). Smart contracts function as coded agreements that self-execute on the Blockchain without relying on intermediaries, reducing both human error and the risk of fraudulent activity (Ante, 2020; Centobelli et al., 2021; Coblenz et al., 2020; Cocîrlea et al., 2020; Das et al., 2021; Marina & Taskov, 2020).

Because many Blockchain systems are inherently programmable, they enhance trust through stronger security, transparent traceability, and cost-effective operations. As a result, Blockchain has become increasingly recognized as a disruptive force that challenges centralized systems, serving as the underlying infrastructure for decentralized IoT-powered applications. These include solutions in areas such as smart healthcare, smart homes, urban management, energy distribution, transportation, manufacturing, logistics,

banking, and insurance (Almagrabi et al., 2021; Lone & Naaz, 2021; Wang et al., 2021b; Yu et al., 2021).

2.1. Smart health care

The rapid progress in health monitoring technologies and the growing availability of remote diagnostic services have contributed to the widespread adoption of electronic health systems in recent years (Biswas et al., 2020; Xu, 2011). One of the key practices in this field is the use of electronic health records, which allow hospitals and medical organizations to document and classify patient information within their databases (Pournaghi et al., 2020; Santos et al., 2021). These systems gather continuous patient data through in-house monitoring devices and transmit it to nearby servers or connected devices for analysis (Aggarwal et al., 2021; Arul et al., 2021; Kumar & Tripathi, 2021a; Ray et al., 2020). However, such processes often lead to fragmented, redundant, and duplicated records across independent healthcare services. Ideally, patients should retain control over their medical data (Rajput et al., 2021), yet, at the same time, sharing these records with healthcare professionals is essential for improving service delivery and ensuring a holistic review of medical history (Charanya & Saravanaguru, 2020; Xiao et al., 2021).

Despite their benefits, electronic health systems face significant challenges, including issues of transparency, traceability, immutability, auditing, provenance, flexible access, trust, privacy, and security (Huang, Sun, et al., 2021; Huang, Zhang, et al., 2021). Currently, there is no unified, trusted platform for storing or exchanging medical information across the healthcare ecosystem (Cernian et al., 2020). Moreover, IoT-enabled devices connected to multiple entities expose vulnerabilities (Aujla & Jindal, 2020), while centralized storage models create risks of single points of failure and breaches of sensitive data (Arul et al., 2021; Biswas et al., 2020; Kumar & Tripathi, 2021b; Qin et al., 2021).

Blockchain technology, as a decentralized and tamper-resistant system, has the potential to transform healthcare data management (Yaqoob et al., 2021). With features such as transparency, distributed validation, and immutability, Blockchain can resolve many of the inefficiencies in managing patient records (Aggarwal et al., 2021; Cadoret et al., 2020; Hussien et al., 2021; Omar et al., 2020; Ray et al., 2020; Yuehong et al., 2016). It enables faster approval processes, seamless interaction among diverse stakeholders, and reduces misinformation and public anxiety during crises (Aggarwal et al., 2021; Omar et al., 2020; Ray et al., 2020). Beyond secure record management, Blockchain also supports interoperability among healthcare providers, facilitating precision medicine and individualized treatment approaches (Tan et al., 2020).

Furthermore, Blockchain-enhanced smart healthcare can go beyond data management by ensuring pharmaceutical product authenticity and preventing counterfeit drugs through supply chain traceability (Danese et al., 2021; Musamih et al., 2021). The incorporation of Blockchain in mobile health services, supported by service-oriented architectures, may also enable decentralized and patient-centered healthcare delivery (Santos et al., 2021).

2.2. Smart Finance

The conventional financial sector is constrained by several critical issues, notably inefficiency, elevated costs, and prolonged transaction durations (Hassani et al., 2018; Tian et al., 2020). As an emerging foundational technology, Blockchain provides a reliable infrastructure to enhance the security of financial operations while mitigating these weaknesses (Rajput et al., 2021; Viriyasitavat et al., 2019).

