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User Interface of Blockchain-Based Agri-Food Traceability Applications: A Review

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ABSTRACT Blockchain technology is a secure distributed ledger for lists of transactions, which has immense potential to solve traditional agri-food supply chain issues. An increasing number of research on blockchain-based traceability applications aims to improve food quality and safety. Still, relatively few works considered user interfaces when developing and reporting their applications, which could lead to usability issues. This paper aims to address this gap by reviewing existing works from user interface perspectives. We gathered 25 review papers on blockchain or agri-food supply chain and 39 research papers that presented screenshots of user interfaces of related applications. We first reviewed 7 review papers that focused on the blockchain-based agri-food supply chain to understand the benefits and challenges in the blockchain applications. We then analyzed 14 blockchain-based agri-food traceability applications and 10 non-blockchain-based agri-food traceability applications. The analysis resulted in categorizations of 5 target user groups, 3 main approaches for collecting data, 5 main approaches for visualizing data, and a discussion of other aspects of user interfaces. However, we found insufficient details and discussions on the user interfaces and design decisions of the applications for further usability assessment. Additionally, user involvement for evaluation is lower in blockchain-based researches than in non-blockchain-based researches. This trend could lead to usability problems of blockchain applications, causing blockchain technology to be underutilized. Finally, we discussed research gaps and future research directions related to user interface design, which should be addressed to ease future blockchain adoption.

INDEX TERMS Blockchain, food, literature review, supply chain, traceability, user interface.

I. INTRODUCTION

Nowadays, people are increasingly interested in cryptocurrency, a new secure payment method that enables anyone to exchange online without the need of trusted parties such as banks or credit card companies. The technology underlying the cryptocurrency is called the "blockchain." Blockchain technology introduces distributed storage for growing lists of transactions, which are grouped into a block before recording on the blockchain. Participants in the blockchain network must mutually agree for a block to be recorded. Once recorded, the data cannot be modified without changing all subsequent blocks. In short, the blockchain is "an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way [1]."

As blockchain technology is gaining more attention, researchers began investigating blockchain applications in other domains, including making the agri-food supply chain transparent and traceable. The agri-food supply chain involves processes to "bring agricultural or horticultural products from the farm to the table [2]." Nowadays, customers are looking for food quality, safety, and nutrition. However, the traditional supply chain, where a central party holds all information, could not provide trustworthy information to interested customers in a timely manner. Applications of blockchain technology, where all involved parties can access and verify digitalized information, are seen as a way to solve traditional agri-food supply chain issues.

A considerable number of research papers (e.g., [3]–[9]) discussed the potential of blockchains in the agri-food domain. However, most papers focused on technical perspectives and rarely paid attention to human factors, which are a crucial part of technology adoption. There is a very limited understanding of how human users could use this blockchain technology to achieve their goals effectively, efficiently, and satisfactorily. User interface designers, as a

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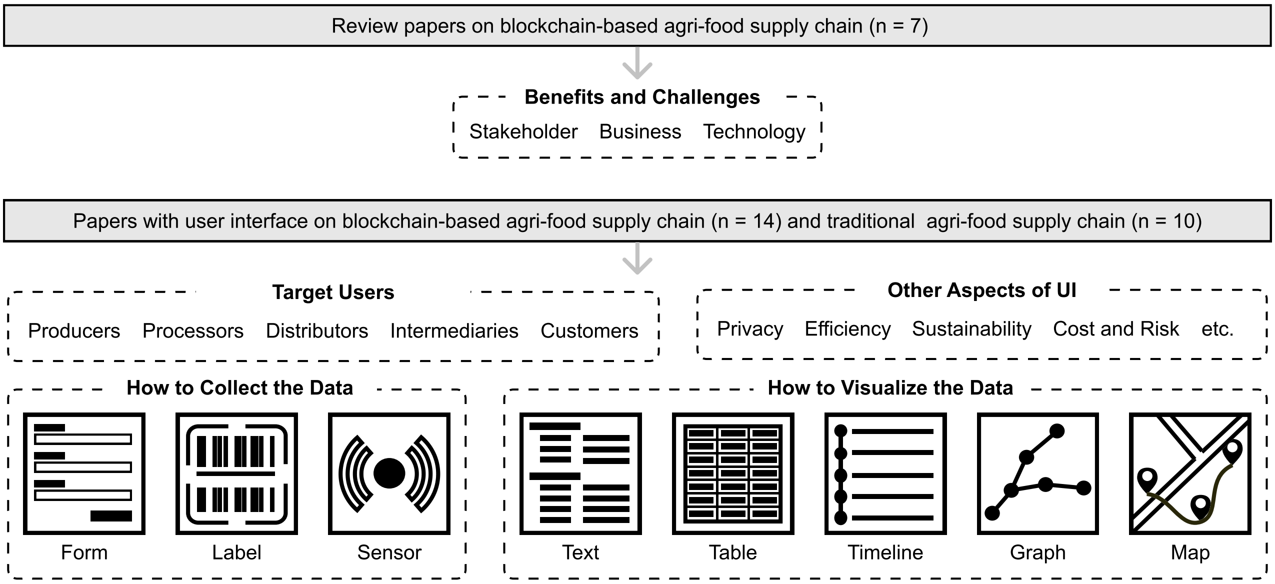

