Blockchain and AI enabled new business models and applications

Mrs Kande Archana[1]
Assistant Professor
Malla Reddy Institute of Engineering and Technology
Hyderabad
Reearch Schalor at JNTUH
Telanagana State ,India
kande.archana@gmail.com

Dr V Kamakshi Prasad[2]
Professor
Jawaharlal Nehru Technological University
Hyderabad,
Telangana State, Inia

Dr M Ashok[3]
Principal & Professor
Malla Reddy Institute of Engineering and Technology
Hyderabad , Telanagana State ,India

Abstract- Abstract:
The bibliometric-content analysis of the integration of artificial intelligence (AI) and blockchain in the business domain. By combining bibliometric techniques and content analysis, this research aims to uncover trends, patterns, and emerging themes within the literature, providing insights into the current state of research and identifying future directions.A systematic approach to literature selection, focusing on scholarly publications related to AI and blockchain integration in business. A rigorous bibliometric analysis is conducted to examine publication trends, authorship patterns, and citation networks. The analysis identifies influential authors, leading journals, and prominent research institutions contributing to this field. In addition to bibliometric analysis, a content analysis is performed to extract and analyze key themes, research topics, and conceptual relationships within the literature. This qualitative analysis helps identify the major research areas, including business model innovation, smart contracts, data privacy, supply chain management, and financial applications.

Keywords—Internet of Things (IoT), Privacy, Security, Data encryption,Authentication,Firmware updates,Privacy by Design,Network Configuration,User consent,User control,Monitoring,Intrusion detection,Physical security,Vendor accountability,User awareness,Best practices,Regulations,Data confidentiality,Data integrity,Trust.

INTRDUCTION

Artificial intelligence (AI) is a technology that can perform complex tasks that require human intelligence, and it holds the potential of exceeding human capabilities (Agarwal et al., 2020; Pandl et al., 2020). AI is one of the main drivers of industrial development as it promotes the integration of emerging technologies in the Fourth Industrial Revolution (IR 4.0) (Goodell et al., 2021; Lim, 2019; Zhang et al., 2021), such as blockchain (Ehrenberg & King, 2020), cryptocurrency (Li & Whinston, 2020), cloud computing (Hsu, 2020), and internet of things (IoT) (Ghaleb et al., 2021). Indeed, the massive amount of data generated by IoT devices, social media, and web applications has fueled the proliferation of AI, wherein the data is utilized in the training of machine learning algorithms (Dinh & Thai, 2018). However, some concerns associated with AI exists. Specifically, privacy has become a critical concern as a result of a series of leaks and misuse of personal data. The Facebook scandal in which millions of users were targeted without consent by Cambridge Analytica, a third-party political firm, is one such example. Other growing concerns with AI include explainability and trustworthiness as the technology does not interact or speak with human users and thus cannot be verified or trusted (Dinh & Thai, 2018).

Likewise, blockchain has gained increasing attention as a technology with a wide range of applications in various fields (Dinh & Thai, 2018; Liu et al., 2019a). Blockchain, which became popular after the emergence of bitcoin in 2008 (Nakamoto, 2008), has remained as a disruptive technology that transforms the way we interact, trace transactions, and automate payments, among others (Roszkowska, 2020). Indeed, blockchain has opened the door of opportunities that enables the direct transference of value between its users in a secure and trusted manner. Moreover, with the execution of smart contracts, the checking of approvals and compliances can become simpler, as blockchain is a shared database that

is synchronized across multiple sites, and thus, such activities can be agreed on by each participant in a distributed network (Soleymani & Paquet, 2020). The data in blockchain is stored in blocks with hash values and timestamps, wherein the blocks are created based on a consensus protocol such as a proof of work or a proof of stake (Dinh & Thai, 2018)—proof of stake is less expensive than proof of work due to higher energy efficiency (Karafiloski & Mishev, 2017). More importantly, all transactions are cryptographically signed on blockchain, wherein all mining nodes that hold a copy of the entire ledger verify every single transaction on the blockchain (Nakamoto, 2008; Zheng et al., 2017). Therefore, blockchain is cost effective and secure as it eliminates the need for a centralized authority to verify the transactions (Karafiloski & Mishev, 2017; Zhu et al., 2021).

The developments of AI and blockchain has propelled their integration to revolutionize the next digital generation ignited by IR 4.0. According to Salah et al. (2019), blockchain can offer explainability, privacy, and trust to AI-based applications, whereas AI can enhance scalability and security while resolving the personalization and governance issues for blockchain-based technologies. As indicated in Table 1, AI and blockchain are technically different in various ways, but they can be used to overcome the shortcomings of each other. In that sense, AI and blockchain are the yin and yang of digital business, wherein AI helps the business to understand, recognize, and decide, whereas blockchain supports the business to execute, verify, and record (Morrison, 2016).

	Artificial Intelligence (AI)	**Blockchain**
Definition	The simulation of human intelligence processes by machines, enabling them to learn, reason, and make decisions.	A decentralized and immutable ledger that securely records and verifies transactions.
Purpose	To mimic human intelligence, automate tasks, analyze data, and make informed decisions.	To establish trust, transparency, and secure peer-to-peer transactions without intermediaries.
Technology	Machine learning, natural language processing, computer vision, neural networks, etc.	Cryptography, consensus algorithms, peer-to-peer networks, smart contracts, etc.
Data Handling	Requires large volumes of structured and unstructured data for training and learning.	Stores transactional data in blocks, forming a chain with cryptographic links to ensure data integrity.
Decision-making	Derives insights, makes predictions, and automates decisions based on learned patterns and algorithms.	Executes predefined actions based on smart contract conditions and consensus rules.
Security	May raise concerns regarding data privacy, bias, and ethical considerations in decision-making.	Provides transparency, immutability, and tamper-resistance through cryptographic mechanisms.
Use Cases	Personalized recommendations, chatbots, image recognition, fraud detection, predictive analytics, etc.	Supply chain transparency, decentralized finance, smart contracts, digital identity, voting systems, etc.
Interoperability	Can be integrated with various systems and platforms, leveraging APIs and data exchange protocols.	Requires interoperability standards for seamless interaction among different blockchain networks.
Scalability	Can handle large datasets and perform computations in real-time, but scalability can be a challenge.	Scalability remains a challenge due to consensus mechanisms, transaction throughput, and network limitations.
Governance	Governed by ethical considerations, responsible AI development, and regulations for fair and unbiased use.	Governance models vary, ranging from decentralized consensus mechanisms to consortium-led networks.