Its applications extend across numerous areas of finance, including cryptocurrency payments, banking operations, securities and derivatives trading, digital settlements, lending services, and financial auditing (Centobelli et al., 2021). Leveraging Blockchain, cryptocurrencies establish a decentralized certification process that upholds transparency and trust each time a transaction occurs online (Centobelli et al., 2021).

By combining Blockchain with cryptography, cryptocurrencies enable secure and pseudonymous exchanges (Tian et al., 2020). They function using consensus algorithms such as proof-of-work or proof-of-stake to validate transaction authenticity (Sapkota & Grobys, 2019). Well-known Blockchain-based digital currencies include Bitcoin, Ethereum, Litecoin, Ripple, and XRP (Kamidoi et al., 2021; Sapra & Dhaliwal, 2021; Zhao et al., 2021).

2.3. Smart Supply Chain

Industry 4.0 reshapes supply chains into intelligent systems characterized by sustainability, economic efficiency, and social value creation (Li, 2011, 2012; Sharma et al., 2021; Portna et al., 2021). IoT contributes significantly to this transformation, though its limited computing power and reliance on centralized cloud structures expose supply chains to vulnerabilities such as data manipulation and single point failures (Li et al., 2021; Sunny et al., 2020). Furthermore, traditional supply chains face challenges including information asymmetry, inadequate product quality, weak security, and lack of transparency (Lou et al., 2021; Zhang et al., 2021c). Blockchain technology addresses these weaknesses by enhancing supply chain visibility, trust, traceability, and operational efficiency (Centobelli et al., 2021; Khan et al., 2021). By reducing the bullwhip effect and ensuring immutable data management, Blockchain establishes trustworthy collaboration among stakeholders (Moosavi et al., 2021; Park & Li, 2021). It further minimizes reliance on intermediaries, ensures secure asset tracking, and streamlines logistics processes to reduce costs and delays (Kopyto et al., 2020; Maity et al., 2021; Saberi et al., 2019). Thus, Blockchain serves as a critical enabler for building agile, resilient, and smart supply chains (Chen et al., 2021a; Jabbar et al., 2020).

2.4. Smart Cities

Smart cities are designed as intelligent digital systems that leverage large-scale IoT networks to provide services based on real-time data collection and analysis (Bohloul, 2020; Cha et al., 2021; Ianuale et al., 2015). One common example is the smart home, which has improved daily convenience and reshaped modern lifestyles (Carter et al., 2020; Ren et al., 2021; Xu et al., 2018a). However, the rapid expansion of smart city applications also raises concerns regarding data security and privacy (Cha et al., 2021). For instance, crowdsourcing platforms often act as centralized trust hubs for requesters and workers, creating vulnerabilities since financial transactions depend on third-party institutions (Tan et al., 2021).

Blockchain technology is increasingly recognized as a key enabler of smart cities, helping them achieve sustainability in social, environmental, and economic dimensions (Wong et al., 2020). Its decentralized and encrypted structure ensures that information transmitted from edge computing devices remains accurate, secure, and tamper-proof (Ferreira et al., 2021). Moreover, the combination of Blockchain and artificial intelligence enhances the reliability and efficiency of urban infrastructure, public utilities, and citizen services (Alghamdi & Khan, 2021; Singh et al., 2020). Practical implementations include Blockchain-based smart contracts in real estate management to reduce costs and increase transparency (Jayabal & Sathia Bhama, 2021; Ullah & Al-Turjman, 2021), as well as Blockchain-supported waste management solutions. For example, Liu et al. (2021) propose a plastic credit system that tracks recyclability, while Chen and Ogunseitani (2021) introduce a Blockchain-based approach to e-waste repair, reuse, and remanufacturing.