FIGURE 1. Overview of paper sources and results. We first reviewed 7 review papers about the blockchain-based agri-food supply chain to understand the benefits and challenges in the blockchain applications. We then analyzed 24 user interfaces of agri-food traceability applications to categorize target user groups, approaches for collecting data, approaches for visualizing data, and other aspects of the user interfaces.

part of the Human-Computer Interaction community, could play a role in connecting the design and implementation of blockchain technology to reality [10], [11].

Domain-wise, research works about the user interface of agri-food traceability applications are relatively scarce. A search in Scopus database on 20 May 2021 with the query *(food OR agriculture) AND ("supply chain" OR traceability)* returned 14,272 document results, while the query *("user interface" AND (food OR agriculture) AND ("supply chain" OR traceability)* returned only 28 document results. As a result, there is very limited knowledge about how to design user interfaces for agri-food traceability applications. Furthermore, the usability of those interfaces may be not confirmed due to the lack of user study.

This work aims to provide a basis for designing usable blockchain-based agri-food traceability applications. We first examined review papers in this domain to understand the current state of the development. We were interested in how blockchain could bring benefits and challenges to stakeholders, businesses, and technology for agri-food supply chains. We then analyzed existing works from a user interface perspective to summarize (1) target users and user interface purposes, (2) how applications collect the data, (3) how applications visualize the data, and (4) other aspects of user interfaces corresponding to the benefits and challenges of the blockchain. We then discuss research gaps and how could our classification provide future directions of research in this domain. Figure 1 illustrates the paper sources and the results.

Our contributions include:

- Analysis of benefits and challenges in applying blockchain technology for agri-food traceability (Section IV)
- Categorization of user interfaces for agri-food traceability (Section V)
- Discussion of research gaps and future directions regarding user interfaces for agri-food traceability (Section VI)

The remainder of this paper is organized as follows. Section II provides the background on blockchain, agri-food traceability, and user interfaces, on which this paper is based on. After that, Section III describes the methodology used to conduct the review and analysis in this paper. The results are presented in Section IV and Section V. Then, Section VI discusses the research gaps and future directions regarding user interfaces for agri-food traceability. Finally, Section VII concludes the paper.

II. BACKGROUND

Our paper aims to understand the intersection of 3 areas: blockchain, agri-food traceability, and user interfaces, which are introduced in this section.

A. BLOCKCHAIN

Blockchain is a technique to store cryptographically linked records across parties in a peer-to-peer network to prevent tampering of records. The blockchain was invented to facilitate bitcoin transactions [12]. A "block" consists of a set of confirmed transactions or records, a timestamp, and a hash code. The hash code is calculated from the content in the block and the previous block (i.e., "chain"). Adding the block to the chain requires the majority of the involved parties to verify the block. For instance, the prover (or miner) proves to the verifiers that the computational effort has been expended for some purpose (Proof-of-Work). Other consensus mechanisms, such as Proof of Authority (PoA) or Proof of Assignment (PoAss), can also be used (see [13] for a review).

Blockchain components include [9], [14], [15]:

- Cryptography: Strong encryption to allow decryption by authorized users only;

- Ledger: A shared and distributed database to store data;
- Consensus: A protocol to prevent minor nodes to modify transactions;
- Smart Contract: Rules, penalties, and actions to be automatically applied to the involved parties once the condition is met.