Table 1: The characteristics of artificial intelligence (AI) and blockchain

In practice, the convergence of AI and blockchain has brought many new opportunities (Makarius et al., 2020). In healthcare, blockchain enables the secure storage of patient data. When access is granted, health professionals gain insights from this data through the patterns churned by AI. Noteworthily, their joint application has helped the healthcare industry to navigate the COVID-19 crisis (Fusco et al.,

2020). BurstIQ, a blockchain-based company providing data solutions for the healthcare industry, is an innovative example that provides a health wallet based on blockchain, AI, and big data to manage patient data. The wallet provides patient health records to health professionals so that they can learn more about the patient's health condition as and when necessary (Daley, 2019). The convergence of the two technologies is also re-inventing the financial services industry by increasing the speed of transactions and enabling trust among transacting parties (Soleymani & Paquet, 2020). Similarly, AI and blockchain has transformed supply chains by digitizing traditional paper-based processes, enabling trustworthy data sharing, and facilitating automated transactions (Yong et al., 2020). IBM's food trust blockchain technology and AI platform is an example that has assisted small scale coffee and cocoa farmers to speed up their transactions and improve their farming decisions (Barbano, 2017).

In literature, the integration of AI and blockchain has been reported to produce wide-ranging applications for different sectors such as autonomous vehicles, finance, smart cities, and 6G networks. Dinh and Thai (2018) offered a conceptual articulation of integrating the two technologies and organizes their benefits through two categories in the form of AI for blockchain and blockchain for AI, whereas Salah et al. (2019) presented insights on blockchain applications for AI through a critical review of the extant literature, and thus, covers only the latter but not the former category. More recently, Pandl et al. (2020) sought to address this knowledge gap as they shed light on the convergence of AI and distributed ledger technology (or blockchain) using a systematic literature review, and thus, covering both categories. However, none of these reviews unpacked the applications of integrating AI and blockchain for business, which is the key activity underpinning economic activity and growth of a country.

Today, the language of business involves compound concepts such as dematerialization, disintermediation, and designing and producing goods on demand (Kumar, 2019). In this regard, success in the next industrial era requires companies to reconfigure their business models in ways where technology becomes central to their operations in order to address these changing demands in the future of work and marketplaces. AI and blockchain are powerful technologies that are well positioned for this endeavor as they hold the potential to reform existing processes for greater efficiency and seamlessness. Indeed, the paradigm of organizations today is transitioning from a hierarchical to a self-organizing model (Subic et al., 2020). While AI and blockchain have initially focused on the finance sector, companies today have come to realize its potential for other sectors, including agriculture, healthcare, logistics, manufacturing, and supply chains. (Pandl et al., 2020). Yet, no study, to date, have shed light on the peculiarities and opportunities for AI and blockchain integration specifically for business through a scientific consolidation of knowledge, which is arguably important for both future research (e.g., what else should we know) and practice (e.g., what should we do) in the field.

This article aims to address the identified research gap by exploring the utility of AI and blockchain integration for business. In particular, this article endeavors to identify the research peculiarities of the field and to explain how the integration of AI and blockchain can benefit different verticals of business in the era of IR 4.0. To do so, this article carries out a study using a bibliometric-content analysis to identify the publication productivity and the intellectual structure of the field. Following the convention of past bibliometric studies (Donthu et al., 2021b, c; Kumar et al., 2021a, b, c; Lim et al., 2022b, c) and the aims of the article, this study addresses the following research questions (RQs):

- RQ1. What is the publication productivity of research on AI and blockchain integration for business? The answer to this research question offers insights on the number and growth of scientific articles in the field.

- RQ2. What are the most influential articles on AI and blockchain integration for business? The answer to this research question enables academic scholars and business professionals to locate the key and seminal articles in the field.

- RQ3. What are the most prominent topics and themes on AI and blockchain integration for business? The answer to this research question provides a comprehensive understanding on the content in the field's body of knowledge.

- RQ4. What are the most promising areas for business to apply AI and blockchain integration? The answer to this research question guides business professionals on the application of AI and blockchain integration.

This article makes several noteworthy contributions. First, this article sheds light on AI and blockchain integration specifically for business, which to date, remains to no avail, wherein such insights are arguably important given that business is the engine of the economy, and thus, their transformation to remain relevant in the digital era is a high priority. Second, this article elucidates the applications and benefits that these technologies can offer to business, which represent important takeaways for both academia and industry. Third, this article represents the first study to perform a bibliometric analysis on AI and blockchain integration, which is an important endeavor to help interested scholars and professionals to gain a scientific overview of existing research in the field (Donthu et al., 2021a). While prior literature reviews on AI and blockchain avail, they remain limited in several ways. For example, the literature reviews by Omohundro (2014), Karafiloski and Mishev (2017), Dinh and Thai (2018), and Salah et al. (2019) are critical rather than systematic in nature, and thus, they are not replicable due to the absence of a review protocol and remain limited to the selective debates that they have deliberately chose to focus. The literature review by Pandl et al. (2020), though systematic, remains limited to manual, subjective insights. The use of bibliometric analysis herein this review can overcome the shortcomings of prior reviews as this review technique is predicated on statistical analysis on objective data (e.g., authorship, publication, citation) (Donthu et al., 2021a), and thus, represents a noteworthy step forward and a seminal contribution to the field. Table 2 presents the research gaps addressed by this study and maps the contribution of research questions toward the research gaps. The comparison of the focus, method, and contribution of the present review against prior reviews, which further accentuates the novelty of the present review, is presented in Table 3.

Research Gaps	Research Questions	Research Contributions
Gap 1: Scalability challenges in AI and blockchain integration.	What are the key scalability challenges when integrating AI and blockchain technologies?	Research on scalable architectures and algorithms for efficient AI and blockchain integration.
Gap 2: Ethical considerations and biases in AI and blockchain applications.	How can ethical considerations be addressed in AI and blockchain integration? How can biases be mitigated in AI algorithms within blockchain systems?	Investigation of ethical frameworks, fairness, and transparency in AI and blockchain applications. Development of techniques to reduce biases and ensure responsible AI deployment.
Gap 3: Interoperability issues between different AI and blockchain platforms.	What are the main interoperability challenges when integrating AI and blockchain systems from different providers? How can seamless interoperability be achieved?	Exploration of interoperability standards, protocols, and mechanisms for seamless integration of AI and blockchain across platforms.
Gap 4: Regulatory and legal frameworks for AI and blockchain integration.	What are the legal and regulatory implications of integrating AI and blockchain? How can compliance with existing regulations be ensured?	Analysis of legal and regulatory frameworks, identification of challenges, and proposals for guidelines and policies to govern AI and blockchain integration.
Gap 5: Real-world applications and case studies of AI and blockchain integration.	What are the practical use cases of integrating AI and blockchain technologies across different industries? How do these integrations provide value and impact business operations?	Investigation of industry-specific applications of AI and blockchain integration, highlighting the benefits, challenges, and outcomes in real-world scenarios.

