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Transparency by Design for Blockchain-Based Supply Chains

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Abstract: Supply chains are experiencing significant advances in digital technologies, particularly those associated with industry 4.0. An example of such technology is blockchain. Blockchain is a disruptive technology characterised by anonymity and identity, consensus mechanism, decentralisation, overall performance and expectancy, reliability of systems and data, and information transparency. Blockchain offers supply chain opportunities to strengthen end-to-end visibility and traceability, leading to enhanced levels of transparency. Supply chains are increasingly exploring blockchain technology and transparency, with many focusing on system development. This paper explores transparency in blockchain-based supply chains to understand the principles underlining its design. A systematic review of literature is used, accompanied by data-driven analysis. The results present the principles within a framework for transparency by design in blockchain-based supply chains. Limitations and areas for future work are also presented.

Keywords: Industry 4.0, Supply Chain Management, Blockchain Technology, Transparency

1. Introduction

Technology is advancing rapidly, and the advancement offers promise for supply chains. It holds the potential for organisations to innovate products, services, and processes to increase productivity and generate competitive advantage [1,2]. Due to globalisation, amongst other external influences, it becomes imperative for supply chains to adapt to advancing technologies [3,4]. The fourth industrial revolution, known as Industry 4.0, encapsulates much of the advances in digital technology. Industry 4.0 characterises the trend toward automation, collaboration, integration, and data exchange in the industry's technology and processes horizontally and vertically [5]. The central vision of Industry 4.0 is for companies to have the capability to minimise dependence on manual, human work, automate their businesses, adapt to customer preferences, move towards autonomous operations and processes premise on learning and intelligence, and significantly boost productivity [6,7].

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Industry 4.0 technological offerings are rapidly reshaping supply chains worldwide and include the internet of things (IoT), robots, advanced human-machine interfaces, 3D printing and additive manufacturing, virtual and augmented reality, artificial intelligence (AI), big data, and blockchain [8]. The offerings bring unprecedented capabilities with potentially significant benefits to companies, including real-time data analysis, visibility, holistic decision making, increased productivity and enhanced competitive advantage [9]. There are significant efforts from around the world toward integrating technologies in order to create innovative, connected, and sustainable supply chains. Blockchain plays an essential role in the fourth industrial revolution. Blockchain is a disruptive technology characterised by anonymity and identity, consensus mechanism, decentralisation, overall performance and expectancy, reliability of systems and data, and transparency.

Supply chain transparency refers to the extent that supply chain stakeholders have a shared understanding of and access to product and process-related information without loss, noise, delay and distortion [10]. Transparency is closely associated with traceability and visibility [11]. Industry 4.0 technologies can support transparency in supply chains, and blockchain technologies are being progressively investigated, with some focus on system structures and architectures to support transparency.

Review studies on blockchain in supply chains have amplified in recent years. Example review studies include; an overview of systems, benefits, and challenges of blockchain adoption in food supply chains [12], the potential of blockchain across supply chains [13], and the success factors for blockchain implementation [14]. Many review studies have highlighted the significance of transparency, yet, little focus has been on transparency by design in blockchain-based supply chains. The research presented in this paper attempts to complement existing studies through a systematic review of the literature and data-driven analysis to build on the concept of "transparency by design" (TbD) in industry 4.0 enabled supply chains, as shown in [15], by proposing a framework for transparency by design in blockchain-based supply chains.

The remainder of the paper begins with the background in Section 2, followed by the methodology in Section 3. Section 4 is the descriptive statistics and results. Section 5 presents the discussion and proposed framework, and Section 6 concludes.

2. Background

2.1. Blockchain-based supply chains.

A blockchain is a block sequence that holds transaction lists like traditional ledger systems. Blocks consist of block headers and block bodies, where the block body is composed of occurring transactions [16]. The blockchain stores transactions' information, price, quantity, quality standards, product specifications, and other supply chain agreements [17,18]. Participants in blockchain-based supply chains can include standard organisations, certification providers, registrars, and supply chain actors [19]. Recent literature on blockchain in supply chains shows a) increasing understanding of the blockchain characteristics [20,21]. b) An increasing identification of the building blocks [22]. c) The use of blockchain to support quality management [23]. d) Blockchain-based trust mechanisms [24]. e) The need for context awareness in blockchains in supply chain management [25]. [26] specified critical success factors contributing to blockchain technology in global supply chains. These included data safety and decentralisation, accessibility, laws and policies, documentation, data management, and quality. Data safety and decentralisation are related to blockchain characteristics that incorporate transparency in the supply chain, such as information over products, processes, and production. Accessibility characteristics include traceability, visibility, and identification of issues and integrity. Blockchain characteristics related to laws and policies support supply chain governance and compliance. Documentation includes the characteristics of auditing, accounting and ecosystem simplification. Data management involves end-user access, controlling transactions, eliminating human error, enabling high-quality data, improved information flow, and data access controls. Quality factors foucs on assurance and fairness,