2.5. Smart Manufacturing

Traditional manufacturing is typically organized around centralized control, a structure that results in high operational costs, lack of visibility into processes, delays, limited flexibility to manage unexpected events, and significant risks to security (Uysal & Mergen, 2021; Wang et al., 2020a; Wong et al., 2021; Zhang et al., 2020; Xu et al., 2013, 2012a; b). The

integration of blockchain into manufacturing addresses these challenges by enabling decentralized, automated smart manufacturing systems that enhance productivity and efficiency (Ghobakhloo & Ching, 2019; Shahbazi & Byun, 2021a).

Smart manufacturing represents a holistic ecosystem, incorporating production units, resources, business processes, employees, suppliers, and customers. It merges cyber and physical technologies, leading to greater technical precision and complexity (Huo et al., 2020; Rossit et al., 2019). Operating as a multi-agent system, it is driven by intelligent, autonomous, and decentralized devices (Wang et al., 2016). Effective implementation requires both horizontal and vertical collaboration, as well as product lifecycle management and seamless information exchange. Through this, manufacturers are better positioned to deliver reliable, flexible, and adaptive production with reduced costs and improved responsiveness to customer needs (Rajput & Singh, 2020; Wang et al., 2016).

Industry 4.0, guided by smart technologies, reduces wasteful production, material handling inefficiencies, and energy consumption (Harikannan et al., 2020). Blockchain provides the foundation for intelligent automation by supporting decentralized control and connectivity, thus boosting sustainability and competitiveness (Villasante et al., 2020). With advancements in AI, IIoT, cloud platforms, and machine learning, the trajectory of manufacturing is moving toward smarter, data-driven decision-making and continuous improvement (Qu et al., 2020).

2.6. Smart Government

Smart government aims to enhance administrative efficiency, strengthen decision-making processes, and advance public service delivery (Shan et al., 2021). Blockchain serves as a secure and immutable data infrastructure that ensures the protection of sensitive governmental records, streamlines operational procedures, integrates hyper-connected services, and prevents corruption through tamper-proof mechanisms (Fallucchi et al., 2021; Hassija et al., 2020). A notable example is Mattereum, which enables the management of legal rights over assets, objects, and information by tokenizing property and introducing automated custodianship (Fallucchi et al., 2021). Similarly, Gao et al. (2021) propose a consortium Blockchain-based system for electronic certificate sharing, designed to overcome the complexities of cross-border governmental services.

2.7. Smart Agriculture

Food traceability plays a crucial role in both the agricultural industry and the shelf life of food products (Shahbazi & Byun, 2021b). However, traditional food supply chains often fall short of consumer expectations because of centralized control, lack of transparency, and unreliable traceability data (Chen et al., 2021c; Ren et al., 2021b; Yang et al., 2021). Blockchain offers solutions by enabling efficient sorting methods and facilitating agricultural data sharing, thus fostering autonomy and intelligence in precision farming. This integration enhances supply chain efficiency, ensures higher quality management, and improves food safety (Saurabh & Dey, 2021; Torky & Hassanein, 2020; Vivaldini, 2021; Xu et al., 2008).

2.8. Smart Transportation

Drones, or Unmanned Aerial Vehicles (UAVs), have become widely utilized in transportation systems for activities such as road surveillance, logistics delivery, and object tracking, all with limited human intervention (Bera et al., 2021; Jian et al., 2021). These tasks involve transferring vast amounts of data to remote servers for analysis, which necessitates high-performance computing resources, fast data transmission, and reliable

networks (Chen et al., 2021a; Han et al., 2021). The rapid growth of UAV usage also brings risks, including security threats, crowded airspace, misuse, and accidental crashes (Singh & Venkatesan, 2021). To secure drone communication, privacy protection and authentication are critical (Xu et al., 2020). Yet, existing solutions struggle with transaction storage overhead, latency, bandwidth constraints, and inconsistent communication reliability (Gupta et al., 2021). Blockchain offers a promising approach by providing secure, reliable communication and safeguarding data integrity (Singh & Venkatesan, 2021). When combined with fog and cloud computing, Blockchain-equipped UAVs can deliver complex, authenticated services with high data availability (Chen et al., 2021a). In addition, Blockchain can enhance Vehicular Ad Hoc Networks (VANETs), which are crucial for real-time vehicle communication and road safety, by enabling secure, anonymous, and rapid vehicle authentication while ensuring transparent and decentralized data management (Maria et al., 2021; Kudva et al., 2021).