Table-2: Mapping of research gaps, research questions, and research contribution

Study	Focus	Method	Contribution
Omohundro (2014)	Application of AI in smart contracts and cryptocurrencies.	Critical review	• How smart contract and cryptocurrencies can provide infrastructure to ensure that AI systems follow stipulated safety and legal regulations.
Karafiloski and Mishev (2017)	Resolving big data challenges through blockchain solutions.	Critical review	• How blockchain can be used for organizing, storing, and processing big data. • The role of blockchain for user authentication, recording data access history, and restricting user access based on need.
Dinh and Thai (2018)	Conceptual ideas of AI and blockchain integration.	Critical review	Two main perspectives: • How AI can be used for blockchain. • How blockchain can be used for AI.
Salah et al. (2019)	Research challenges on the use of blockchain for AI.	Critical review	Using blockchain for AI improves: • Data security. • Business process efficiency. • Trust on robotic decisions. • Collective decision making. • Decentralized intelligence.
Pandl et al. (2020)	Convergence of AI and distributed ledger technology (or blockchain).	Systematic literature review	Insights on the different ways in which: • AI can benefit distributed ledger technology. • Distributed ledger technology can benefit AI.
The present study	Applications of integrated AI and blockchain platforms in business.	Bibliometric-content review	Insights on AI and blockchain integration in business in terms of: • Publication productivity by year. • Most influential articles. • Prominent topics and co-occurrences. • Intellectual structure and its major thematic clusters. • 10 application areas.

Table 3 Comparison of the present study against existing literature reviews in the field

The rest of the article is organized as follows. The article begins with a disclosure of the methodology guiding its study, followed by a detailed presentation of the results from a bibliometric-content analysis. The article concludes with key takeaways from the study, with limitations acknowledged and suggestions for future research offered at the end.

2 METHODOLOGY

The present study adopts bibliometric analysis to determine the performance (e.g., publication productivity, most influential articles) and intellectual structure (e.g., topics, themes, application areas) of the literature on AI and blockchain integration in business. In essence, bibliometric analysis is a well-established scientific method for analyzing a body of literature, wherein bibliometric data (e.g., publication and citation information) are analyzed using quantitative tools (Pritchard, 1969; Donthu et al., 2021a; Mukherjee et al., 2021). The methodology is a recognized method of scientific enquiry having applications in various disciplines, including business (Donthu et al., 2021b, c; Kumar et al., 2021a, b, c; Lim et al., 2022b, c; Zupic & Čater, 2015). Noteworthily, many methods to review the literature avail (Lim et al., 2022a; Paul et al., 2021), but the bibliometric method is the most objective due to its reliance on a review protocol and quantitative analytical techniques—the other review methods either lack a review protocol (e.g., critical) and/or remain limited to subjective interpretations due to the absence of objective analysis techniques (e.g., thematic) (Donthu et al., 2021a; Lim et al., 2022a). Specifically, the present study adopts the four-step procedure for bibliometric analysis recommended by Donthu et al. (2021a), which includes *defining the aims and scope for*

study, *choosing the techniques for analysis*, *collecting the data for analysis*, and *conducting the analysis and reporting the findings*. The overview of the study's methodology is presented in Fig. 1.

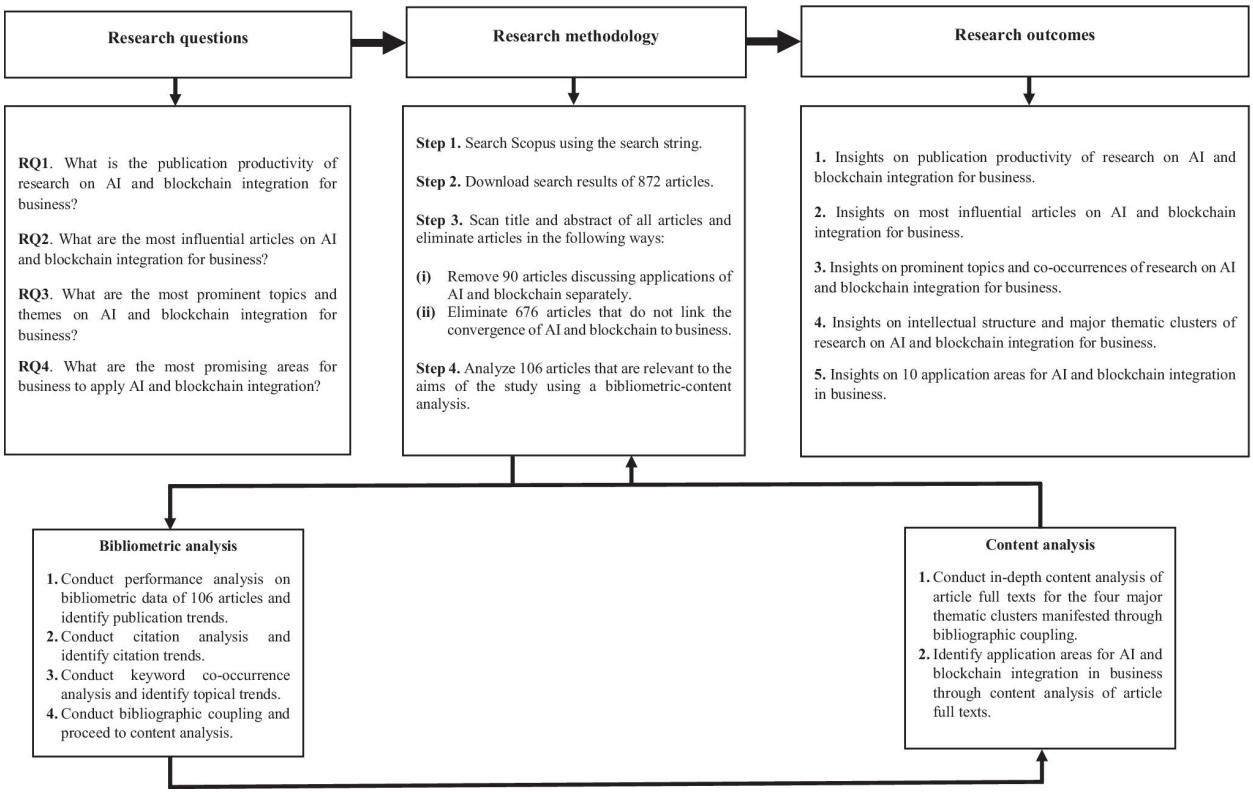

Fig-1: Research design and scheme of analysis

2.1 Defining the Aims and Scope for Study

The present study aims to shed light on the bibliometric and intellectual structure of the extant literature pertaining to AI and blockchain integration for business. The bibliometric structure encapsulates the publication productivity, whereas the intellectual structure pertains to the major topics and themes of research in the area under study. The scope for study is relatively large, as AI and blockchain are rich areas of research.