Main features and characteristics of blockchain include [3], [13], [14], [16]:

- Decentralization: Nodes (participants) in a peer to peer network work together to process and validate data without a need for a single central trust party;
- Trust-less: Each participant can participate without knowing each other;
- Anonymity: Each participant can communicate using a generated virtual identity code;
- Permission-less: There is no restriction of participants;
- Autonomy: Each node can safely perform transactions without third party intervention;
- Ownership and uniqueness: A block include transaction information as well as its owner and a unique hash code;
- Irreversibly and Persistency: Canceling a transaction is impossible once a chain adds the block;
- Immutability: Timestamps and controls ensure that stored data cannot be changed;
- Transparency: Involved parties can access and trace stored data;
- Auditability: Securely linked blocks facilitate transaction verification and tracking;
- Provenance: A digital information attached to each product can prove its authenticity and origin;
- Censorship resistant: Transactions cannot be censored as a network does not need controllers;
- Open source: Everyone in the network can access the source with a sense of hierarchy.

Not all features are desirable. For instance, the permission-less property could introduce security issues since anyone can create a transaction that could be used for malicious purposes. Implementation of a blockchain system could differ in terms of who are the provers and validators of blocks, who can access the system, security and efficiency level, design methods, and blockchain authority [13]. These choices could classify blockchains into three types: public, private, and consortium blockchain (i.e., permissioned or hybrid blockchain).

This paper does not focus on the technical aspects of blockchain. Rather, we focus on how these features could benefit or raise issues in agri-food traceability applications as well as how they influence user interface design.

B. AGRI-FOOD SUPPLY CHAIN AND TRACEABILITY

Agri-food supply chain is "the activities from production to distribution that brings agricultural or horticultural products from the farm to the table [2]."

The agri-food supply chain is more complex and difficult to handle than other supply chains due to the presence of various stakeholders and influences. Agri-food products have limited shelf life. Food safety and quality depend on time as well as environments, such as weather and transportation. Contamination can occur at any stage. Furthermore, food globalization results in longer food chains, which complicates foodborne disease investigation and product recall [17]. This complexity leads to the need for higher efficiency and closer partner collaboration.

Traditional food supply chains generally rely on a central party to manage information, which could lead to transparency and trust issues. For instance, a company may release only information beneficial to them. Customers could have difficulty verifying many food characteristics claimed by the company. When there are food safety scandals, the information asymmetry situation between the public and food manufacturers could affect customers' judgments and result in decreasing sale volume [18].

Traceability systems offer a means to address issues in food supply chains. International Organization for Standardization (ISO) defined traceability as "the ability to follow the movement of a feed or food through specified stage(s) of production, processing, and distribution" in ISO 22005:2007 [19], though the actual definition of traceability varies by the variety of food [20]. Regardless of minor differences in the definitions, knowing movement and steps in the production process could facilitate recalling contaminated products, thus improving consumers' safety and confidence.

The traceability can be categorized based on several stakeholders involved and traceability requirements. The traceability could involve a single stakeholder (i.e., intra-company or internal level) or all stakeholders (i.e., supply chain or external level) [21], [22]. European Community market categorizes traceability into mandatory traceability and voluntary traceability [21], [23]. Mandatory traceability mainly aims for financial purposes whereas voluntary traceability mainly aims for food safety and quality. Trustworthy and complete traceability require both mandatory and voluntary traceability processes. However, as each stakeholder has various standards and tracking methods, the voluntary system is complex with a wide variety of acquired data [24].

In general, Corallo *et al.* [21] suggested four major questions when developing a traceability system:

- which data to collect,
- who own the data,
- how to collect the data, and
- how to make the data available and understandable.

This paper focuses on the supply chain (external level). We are particularly interested in how to collect the data, and how to make the data available and understandable, which influence and could be benefited by better user interface design.

C. BLOCKCHAIN-BASED AGRI-FOOD TRACEABILITY

Many researchers are adopting blockchain technology as a way to facilitate traceability. The blockchain is deemed to "bring transparency, enhance information authenticity, and speed up food recall [9]." The blockchain potential is demonstrated by a considerable number of review papers that focused on the blockchain-based supply chain in agriculture or food domain [3]–[9], with the highest number of 178 reviewed items by Dutta *et al.* [3].