2.9. Smart Education

In higher education, current certification systems for academic achievements are often inefficient, costly, and prone to fraud (Capece et al., 2020; Castro & Au-Yong-Oliveira, 2021). Blockchain introduces the concept of *smart education* by enhancing the management of academic transcripts, credentials, student records, and digital libraries (Raimundo & Rosário, 2021). Through its immutable and verifiable nature, Blockchain ensures the authenticity of diplomas and certificates, enabling students to obtain secure, tamper-proof versions more efficiently (Capece et al., 2020). Furthermore, Blockchain promotes decentralization in online education and lifelong learning, granting learners greater autonomy over their educational data and progress (Mikroyannidis et al., 2020). It also strengthens privacy protection, facilitates data sharing, and enhances information traceability within e-Portfolios (Li, 2020; Zheng, 2021).

2.10. Smart e-Commerce

E-commerce has become one of the most dominant retail channels in recent years. Within this domain, Blockchain technology facilitates decentralized marketplaces by enabling secure, real-time transactions, minimizing fraudulent activities, and strengthening both traditional and digital commerce, as well as public and private transportation systems (Christidis & Devetsikiotis, 2016; Mohammed et al., 2021). For instance, Zhou et al. (2021b) developed a Blockchain-based decentralized reputation framework that records and manages the credibility of both buyers and sellers in e-commerce settings. Similarly, Li et al. (2020a) introduced a Blockchain-powered logistics finance execution platform, providing e-commerce retailers with improved efficiency in implementing logistics financing solutions.

2.11. Smart Grid

The global energy market is undergoing a transformation from centralized distribution toward peer-to-peer (P2P) energy exchange, fueled by the proliferation of microgrids that harness renewable resources (Hariharasudan et al., 2020). Households producing green energy can directly trade electricity with one another, creating new opportunities for economic benefit (Doan et al., 2021). To ensure efficiency in supply and demand, grid operators rely heavily on advanced data networks for monitoring, analysis, and system coordination (Khattak et al., 2020; Marín-López et al., 2020).

Blockchain serves as a critical enabler of this transition, as it allows secure integration of vast and growing interconnections in distributed grids. It supports the movement toward active distribution networks by safeguarding privacy and reliability in decentralized electricity transactions (Hariharasudan et al., 2020; Mollah et al., 2020; Guo et al., 2020).

Smart grids, designed with cloud and fog computing infrastructures, represent a new paradigm in power systems by incorporating renewable and green technologies (Khattak et al., 2020; Mollah et al., 2020). They enable two-way flows of both electricity and information across networks, allowing dynamic optimization of transmission based on real-time user needs and predictive scheduling (Kumar et al., 2020; Wang et al., 2020b; He et al., 2021). This innovation significantly reduces theft, losses, and operational expenses while improving customer interaction and comfort (Khattak et al., 2020). With self-healing mechanisms, smart grids empower consumers as active participants (Kumar et al., 2020). Blockchain further strengthens these capabilities by ensuring data integrity, preventing tampering, deletion, or unauthorized alterations of energy records (Khattak et al., 2020).

3. Result and Discussion

Blockchain technology offers significant potential for enhancing data sharing and trust computation, yet several obstacles remain unresolved. Key challenges include interoperability, survivability, and manageability (Hardjono et al., 2019). Current Blockchain systems also face major technical constraints such as excessive energy consumption, inefficiencies in consensus mechanisms, heavy computational overhead, and limited transaction throughput (Centobelli et al., 2021; Yang et al., 2020; Yun et al., 2020). High transaction latency further creates uncertainty among participants (Centobelli et al., 2021).