2.2 Choosing the Techniques for Analysis

The present study employs a combination of bibliometric and content analysis techniques to map the development of the literature pertaining to AI and blockchain integration for business. In particular, the study conducts a performance analysis using a variety of bibliometric measures such as citations, cite score, impact factor, publication count, and *h*-index, as well as keyword co-occurrence analysis and bibliographic coupling to unpack the major topics and themes in the research field, which subsequently informs the authors' reading of article full text for the content analysis.

2.3 Collecting the Data for Analysis

To identify the articles and associated bibliometric and bibliographic data for analysis, the authors engaged in brainstorming with subject-matter experts on AI and blockchain to develop the keywords to be included for the search. In essence, the concept of "AI-enabled blockchain" is an amalgamation of two technologies, namely AI and blockchain. In order to ensure that both of these concepts are comprehensively captured by the search keywords, the authors included a search string for data search comprising of keywords covering the two technologies, as presented in Table 4.

Search string	Search results
(“Machine Learning”) OR (“AI”) OR (“Neural Network”) OR (“Artificial Intelligence”) OR (“Deep Learning”)	872 articles
AND	
(“Blockchain”) OR (“Block-chain”) OR (“Block chain”) OR (“Bitcoin”) OR (“Ethereum”) OR (“Hyperledger”) OR (“Cryptocurrency”) OR (“Smart contract”) OR (“Distributed Ledger Technology”) OR (“DLT”) OR (“Distributed Ledger”)	

Table 4: Search string and search results

The first part of the search string consists of terms related to AI (e.g., “artificial intelligence” and “machine learning”) and its most common applications (e.g., “neural network” and “deep leaning”). The second part of the search string comprises of keywords related to blockchain (e.g., “blockchain”, “distributed ledger”, and “hyperledger”) and its most common applications (e.g., “bitcoin”, “ethereum”, and “smart contract”). The search is limited to document type (i.e., article and review), source type (i.e., journal), language (i.e., English), and year of publication (i.e., up to 2020). The search was conducted in February 2021. The data for the study is fetched from Scopus as it is the largest scientific database for peer-reviewed research publications (Bartol et al., 2014; Donthu et al., 2021a; Paul et al., 2021). The search of both search strings resulted in 872 articles.

In order to select the articles that are relevant for the study, the authors follow a two-step approach. In the first step after the results were returned from the Scopus search, two co-authors independently coded the articles (i.e., AI, blockchain, and AI and blockchain) before coming together with another co-author to collectively review, identify, discuss, and agree on the removal of 90 articles that discussed about the applications of AI and blockchain separately as they do not cover the “integration” of these technologies, which is the focus of the present study. In the second step, the same group of co-authors decided to eliminate 676 articles that did not link the convergence of AI and blockchain to business using the same process in the first step but with different codes (i.e., business, non-business). These articles explain only the technical aspects of the integration of AI and blockchain without inferring to how it brings cost-effectiveness, resilience, and flexibility to the business. After removing 676 articles, 106 articles that are relevant to the aims of the study were retained for analysis. The overall coding agreement for articles across the two steps was at 96% between two co-authors and a majority vote was implemented to resolve disagreements with the inclusion of another co-author in line with La Paz et al. (2020). Table 5 presents the inclusion and exclusion criteria used for shortlisting the articles relevant to the study.

Steps	Articles excluded	Reason for exclusion	Articles included	Reason for inclusion
Step 1. Scopus search	0	Not a filtering step.	872	Results returned from search.
Step 2: Read title and abstract of articles	90	Articles do not cover the integration of AI and blockchain—only either one of the two technologies, not both.	782	Articles cover the integration of AI and blockchain.
Step 3: Read full text of articles	676	Articles focus only on core technical aspects of integrated AI and blockchain platforms, and do not explicitly explain the benefits of the technological integration to business functions.	106	Articles goes beyond core technical aspects, and explicitly discuss the applications and benefits of integrated AI and blockchain platforms in/for business.

Table 5 Inclusion and exclusion criteria and procedure

1) 2.4 Conducting the Analysis and Reporting the Findings

The final step involves conducting the bibliometric-content analysis and reporting the findings from the analysis. To do so, the authors use VOSviewer (Van Eck & Waltman, 2010) and Gephi software to perform bibliometric analysis and to visualize its output in a network. Additionally, the authors use a Python code to create word clouds representing the main themes of bibliographic clusters to enrich the presentation of the findings, wherein Python 3.7 in combination with Jupyter Notebook were used to run the code and to generate the word clouds. The full text of each article in each major thematic cluster revealed through the bibliometric analysis was read and analyzed accordingly. The findings of the bibliometric-content analysis are reported in the next sections.

3 Findings

Findings from the bibliometric-content analysis are presented based on the research questions that they address. In particular, findings pertaining to publication productivity, influential articles, prominent themes, and promising application areas are related to the first, second, third, and fourth research questions, respectively, and the sections are organized as follows.

2) 3.1 Publication Productivity

To answer RQ1—i.e., what is the publication productivity of research on AI and blockchain integration for business—the study analyzes the total publications in the field by year. The bibliometric data employed for the analysis is collected from Scopus. Bibliometric data is a form of big data consisting of information associated to scientific publications, such as publication (e.g., title, abstract, keywords, year) and citation (e.g., author, document, and journal citation count) information (Broadus, 1987; Donthu et al., 2021a).

The number of publications on AI and blockchain integration for business is shown in Fig. 2. In particular, all publications in this domain are published between 2017 and 2020, with most publications appearing in 2019 and 2020, which reflects its status as an emerging field of research that has started to get popular recently. Indeed, AI and blockchain are two hallmark technologies of IR 4.0 that were introduced only in 2016, and thus, it is unsurprising that research of its integration have entered academia only in 2017, as initial research investment have focused on each technology independently, and proliferated since 2019, which signals that the integration of AI and blockchain are indeed important for business.