This paper also focuses on blockchain-based supply chain traceability in the agriculture or food domain. We provide an analysis of the review papers in this domain. Additionally, we present a discussion on the user interface (i.e., how to collect the data and how to make the data available and understandable), which was not discussed in other review papers.

D. HUMAN-COMPUTER INTERACTION AND USER INTERFACE DESIGN

"Human-computer interaction (HCI) is a multidisciplinary field of study focusing on the design of computer technology and, in particular, the interaction between humans (the users) and computers [25]." HCI overlaps with multiple research areas, including user interface (UI) design that concerns the mean for users to interact with a system. User interface design generally aims at improving usability, which can be assessed by five quality components (learnability, efficiency, memorability, errors, satisfaction) [26]. One basic method to evaluate usability is user testing. Researchers can identify usability problems by observing representative users perform representative tasks with the user interface.

Successful software development desires usable interfaces. However, studies on HCI and UI for blockchain are still inadequate. Foth [11] discussed a beef supply chain case study and blockchain research agenda for HCI, calling for interaction designers to be aware of blockchain technology. Elsden *et al.* [10] surveyed 200 emerging blockchain startups, projects, and applications to identify the role of HCI in connecting the design and application of blockchain technology. They found that research in HCI mostly focused on money, finance, and peer-to-peer exchange. They suggested more researches in engaging participants and designing with blockchain in other domains.

This paper focuses on the agri-food domain. We investigated works that engaged participants in their development process and looked for classifications that could aid blockchain designing.

III. METHODOLOGY

We conducted a systematic literature search in the Scopus database, which is one of the largest databases of peer-reviewed literature. The search was done during November and December 2020 using the following queries for title, abstract, and keywords (TITLE-ABS-KEY).

- Q1: blockchain AND (food OR agriculture) AND ("supply chain" OR traceability)
- Q2: "user interface" AND (food OR agriculture) AND ("supply chain" OR traceability)
- Q3: blockchain and "user interface"
- Q4: blockchain and HCI

We interested in (1) blockchain, (2) agriculture, food, supply chain, and/or traceability, and (3) user interface. Figure 2 illustrates three topics of interest and how the query aims to address the overlapping topics. The white areas, such as blockchain without user interface in other domains, are not in the scope of this paper.

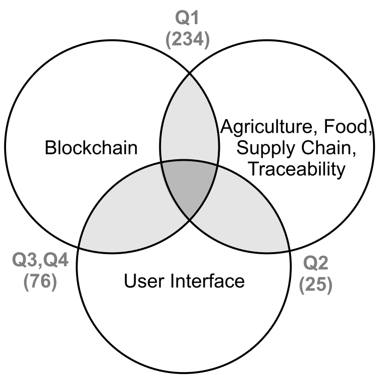

FIGURE 2. A diagram showing the topics of (1) blockchain, (2) agriculture, food, supply chain, and/or traceability, and (3) user interface. Grey areas indicate where each Query covered. The number behind the query number is the number of papers returned by the query.

We formulated these queries to cover all aspects that could be useful in designing a user interface for blockchain-based agri-food traceability applications. The first query aimed to gather all works on blockchain-based agri-food traceability applications. We excluded the term "user interface" from this query. Instead, we manually skimmed papers for a user interface to avoid missing works that did not focus on the user interface but implemented one. The rest of the queries aimed to gather the user interface of similar works, i.e., either agri-food traceability application or blockchain application in general, that may be applicable to blockchain-based agri-food traceability applications. They also helped to gather related works that used other specific terms, such as coffee instead of agriculture. There was no publication year restriction.

We found 335 articles in total. After removing 7 duplicated articles, we filtered the results using the following inclusion criteria:

- The full-text of the article was in English;
- The article was a full research or review paper (e.g., workshop papers and proceedings are excluded);
- The full-text of the article was available and accessible;
- The article discussed either blockchain, agriculture, food, supply chain, or traceability in detail.

We then group the articles into two major categories:

- The article that provided an overview of the topic (i.e., review papers)
- The article that contained a screenshot of the user interface of the application

We then further group articles based on topics: blockchain, agriculture, food, supply chain, traceability, and/or user interface. Figure 3 provides the overview of our review methodology and topic grouping. Note that works outside a group might briefly mention the group. For example, two review papers of blockchain in general might mention the supply chain in their discussion, but not in detail.