Blockchain characteristics, such as disintermediation, tamperproof, trust-less, smart contracts, reliable and transparent information flow, immutable, and non-reputation, can enable supply chain management [27]. The literature offers insight into how blockchain can support supply chain management. For example, blockchain offers promises to support trust and reputation [28], traceability and supplier engagement, sustainability [29], improved monitoring, transparency and control [30], provenance, and authentication [31]. Table 1 shows existing research on blockchain-based supply chains and it's benefits.

Table 1. Blockchain Applications and Benefits in Supply Chain.

Source	Focus and supply chain	Benefits
[32]	A blockchain-based quality solution in a grain supply chain	Reduced supply chain disputes; Efficiency; Transparency; Quality management.
[30]	A blockchain-based price monitoring system in the agri-food supply chain	Improved control; Disintermediation; Transparency.
[33]	A Blockchain-based rice quality supply chain.	Tamperproof data; Transparency; Data quality; Improved product quality; Disintermediation.
[34]	Blockchain-based food provenance and traceability	Improved product lifecycle management.
[35]	Research how blockchain can improve efficiency in the freight booking industry through smart contracts and blockchain technology.	Improve security and accessibility.
[36]	A literature review on blockchain application in the public sector supply chains highlighting opportunities and challenges.	Reduction of paperwork; Reducing human error; Improved coordination.
[37]	A study on the benefits and challenges of blockchain in the automotive industry.	Traceability ; transparency; tamper-proof; reduced transaction costs; efficiency; automation; data protection; security; disintermediation.

2.2. Transparency by Design

Transparency is increasingly researched across disciplines and is becoming progressively vital for supply chains. Transparency has been defined differently regarding scope. Business transparency refers to complete, on-time, accurate information, fosters honesty towards stakeholders, improves collaboration, and allows for collective decision-making [38]. Supply chain transparency shares accurate data regarding operations, processes, and goods, including their sourcing and origin, processing methods, and logistics [39]. Process transparency refers to the organisational policies to ensure that information is provided to all stakeholders, in addition to being accessible, able to be used, understandable, and presented [38]. Data transparency is the ability to easily access and work with data, regardless of where they are located or what application has created them [40].

It has been shown that transparency should be built into and included when designing processes, taking a proactive approach rather than a reactive one [15], leading to the concept of Transparency by Design or TbD, a development on the privacy-by-design concept. Until now, TbD has had some focus on information systems and data processes [41]. However, the concept has only recently been shown in industry 4.0 technologies in supply chains e.g. Artificial Intelligence or AI [15]. [15] propose a framework for TbD for artificial intelligence in supply chains identifying nine principles for TbD under three categories. a) accountability includes inspectability, responsiveness, and reporting, b) system design includes proactivity, integration, and audience focus and c) information on data processing and analysis includes data processing, decision-making standards, and risk disclosure.

3. Method

There has been little on the concept of transparency-by-design for blockchain-based supply chains, and it can be beneficial to study the principles to support existing frameworks such as those presented in [15], leading to the main research question is RQ 1: What are the principles for transparency by design in blockchain-based supply chains?

A systematic review of articles and data analysis of papers published in journals and conferences is conducted, focusing on papers with high relevance to the research question. The search string Title: (Transparency AND "Supply Chain" AND Blockchain) is used to elicit the articles. The selected databases included Science Direct, Emerald Insight, IEEE Explore, and Scopus. The limited search string was used only to identify the relevant papers on transparency in blockchain-based supply chains, thus essential inclusion criteria. Other inclusion criteria were to include only journal and conference papers, non-duplicates, and papers in the English language. Fig. 2 shows the search results.