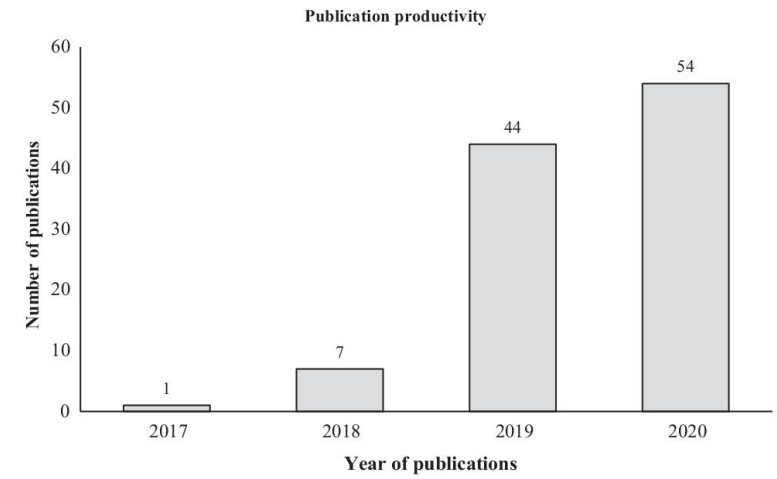

Fig : Annual distribution of publications on AI and blockchain integration for business

3.2 Most Influential Articles

To answer RQ2—i.e., what are the most influential articles on AI and blockchain integration for business—the study conducts a performance analysis by means of citation network for the 106 articles under review. There are several metrics to measure the influence of a publication, but the most prevalent metric is citations (Ding & Cronin, 2011), wherein the influence of a publication is assessed through the number of times it is cited by other publications (Donthu et al., 2021a). VOSviewer and Gephi software were employed to derive the citation network between publications. Figure 3 presents the citation network among publications and Table 6 shows the leading original articles by the number

of citations. Mamoshina et al.'s (2018) article on the convergence of AI and blockchain in healthcare tops the list with 102 citations, followed by Liu et al.'s (2019b) article on performance optimization for blockchain-enabled IoT systems and Mao et al.'s (2018) article on credit evaluation system based on LSTM and blockchain with 47 and 44 citations, respectively.

Rank	Year	Title	Author(s)	Journal	TC
1	2018	Converging blockchain and next-generation artificial intelligence technologies to decentralize and accelerate biomedical research and healthcare	Mamoshina et al.	*Oncotarget*	102
2	2019	Performance optimization for blockchain-enabled industrial internet of things (IIOT) systems: A deep reinforcement learning approach	Liu et al.	*IEEE Transactions on Industrial Informatics*	47
3	2018	Credit evaluation system based on blockchain for multiple stakeholders in the food supply chain	Mao et al.	*International Journal of Environmental Research and Public Health*	44
4	2020	Machine learning adoption in blockchain-based smart applications: The challenges, and a way forward	Tanwar et al.	*IEEE Access*	39
5	2019	Blockchain adoption: A value driver perspective	Angelis and da Silva	*Business Horizons*	37
6	2020	BlockIoTIntelligence: A blockchain-enabled intelligent IoT architecture with artificial intelligence	Singh et al.	*Future Generation Computer Systems*	27
7	2020	Smart contract privacy protection using AI in cyber-physical systems: Tools, techniques and challenges	Gupta et al.	*IEEE Access*	27
8	2019	Regulating Cryptocurrencies: A supervised machine learning approach to de-anonymizing the bitcoin blockchain	Sun Yin et al.	*Journal of Management Information Systems*	26
9	2019	Machine learning based privacy-preserving fair data trading in big data market	Zhao et al.	*Information Sciences*	25
10	2019	A blockchain and automl approach for open and automated customer service	Li et al.	*IEEE Transactions on Industrial Informatics*	19
11	2019	An intelligent blockchain-based system for safe vaccine supply and supervision	Yong et al.	*International Journal of Information Management*	14
12	2020	Food traceability system from governmental, corporate, and consumer perspectives in the European Union and China: A comparative review	Qian et al.	*Trends in Food Science and Technology*	10
13	2020	Blockchain and machine learning for communications and networking systems	Liu et al.	*IEEE Communications Surveys and Tutorials*	9

14	2020	IoT-blockchain enabled optimized provenance system for food industry 4.0 using advanced deep learning	Khan et al.	*Sensors*	8
15	2020	Blockchain for explainable and trustworthy artificial inteavblligence	Nassar et al.	*Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery*	8
16	2020	Transforming business using digital innovations: The application of AI, blockchain, cloud and data analytics	Akter et al.	*Annals of Operations Research*	avb
17	2020	Artificial intelligence implementations on the blockchain. Use cases and future applications	Sgantzos and Grigg	*Future Internet*	8
18	2019	Big data, blockchain, and artificial intelligence in cloud-based accounting information systems	Ionescu	*Analysis and Metaphysics*	7
19	2020	CrowdSFL: A secure crowd computing framework based on blockchain and federated learning	Li at al.	*Electronics*	5
20	2019	A blockchain-based evaluation approach for customer delivery satisfaction in sustainable urban logistics	Tian et al.	*International Journal of Production Research*	4

Fig: Citation network for publications on AI and blockchain integration for business

3.3 Areas for AI and Blockchain Integration in Business

To answer RQ4—i.e., what are the most promising areas for business to apply AI and blockchain integration—the study scans the review corpus using a content analysis and the ensuing findings are presented in Table 10, wherein 10 promising areas for potential application of these hallmark IR 4.0 technologies are earmarked and explained with application exemplars and their associated technologies, value, and source.