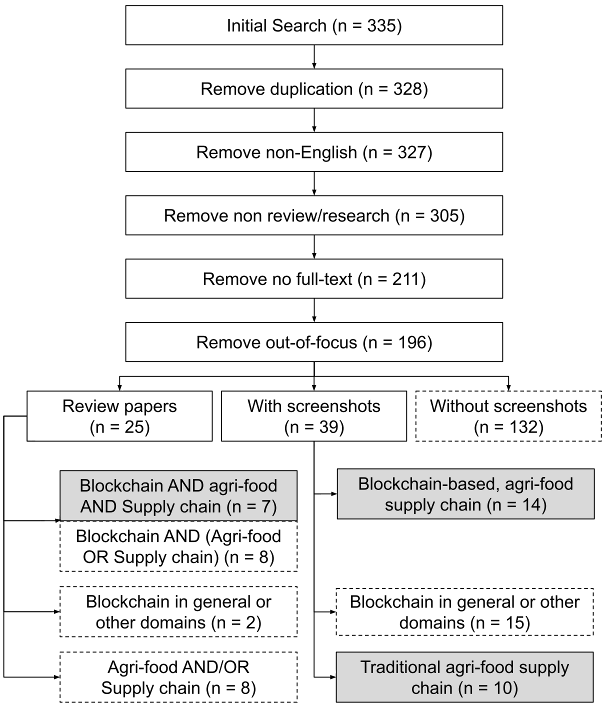

FIGURE 3. Review methodology where n is a number of articles. The shaded boxes indicated papers we focused in this review while the dashes boxes indicated papers that we skimmed through.

As demonstrated in Figure 3, the majority of works in blockchain-based agri-food traceability do not present a screenshot of the user interface, which could be one reason for lacking a review paper in this domain.

Finally, we focused on 7 papers that reviewed blockchain-based agri-food supply chain, 14 papers included screenshots of blockchain-based agri-food supply chain applications, and 10 papers included screenshots of non-blockchain-based (traditional) agri-food supply chain applications. We first analyzed the review papers to understand the current development, benefits, and challenges in applying blockchain to agri-food supply chain traceability in Section IV. The analysis provided a basis for analyzing user interfaces in Section V and discussion in Section VI.

Note that we gave higher priority to screenshots since it allowed better analysis of user interface elements than text description. Other articles that fitted the criteria but did not fall into any group were skimmed and included in this review only when we found them useful in the discussion. We also performed ad-hoc searches for key papers that were cited in gathered papers or deemed as useful for our discussion. The ad-hoc articles were not included in the figures.

Our method has two limitations. First, there could be works that addressed specific agri-food products but did not show up in our search results. The queries could retrieve some specific agri-food products. For instance, the query "blockchain and 'user interface'" did retrieve a blockchain-based autonomous coffee machine [27]. However, the queries excluded the works about blockchain-based coffee supply chains without the "user interface" keyword. Due to the vast variety of agri-food products, formulating queries for all products is very difficult. Second, we inspected the user interface manually from the provided screenshots. Thus, we might not be able to fully examine all user interface features.

IV. BENEFITS AND CHALLENGES: A REVIEW OF REVIEWS

This section summarizes the benefits and challenges of applying blockchain to the agri-food supply chains for traceability discussed in the review papers.

We found 25 review papers of related topics, as listed in Table 1. The table notes whether the paper apparently discussed (1) models or frameworks to design or implement applications, (2) benefits or opportunities, and (3) challenges regarding the topic they reviewed. We found that most review papers discussed at least one of these three aspects in at least one section of the papers. Only [28] focused on technology applications.

Our analysis focused on seven review papers [3]–[9] that directly discussed blockchain-based supply chain in the agriculture or food domain (a part of Q1 area in Figure 2). Other review papers that missed some of the components, e.g., discussed only agriculture but not food, were noted. However, we decided to exclude the notes in this analysis since those findings may not directly apply to our focus domain and the seven review papers should be sufficient for this analysis.

The seven papers discuss the benefits and challenges of blockchain in many aspects in their texts. We extracted the benefits and challenges and organized them into three categories: stakeholders, business, and technology. Table 2 provides the overview of the topics that each paper discussed and their references to support the discussion. Note that we removed some dead links and references that we deemed to be too general to support the arguments.