Descriptive statistics were used to show the trends of a) publication by year and b) publication by research area. A data-driven, inductive content analysis was adopted to allow themes and principals to emerge from the literature, focusing on the included papers' results, discussion, and contribution/conclusion sections. The data analysed in the content analysis focused on three main principles containing dimensions a) blockchain design (e.g. design of blockchain architecture, prototypes, and systems), b) blockchain enablers and applications (e.g. traceability, transparency, visibility, enhanced sustainability, improved performance) for supply chain transparency and, c) technical characteristics (e.g. usability, bandwidth, integrity, scalability). Table 2 was used for data categorisation within the three dimensions.

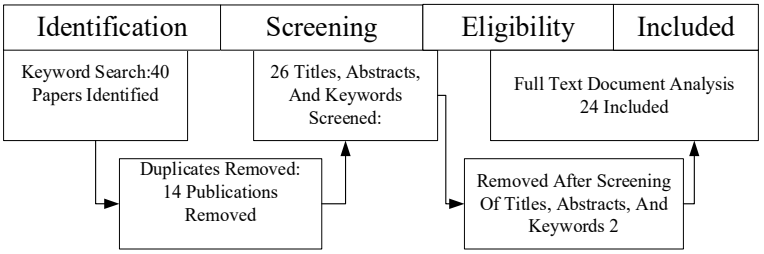

Fig. 1. Search and Scanning Results

4. Descriptive Statistics and Results

The publication by year is shown in Fig. 2, with papers arising in 2017 and significant growth from 2020 onwards. The publications by subject area are shown in Fig. 3. Many papers focused on multiple areas, notable are computer science, engineering, business management, and decision sciences, showing the importance of the topic across disciplines

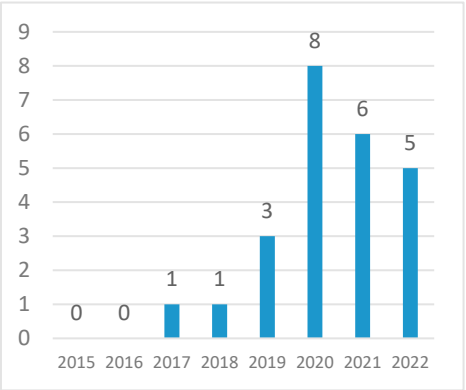

Fig. 2. Publication by Year

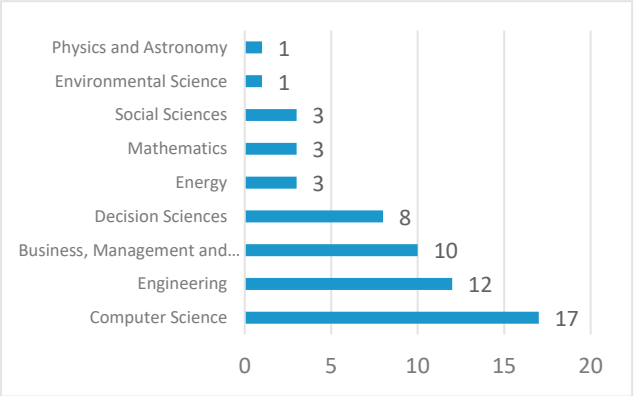

Fig. 3. Publication by Subject Area

Based on the content analysis, Table 2 shows the results by the headings; citations, supply chain, research focus, blockchain design, enablers and applications, and technical characteristics needed to support transparency in blockchain-based supply chains.

The inductive content analysis identified 120 principle factors relating to blockchain-based transparency in supply chains. The principle factors were those within the results, discussion, and conclusion sections linked to the blockchain, transparency, and supply chain. Several principle factors were identified in more than one of the included papers, and these are shown in Fig. 4, Fig. 5, and Fig. 6.