No	Area	Application exemplar	Value of application	Technologies	Source
1	E-commerce	Optimization of e-commerce platform	The structure of e-commerce websites can be optimized through AI and blockchain integration, whereby the application of blockchain technology solves the problem of cross border electronic payment, whereas the recommender system in e-commerce based on machine learning algorithms can help in online decision making.	• Blockchain • Deep learning • Neural network	Li et al. (2019)
2	Finance and accounting	Automated insurance system	An automated insurance system framework based on blockchain and extreme gradient boosting (XGBoost) machine learning	• Blockchain • Machine learning	Dhieb et al. (2020)

			algorithm can help to detect fraudulent claims, provide information about risky customers, and reduce monetary loss for the insurance industry.		
		Credit evaluation system	A credit evaluation system based on blockchain and deep learning network can provide reliable information about transactions and credit evaluation of traders.	• Blockchain • Deep neural network	Mao et al. (2018)
		Financial portfolio optimization	Blockchain and neural network together helps in audit and secure settlement process, whereas deep reinforcement learning can enhance management and optimization of financial portfolio.	• Blockchain • Convolutional neural network • Deep reinforcement learning	Soleymani and Paquet (2020)
		FinBrain	Integration of technologies like AI, big data, blockchain technology, and cloud computing with finance can lead to automated and secure financial transactions.	• AI • Cloud computing • Blockchain • Big data	Zheng et al. (2019)
		Preventing corporate frauds	Integration of AI, blockchain, and smart contract can overcome the deficiencies of auditing and financial reporting and prevent corporate frauds caused by the failure of the auditor.	• Blockchain • IoT • Machine learning • Smart contract	Roszkowska (2020)
3	Healthcare	COVID-19 safe clinical practice	A generalizable predictive system that can contribute to controlling the pandemic risk and thus safeguarding both economic and public health.	• Blockchain • Machine learning	Fusco et al. (2020)
		GuardHealth	A data privacy preserving and sharing system that is based on a consortium of blockchain, smart contract, and a trust model implemented through graph neural network.	• Blockchain • Graph neural network • Smart contract	Wang et al. (2020)
		Hospital consolidation	A decentralized patient assignment system based on blockchain technology, machine learning, and integer programming that can enable healthcare providers to perform shared decision making by accessing the data about patients and collaborate with each other.	• Blockchain • Integer programming • Machine learning	Badré et al. (2020)
		Health data repository	A predictive model based on a machine learning classifier to	• Blockchain • Machine	Uddin et al. (2020)

			help patients make data storage decisions in different types of blockchain-based data repository.	learning	
4	Intellectual property right (IPR)	IPR management	AI and blockchain can be used to manage the IPR lifecycle, wherein blockchain-based solutions can be used for notarization of IPR assets, whereas machine learning-based data processing pipeline can be used to compare the IPR assets among competitors.	• Blockchain • Machine learning	Ragot et al. (2020)
		IPR management system	New IPR can be registered on a blockchain platform that can empower eligible stakeholders to use IPR data from the blockchain network, wherein text mining can help to identify the type of IPR for retrieval.	• Blockchain • Text mining, clustering, and classification	Alnafrah et al. (2019)
5	Management	Corporate online dispute resolution system	AI and blockchain integration can help parties of dispute to discover their own best/worst alternative to a negotiated agreement.	• AI • Blockchain	Barnett and Treleaven (2018)
		Corporate governance	AI can reduce reliance on humans for decision making in corporations, whereas blockchain can reduce the cost of voting and trade clearance by promoting direct shareholder requirement.	• AI • Blockchain • Distributed ledger	Bruner (2020)
6	Marketing	Customer satisfaction	A blockchain-based evaluation technique that can be used to provide a secure platform and that can predict customer satisfaction through the Long Short-Term Memory (LSTM) machine learning algorithm.	• Blockchain • Machine learning	Tian et al. (2020)
		Customer service	An open and automated customer service platform based on blockchain, IoT, and machine learning can enable small companies that do not have sufficient experience and data to automate their customer services without relying on third parties.	• Blockchain • IoT • Machine learning	Li et al. (2019)
7	Smart manufacturing	Cyber production system	A blockchain-enabled cyber production system can solve the problems of existing manufacturing practices when integrated with AI tools.	• AI • Blockchain	Lee et al. (2019)
		PriModChain	PriModChain integrates ethereum blockchains, federated machine	• Differential privacy	Arachchige et al. (2020)

			learning, differential privacy, and smart contracts to improve the reliability and trustworthiness of IIoT data.	• Ethereum blockchain • Federated machine learning • Smart contract	
		Production capability evaluation system	A production capability evaluation system based on blockchain, IoT, and machine learning can help to improve production efficiency.	• Blockchain • IoT • Machine learning	Li et al. (2019)
8	Social media	Controlling spread of false social media messages	Blockchain's proof of work consensus algorithm can be used to reduce the spread of false information through social media, whereas parallel-dot-custom classifier of machine learning can be used to segregate the social media messages such as tweets as political and non-political.	• Blockchain • Machine learning.	Alagu Vignesh and Harini (2019)
		Secure instant messaging	A blockchain-based instant messaging scheme designed on Linux platform can be used to secure instant messaging, wherein machine learning algorithms detect anomaly in instant messaging by monitoring the activities on blockchain.	• Blockchain • Linux • Machine learning	Yi (2019)
9	Supply chain	Humanitarian supply chain	A framework integrating AI, blockchain, and 3D printing can improve the flow of products, information, and financial resources for humanitarian purposes.	• AI • Blockchain • Smart contract • 3D printing	Rodríguez-Espíndola et al. (2020)
		Smart farming	A platform based on the application of AI, blockchain, edge computing, and IoT can monitor the state of inventory in real time and ensure the traceability in the production process.	• AI • Blockchain • Edge computing • IoT	Alonso et al. (2020)
		Vaccine blockchain system	An intelligent system based on blockchain and machine learning can address the problem of vaccine record fraud and vaccine expiration in supply chains.	• Blockchain • Machine learning • Smart contract	Yong et al. (2020)
10	Transportation	Automation in airports	AI and blockchain enable airports to know their passengers' preferences and to meet the need of the travelers in a better way.	• Blockchain • Predictive analytics	Mayer (2019)
		Railway	Blockchain and big data analytics	• Descriptive	McMahon

		asset management	can be used for railways asset condition management.	analytics • Diagnostic analytics • Predictive analytics • Prescriptive analytics	et al. (2020)

Table 10 Promising areas for AI and blockchain integration in business

The content analysis of the review corpus reveals that integrated AI and blockchain platforms have a wide range of applications for different areas in business, some of which are generic (e.g., management, marketing), and thus can applied across all industries, while some are specific to an industry (e.g., e-commerce, healthcare). In particular, the 10 areas unpacked through the analysis include e-commerce; finance and accounting; healthcare; intellectual property right; management; marketing; smart manufacturing; social media; supply chain; and transportation. AI and blockchain are the key technologies propelling the wave of digital transformation. The convergence of both of these technologies can improve current business practices and introduce new business models that can act as independent economic agents making decisions autonomously. Blockchain can enhance transparency, trust, privacy, and security of business processes (Mao et al., 2018), whereas AI can detect patterns in data and optimize business practices (Salah et al., 2019). These two technologies are complementary by design and their true potential can only be unlocked if they are integrated (Sandner et al., 2020).