The operation of Blockchain requires massive computational resources, trusted authorities, extensive storage for ever-growing blockchains, and high CPU processing capabilities to execute consensus algorithms (Andola et al., 2020; Ekanayake & Halgamuge, 2021; Na & Park, 2021). Consequently, existing Blockchain solutions are not well-suited for IoT devices (Yun et al., 2020). Similarly, Blockchain mining and computation-intensive applications demand considerable processing and storage capacity, which limits its deployment in mobile environments (Nguyen et al., 2020). To ensure reliability, Blockchain systems must also achieve robust fault tolerance for maintaining safety and liveness in publicly accessible and verifiable ledgers (Nijisse & Litchfield, 2020). Despite its cryptographic foundations, Blockchain remains vulnerable to security breaches and privacy threats (Yu et al., 2021; Zamani et al., 2020; Zhou et al., 2021a). For instance, the structure of Blockchain makes the latest block particularly exposed to attacks, where malicious nodes may alter data, generate new blocks, and manipulate the chain (Alwabel & Kwon, 2021).

Beyond technical limitations, organizational and managerial barriers also hinder Blockchain adoption. These include misalignment with information system success models and task-technology fit (Alazab et al., 2021), low awareness and understanding among businesses (Mathivathanan et al., 2021), competitive and partner-related pressures (Kamble et al., 2021), inadequate top management support, insufficient competitive pressure, and lack of technical competence (Fernando et al., 2021). Regulatory uncertainty and the absence of clear legal frameworks further complicate adoption (Balasubramanian et al., 2021).

Nevertheless, Blockchain offers promising attributes such as decentralization, transparency, interoperability, immutability, traceability, and privacy protection, making it a viable enabler for Industry 4.0 applications (Zhang et al., 2020). Its integration with IoT significantly expands potential use cases (Centobelli et al., 2021), including smart healthcare, finance, supply chain, cities, manufacturing, government, agriculture, transportation, education, e-commerce, and energy systems.

Emerging technologies are reshaping the Blockchain landscape. The expansion of fifth-generation (5G) networks has accelerated data processing and transmission capabilities, while edge computing provides distributed computational power and reduces latency compared to traditional cloud computing (Shahbazi & Byun, 2021b; Sun et al., 2021; Wu et al., 2020). With the deployment of network slicing and mobile edge computing, 5G

enhances network flexibility and responsiveness (Togou et al., 2020). The ubiquity of mobile devices further drives the development of Blockchain-enabled applications on mobile platforms (Kamble et al., 2021).

Artificial Intelligence (AI) also plays a crucial role in Industry 4.0, enabling capabilities such as self-optimization, self-awareness, and self-monitoring (Peres et al., 2020). By perceiving their environment, analyzing acquired data, and solving complex problems through learning, AI systems are transforming manufacturing processes and business models. The convergence of AI and Blockchain has the potential to establish secure, immutable, and decentralized infrastructures for managing the sensitive information generated and used by AI-driven systems (Centobelli et al., 2021). Organizations can benefit from this synergy to address the multifaceted challenges of digital transformation.

4. Conclusions

A comprehensive understanding of Blockchain adoption requires examining governance and risk management, technological features, potential benefits, and its integration with other emerging technologies such as IoT, cloud computing, and 6G. Such integration highlights that the relevant unit of analysis is not limited to individual firms but extends to networks and ecosystems shaped by Blockchain.

Blockchain stands as one of the most disruptive innovations in ICT, offering scalability, interoperability, and adaptability that provide fertile ground for further IS research. Future inquiries will likely address how organizations—both traditional and digital-native—can absorb and adapt Blockchain to create business value and sustain competitive advantage.

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