Table 2: Results of Content Analysis

Citation	Supply Chain	Focus	Blockchain Design Considerations	Blockchain Enablers and Applications for Supply Chain Transparency	Blockchain Technical Characteristics
[42]	General	How blockchain-based traceability can contribute to transparency in multiple supply chain scenarios.	Allows for system integration	Traceability; Visibility; Eliminating counterfeit products; Monitoring safety and quality; Management of business processes; Governance of agreements, processes, and products; Penalty and reward	Smart contracts; Data integrity
[43]	Circular supply chain	Blockchain technology potential to improve trust, traceability, and transparency in circular supply chain processes.	Elimination of central authority; System integration; Customisable	Trust; Traceability; Disintermediation; Information disclosure; Guarantees responsibility; Reduced business expense; Improve information flow; Time-saving; Enhanced efficiency	Smart contracts; Tamperproof; Privacy
[44]	Global Supply Chain	A system architecture is developed to integrate blockchain, big data, and IoT to support traceability in supply chain social sustainability	System architecture	Traceability; Supports social sustainability; Traceability of production and logistics; Supply chain transparency; Labour and human rights; Workplace and health safety	
[45]	Sustainable supply chain	Enablers of sustainable supply chain transparency.		Product transparency; Participant transparency; Range of transparency	Reliability; Security; Complexity; Reliability; Security; Complexity
[46]	General	A blockchain architecture to improve the transparency of information and build trust between supply chain stakeholders	System architecture	Real-time transparency; Traceability	
[47]	Supply Chain Finance	A proposed blockchain and IoT information framework to improve information transparency in supply chain finance business processes.	System architecture	Improved business processes	
[48]	Digital content supply chain	Blockchain's ability to improve transparency in the supply chain and control provenance.		Role of government; Trust; Provenance	Privacy; Open source;
[49]	Mining Supply Chain	Case studies adopting blockchain in the mining industry.	Allows for system integration	Regulatory driven; Supply chain transparency	Data provenance
[50]	General	A proposed architecture that can be applied in various food supply chains	System architecture; Allows for system integration	Traceability; Enables authenticity; Transaction data; Logistics data; Quality data; Traceability of data; Process and stakeholder data	Smart contract
[51]	Organic Food Supply Chain	A blockchain based solution to verify food quality and the origin of an agricultural supply chain.	System architecture; System testing; Consumer participation; Allows for system integration	Quality control; Trust	Token model; Smart contracts
[52]	Wood Supply Chain	Blockchain architecture for tracking the wood supply chain to origin for complete transparency.	System architecture; System testing	Traceability; Smart contracts; Visualisation; Veracity	Immutability; Cloud system; Reliability; Scalability; Apis
[53]	Reverse auction supply chain	A blockchain-enabled supply chain model is proposed showing how transparency can be maintained in the bidding process of reverse auctions.		Costs savings	Smart contracts
[54]	Fashion supply chain	Application of blockchain and information disclosure within fashion supply chains.		Information disclosure; Risk reduction; Willingness to pay	
[55]	General	A model to support supply chain transparency through sustainability risk mitigation in global supply chains	Costs of system; Time to implement	Performance; Participation degree; Scope of operation; Traceability; Participant operations; Participant sustainability conditions	Neutrality and interoperability; Throughput capability; Scalability; Security; Reliability

[56]	Agri-food supply chain	The research investigated the enablers of transparency in blockchain-based food supply chains.	Costs of system	Food safety and quality; Agri-food distribution; Food origin and sourcing; Traceability; Implementation costs; Tracking storage condition; Supply chain; The authenticity of labels; record keeping; supplier verification; responsiveness to corrective action; Inventory management; Collaboration; Managing intermediary transactions; Traceability; Provenance	Immutability; Auditability; Provenance; Privacy; Security; Digital infrastructure; Interoperability; Smart contracts; Regulatory
[57]	General	Blockchain capabilities and potential prerequisites.	Allows for system integration	Visibility	

Table 2 Continued: Results of Content Analysis

Citation	Supply Chain	Focus	Blockchain Design Considerations	Blockchain Enablers and Applications for Supply Chain Transparency	Blockchain Technical Characteristics
[11]	General	Blockchains impact transparency, emphasising the relationship of security with security and blockchain.		Traceability; Visibility	Security; Confidentiality; Integrity; Availability; Cryptography system; Decentralised consensus; Distributed ledger
[58]	Medical supply chain	Blockchain application in the medical supply chain	System architecture		Decentralisation; Immutability; Durability; Scalability; Automation; Integrity
[59]	Food supply chain	Enablers of blockchain adoption in the food supply chain and study their relationship.	Adhering to government regulations	Transparency system; Fraud detection; Inventory management with provenance and low risk; Cost reduction; Safe and quality food; Customer satisfaction	
[60]	Food supply chain	blockchain technology adoption in a small coffee company.	Adhering to government regulations; Consumer driven	Point of origin information; Documentation; Real-time material flow; Reduced time; Improved ability to meet standards; Cost reduction; Error reduction	
[61]	Financial supply chain	Blockchain in the financial supply chain as a solution to improve monitoring and transparency.		Verification of physical transactions; Automation	Privacy; Security; Disintermediation; Integrity
[62]	Agri-Food Supply Chain	IoT and blockchain-based prevention system for safe farming practices.	Allows for system integration; System architecture;		
[63]	General	Assessment of the combined impact of RFID, Blockchain and IIoT on supply chain transparency.	Allows for system integration	Secure transaction data; Reduce time of transactions; Cost reduction; Efficiency	Security; Privacy; Auditability
[64]	General	A demonstration of blockchain with IoT, highlighting pros and cons for supply chains, emphasising traceability and transparency.		Efficiency; Traceability; Trust; Reduced fraud; Automation	Security; Safe data
[65]	General	A Blockchain-based supply chain model in IIoT context to discuss the privacy and transparency trade-off.	Design for consumer satisfaction;	Efficiency; Fraud tracking; Real-time supply/demand data; Traceability; Avoid delay; Issue identification	Security; Tamperproof
	Total Factors		11 Factors	78 factors	31 Factors