When AI and blockchain are used independently, they can cause series of concerns. On the one hand, AI suffers from issues related to trustworthiness, privacy, and explainability. On the other hand, blockchain experiences weaknesses such as security and scalability. The amalgamation of these two technologies can overcome these weaknesses and benefit businesses through secure data sharing and automatization of business processes (Sandner et al., 2020). In recent years, numerous business cases of AI and blockchain integration have emerged. The confluence of AI and blockchain creates a highly trustworthy technology-enabled decision-making system that contributes toward a secure ecosystem for data exchange and transactions. Specifically, blockchain provides frictionless information access to AI models and helps to make accurate decisions in business. The amalgamation of AI and blockchain technologies has also introduced decentralized autonomous business models that brings greater flexibility, agility, and cost-effectiveness to business. For example, Lee et al. (2019) introduce cyber physical system (CPS) for manufacturing industry, which facilitates self-optimizing, self-adjusting, and self-configuring production systems and solves the inadequacies of existing manufacturing processes. CPS has laid the foundation to build advanced production systems in which every functional element of the production chain such as design, manufacturing, supply chains, customer service, and support can be influenced (Lu, 2017).AI and blockchain, with the hardware support of IoT, can also make supply chains more resilient and robust as products are traceable in real time throughout the supply chain (Alonso et al., 2020). Moreover, these technologies can improve the flow of products, information, and financial resources across supply chains (Rodríguez-Espíndola et al., 2020).

In accounting, blockchain can help prevent incorrect predictions generated by AI algorithms due to faulty data generation systems or tampering of data sources by authenticating the data generators. Specifically, AI, blockchain, and IoT can help companies to increase the quality of the audit process by improving the reliability of financial statements (Roszkowska, 2020), thereby overcoming audit-related problems and mitigating the risk of accounting fraud.
In finance, Irwin and Turner (2018) proposes an optimal solution for tracking illicit bitcoin transactions by using AI algorithms to analyze big data collected form bitcoin blockchain. Similarly, in insurance, extreme gradient boosting machine learning algorithm can detect fraudulent claims and risky customers by analyzing the data stored on blockchain (Dhieb et al., 2020). Noteworthily, blockchain can easily eliminate fraudulent practices in business and AI can create data classifiers and filters that makes it possible to verify the authenticity of the processes and users on a decentralized blockchain infrastructure (Salah et al., 2019). In healthcare, blockchain protects privacy and increases security of health data (Wang et al., 2020). Integration of AI and blockchain create predictive system contributing to clinical workflow (Mamoshina et al., 2018). Using these technologies, patients can own and control their medical records. In marketing, blockchain-based customer data acquisition can help companies to provide automated customer service. Li et al. (2019) propose an automated customer service platform based on machine learning, blockchain, and IoT, which helps small scale firms to provide high quality customer service without depending on third parties. This will eventually lead to higher satisfaction

levels among the customers and improve the company's profit. Moreover, customer satisfaction can be predicted using LSTM machine learning algorithm on a blockchain-based platform. In social media, blockchain's proof of work consensus algorithm can bring down the spread of false information (Alagu Vignesh & Harini, 2019) and machine learning algorithms can detect anomaly in instant messaging (Yi, 2019). Noteworthily, blockchain technology offers a potential solution to combat the increasing threat of misinformation in social media content (Christodoulou & Christodoulou, 2020). Specifically, blockchain holds the promise to restore trust in the digital ecosystem by offering greater transparency into the content lifecycle (Narayanan & Attili, 2021). Due to its decentralized nature, blockchain can track the digital journey of the content, verify its source, and check how it may have been manipulated. Additionally, a blockchain-based system backed by AI can authenticate the identity of the content creator and gauge his or her reputation for accuracy. This is supported by Christodoulou and Christodoulou (2020), who illustrated the implementation of a decentralized application built on Ethereum (blockchain) as a valuable tool for combating misinformation and fake news.

To this end, it is clear that the convergence of AI and blockchain can take place in multiple dimensions. Products, services, and business models can benefit from the integration of these technologies, wherein the convergence can digitally transform industrial corporations to drive the advancement of their business and pave their way into a new digital era (Makarius et al., 2020). Numerous exemplars exist for each area where AI and blockchain can be integrated for process improvement and value creation (e.g., asset management, customer service, dispute resolution, fraud prevention, production evaluation, supply chain monitoring). Moreover, the analysis shows that AI (e.g., edge computing, machine learning) and blockchain (e.g., distributed ledger, ethereum, smart contract) can manifest in numerous ways and that available proposals in the literature are highly technical and systems based (e.g., cyber production system, production capability evaluation system). More importantly, the review indicates that each application exemplar is supported with empirical and pragmatic evidence demonstrating its effectiveness and value, and as a whole, making a strong case on the valuable promise that AI and blockchain integration hold for business. Figure 10 presents the framework showing integration of AI and blockchain and highlights the application areas and benefits of integrated AI-blockchain platforms.

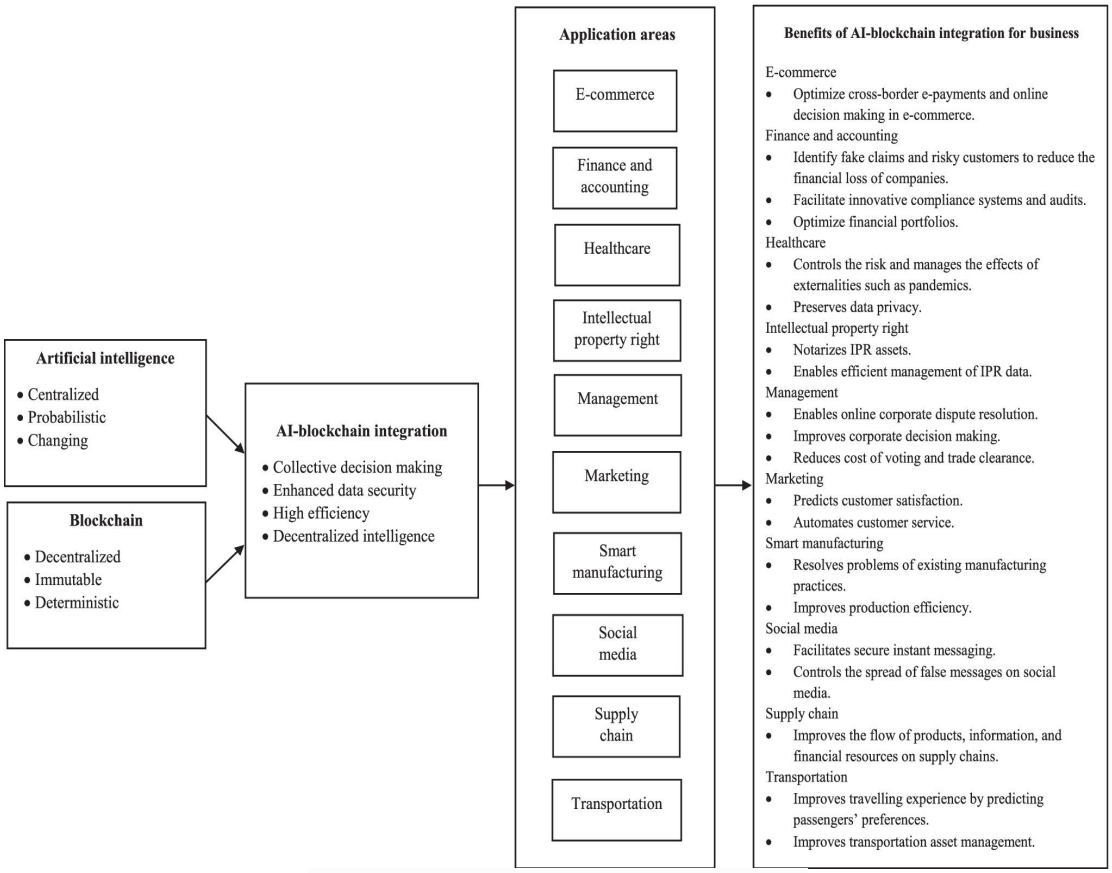

Fig: Framework for AI-block chain integration in business

Conclusion

AI and blockchain are two of the hallmark technologies of IR 4.0. Although the two technologies are relatively different in their own ways, the subject of amalgamation has received interest among scholars and professionals alike. Yet, there is a scarcity of research that consolidates and examines the state-of-the-art insights on the applications of integrated AI and blockchain platforms in business. The present study sought to address this gap through a bibliometric-content analysis, and in doing so, provides five key takeaways.

First, the study clarifies that AI and blockchain are IR 4.0 technologies that were introduced in 2016, with early research that integrates the two technologies for business emerging in 2017 but proliferated exponentially only from 2019 onwards. Here, the proliferation of research witnessed reaffirms the study's contention that AI and blockchain integration holds immense promise for business applications.

Second, the study identifies Mamoshina et al.'s (2018) article on the convergence of AI and blockchain in healthcare, Liu et al.'s (2019b) article on performance optimization for blockchain-enabled IoT systems, and Mao et al.'s (2018) article on credit evaluation system based on LSTM and blockchain as the most influential articles on AI and blockchain integration for business. It is important that prospective authors are cognizant of the seminal articles in the field in order to position and design future research in novel ways to extend the knowledge of prior research.

Third, the study reveals that "blockchain and machine learning", "blockchain and smart contract", and "blockchain and security" are the most popular topics for research, and the revelation of "blockchain and machine learning" as the sturdiest association in the corpus is another source of triangulation to highlight the promise and importance of AI and blockchain integration in business, wherein machine learning is the AI technology that seems to be most relevant and sought after for business endeavors.

Fourth, the study unpacks four major thematic clusters that underpins the intellectual structure of research relating to AI and blockchain integration for business, namely IR 4.0 and supply chains, smart healthcare, secure transactions, and finance and accounting. Here, two clusters are generic and thus transcend across industries (i.e., IR 4.0 and supply chains and secure transactions) and two clusters are specific and thus industry focused (i.e., smart healthcare and finance and accounting). The small number of major thematic clusters is an indication that research on AI and blockchain integration for business is relatively new, and thus, research that spurs its continued growth to enrich existing clusters and to propel the emergence of new clusters is highly encouraged.

Fifth, the study reveals 10 areas for AI and blockchain integration in business suggested by existing studies in the field, namely e-commerce; finance and accounting; healthcare; intellectual property right; management; marketing; smart manufacturing; social media; supply chain; and transportation, wherein exemplars of integrating the two IR 4.0 hallmark technologies for business endeavors are offered alongside its potential value and sources.

To this end, this article has contributed in four major ways. First, this article has mapped the publication productivity of AI and blockchain integration for business, showing that the field remains in its infancy and has tremendous scope for growth and future research. Second, this article has identified the most influential articles in the field, thereby laying the foundation for future research to build on the seminal insights curated herein. Third, this article has unpacked the most prominent topics and themes on AI and blockchain integration for business, which enables prospective authors to gain a one-stop state-of-the-art insights of literature in the field. Fourth and finally, this article has revealed 10 application areas for AI and blockchain integration in business, which should be useful for business professionals who wish to leverage on scholarly research to identify areas for business transformation using the two IR 4.0 technologies, including exemplars that they could follow.

This article also delivers important implications to different stakeholders, including business managers, AI and blockchain developers, information technology (IT) vendors, and future scholars. For business managers, the knowledge about the potential of integrating AI and blockchain in business can encourage them to develop and implement projects utilizing both these technologies to foster resilient business operations and improve the performance of firms (Fosso Wamba & Queiroz, 2021; Rubin et al., 2021). AI and blockchain developers also stand to gain acute insights on how integrating these two technologies creates business synergy. Therefore, AI and blockchain developers can collaborate to develop automated and decentralized business applications that offer better governance, higher

performance, and greater security of user confidentiality and privacy (Siala & Wang, 2022). IT vendors will also be able to better identify the market for AI and blockchain business solutions and position the value they bring through the identified areas for AI and blockchain integration in business. Finally, future scholars will be able to advance knowledge in the field by building on the current overview of AI and blockchain integration in business and venturing into new areas that would create new streams or enrich existing streams of research in the field. In this way, this article empowers both professionals and scholars with state-of-the-art insights so that they will be aware of the opportunities for AI and blockchain integration to enhance the growth, resilience, and robustness of business practices.

Nonetheless, this article, like any others, concedes its limitations. First, the data in this article is bounded by the accuracy and completeness of its source, and in this case, Scopus. It is important to note that Scopus, as a scientific database, was not developed for bibliometric analysis, and thus, may contain (unintended) errors. To mitigate potential (unintended) errors, the authors have ensured that they cleaned the bibliometric data retrieved from Scopus to the best of their ability, wherein duplicates and erroneous entries are removed, as recommended by Donthu et al. (2021a). Second, AI and blockchain integration is a dynamic field of research and a radical transformation in practice. In that sense, new innovations in its application and integration are expected, and thus, new streams of research are likely to proliferate rapidly. Therefore, prospective authors should not only rely on the review insights herein, but also to keep themselves updated with the latest research in the field, which can be done by using the search string herein this study.

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