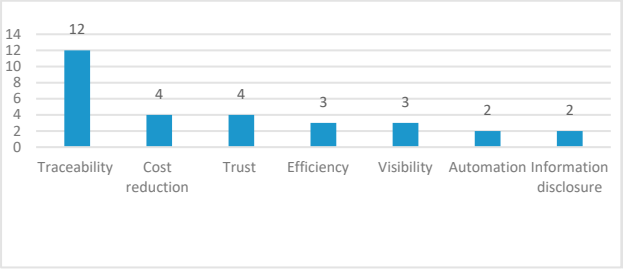

Fig. 4. Enablers and Applications

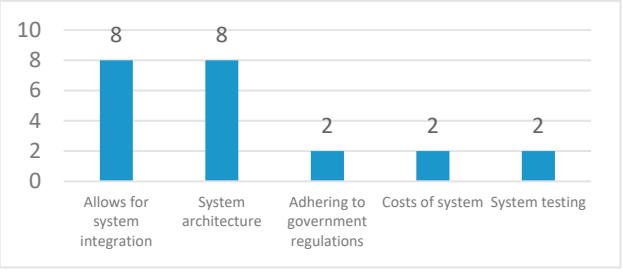

Fig. 5. Blockchain Design

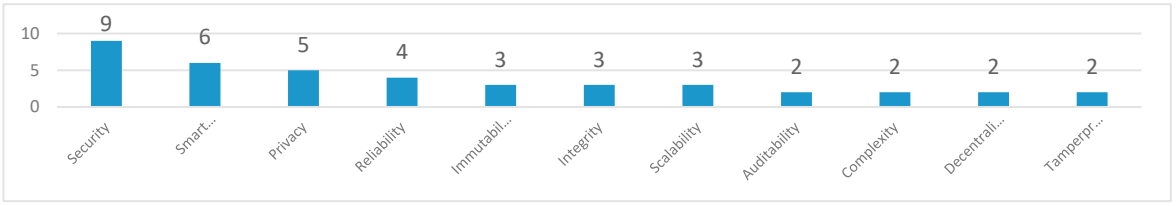

Fig. 6. Technical Characteristics

5. Discussion

Transparency enabling technologies, i.e. blockchain, need considerable understanding amongst stakeholders to reach desired levels of functionality. A framework for TbD in blockchain-based supply chains is proposed to provide further understanding for stakeholders, researchers, developers, and policymakers, see Fig.7. The framework considers three principles containing dimensions, namely, a) blockchain design considerations, b) blockchain enablers and applications for supply chain transparency, and c) blockchain technical characteristics. Due to differences between supply chains, context awareness is included in the framework. Context awareness is "the awareness of the circumstances that form the setting for visibility and in terms of which it can be fully understood" [66]. As context-aware blockchain systems, they will be able to understand situations, needs and applications in supply chains. Context-awareness would support necessary adaptions between system design, technical characteristics, enablers, and applications, thus increasing the applicability and adaptability of the proposed framework.

Under the dimension of blockchain design, architecture development is an essential principle as it shows the proposed layers required to reach desired levels of transparency. Developing an architecture provides clarity and understanding of the applicability of blockchain. For example, [44] highlights blockchain layers and requirements, including smart objects, communication channels, data analysis, blockchain networks, key applications and typical users. Blockchain-based architecture to support transparency has been used to develop the understanding of the technology across supply chains, for example, in [47] the financial supply chain, showing increased trust in firms from a lender perspective. Prototype development and simulation is also essential to test the proposed system. Tests and simulations focus on the performance of a system, like in [52] who tests blockchain in the logging industry by measuring aspects of time, success rates, fraudulent trees and rejected trees. An additional principle of the blockchain design dimension is to allow for system integration, as blockchain technology will benefit from pairing with other technologies—for example, IoT and blockchain [63]. System integration can be important for transparency in blockchain-based supply chain design [44], and is often incorporated into the system architecture [67]. System integration may consider embedding other enabling technologies to support blockchain-based supply chains, such as AI, IoT and cloud computing [11]. An example is IoT, which can collect data over transportation processes and storage conditions [41], which can be stored on the blockchain. [63] suggests that combining technologies such as RFID, IIoT, and Blockchain are complementary and can further support performance. Big data analytics combined with blockchain have also been identified as an essential technology to help monitor and analyse data related to social sustainability transparency in supply chains. Artificial intelligence to support blockchain through enhanced predictive capability and automation are also show promise to support transparency [62].

Principles in the dimension of 'enablers and applications' relate to blockchain technology requirements and outcomes for transparency. Traceability and visibility have been discussed as enablers of creating transparency [11]. Traceability supports transparency by providing open and accessible information about a product's characteristics, a geographical indication of origin, movements, processes, and ownership [68], and is an important consideration for supply chain stakeholders. Also noteworthy is that traceability systems may significantly enable transparency throughout the supply chain processes [42]. Supply chain visibility is noted as a predecessor of supply chain transparency [57]. Visibility focuses on specific supply chain processes and outcomes [11], such as sustainability performance and information sharing [45], and is essential to enhance data accuracy in blockchain-based transparency systems. Increased trust is an essential application of blockchain technology [55], and transparency is likely a necessary condition for trust. Blockchain also offers a trustless approach by removing the need for intermediate supply chain actors using techniques like smart contracts. To ensure the development and sustain transparency systems, reduced costs and cost savings have been seen as critical success factors [59]. Transparency can improve cost savings through sharing information openly in the supply chain and can help improve inventory levels and forecasts [49], thus, providing enhanced performance.

The dimension of technological characteristics will support achieving transparency in a blockchain-based supply chain. Security and privacy, for example, often present significant challenges to achieving transparency when considering privacy and security needs. [11] defines security through confidentiality, integrity, and availability and discusses their relationship with transparency. Confidentiality negatively affects blockchain-based transparency, while integrity and availability positively correlate [11]. Smart contracts may help overcome privacy and security and enhance performance through real-time quality and control monitoring [50]. For smart contracts, the reliability and quality of data are required to reduce the issue of fraudulent and inaccurate information on a blockchain.

Fig. 7. Transparency by Design in Blockchain-Based Supply Chain Framework.

The framework illustrated in Fig.7 compliments the concept of transparency-by-design for industry 4.0 technologies, adapting it to blockchain-based supply chains. The framework may benefit supply chain practitioners, providing insight into fundamental principles for blockchain design, enablers, applications, and technological characteristics. The framework and its considerations can provide guidance when designing the supply chain to foster blockchain capabilities. Further development of the principles and their dimensions would be helpful in specific sectors, supply chains, or organisations through the opinion of supply chain stakeholders, consumers, developers, and policymakers.

6. Conclusion and Future Work

This research applies a data-driven approach to a systematic review of literature by evaluating the results and contributions of existing publications. The results identified 120 principles across three key dimensions: technical characteristics, enablers, applications, and blockchain design. The principles identified through the literature review in the research are put forth in a framework for transparency by design for blockchain-based supply chains. Seven conclusions are made. (1) The principles consist of 31 technical characteristics, 78 enablers and applications, and 11 considerations for system design. The principles appearing more frequently in the results are included in the proposed framework: ten technical characteristics, five system design considerations, and seven enablers and applications. (2) privacy and security are critical technical characteristics and must be appropriately handled when designing for transparency in blockchain-based supply chains. (3) Smart contracts may help overcome challenges associated with privacy and security. (4) Traceability and visibility are critical transparency components and should be considered in the design. (5) System architecture development and testing is a significant need when designing for transparency, as it will contribute to the helpful development and deployment of the system. (6) System integration can support transparency in blockchain-based supply chains through better monitoring and forecasting. (7) Context-awareness can support necessary adaptions between system design, technical characteristics, enablers, and applications and increase the applicability of the proposed framework. The theoretical approach is a limitation of this research. Future work should focus on applying the framework for design by transparency in an empirical study. Also, expert and supply chain stakeholders should validate the principles, dimensions, and overall framework.

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