A. STAKEHOLDER

This section discusses the benefits and challenges that apply to an actor in a supply chain. Each review paper identified different supply chain phases and stakeholders. For instance, traceability business stages by Feng *et al.* [4] included farming, harvesting, processing, logistics, cold storage, and consuming. On the other hand, steps in the food supply chain by Galvez *et al.* [8] included production, processing, storage, distribution, retailers, and administration. Regardless of the differences, we could classify the target stakeholders of benefits and challenges into producers, intermediaries, consumers, and regulators.

1) PRODUCERS

Producers refer to people who produce an agricultural product or food ingredients, such as farmers or fishermen. Blockchain could safeguard farmers [3] and provide financial benefits to small or medium-size farmers in developing countries [6]. Blockchain-based applications, such as AgriLedger [44], FarmShare [43], and Davcev's application [45], were deemed to foster cooperation among farmers and other stakeholders of the chain. Such cooperation could improve financial inclusion in developing economies [46].

TABLE 1. The list of 25 review papers with title, year of publication, where number of reviewed papers as well as an indication whether the paper apparently discussed model/framework, benefits/opportunities, or challenges.

Title	Year	n	Model	Benefits	Challenges
Blockchain with agriculture, food, supply chain, and traceability					
Future challenges on the use of blockchain for food traceability analysis [8]	2018	NA	✓	✓	✓
Blockchain technology in agri-food value chain management: A synthesis of applications, challenges and future research directions [7]	2019	71			✓
The rise of blockchain technology in agriculture and food supply chains [6]	2019	NA	✓	✓	✓
A content-analysis based literature review in blockchain adoption within food supply chain [9]	2020	26		✓	✓
Applying blockchain technology to improve agri-food traceability: A review of development methods, benefits and challenges [4]	2020	NA	✓	✓	✓
Blockchain in agriculture traceability systems: A review [5]	2020	NA			✓
Blockchain technology in supply chain operations: Applications, challenges and research opportunities [3]	2020	178		✓	✓
Blockchain with agriculture, food, supply chain, or traceability					
A Survey on Using Blockchain in Trade Supply Chain Solutions [29]	2019	35	✓	✓	
A survey on blockchain technology and its proposed solutions [30]	2019	NA		✓	✓
A systematic literature review of blockchain technology in agriculture [31]	2019	NA			
Integrating blockchain and the internet of things in precision agriculture: Analysis, opportunities, and challenges [13]	2020	NA	✓	✓	✓
Blockchain and agricultural supply chains traceability: Research trends and future challenges [32]	2020	38		✓	✓
Blockchain for 5G-enabled IoT for industrial automation: A systematic review, solutions, and challenges [14]	2020	NA	✓		✓
Blockchain Technology in Current Agricultural Systems: From Techniques to Applications [33]	2020	NA			✓
Blockchain and supply chain sustainability [34]	2020	79	✓	✓	
Blockchain					
A Comprehensive Survey of Blockchain: From Theory to IoT Applications and beyond [35]	2019	NA			✓
A Review of Blockchain-Based Systems in Transportation [36]	2020	371		✓	✓
Agriculture, food, supply chain, and/or traceability					
Transparency in food supply chains: A review of enabling technology solutions [37]	2019	NA		✓	✓
Determining the provenance and authenticity of seafood: A review of current methodologies [38]	2019	NA	✓	✓	
A systematic literature review on machine learning applications for sustainable agriculture supply chain performance [39]	2020	93	✓		✓
Food traceability system from governmental, corporate, and consumer perspectives in the European Union and China: A comparative review [20]	2020	NA	✓		
Transforming agriculture supply chain with technology adoption-: A critical review of literature [28]	2020	50			
Agri-food 4.0: A survey of the Supply Chains and Technologies for the Future Agriculture [40]	2020	NA		✓	✓
Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications [41]	2020	84	✓		
Overview of Edge Computing in the Agricultural Internet of Things: Key Technologies, Applications, Challenges [42]	2020	NA	✓		✓
	Total		12	14	18

Transparency of information could provide a fairer solution to conflicts among farmers. Blockchain applications could also provide a platform for traceability (e.g., [158]) or insurance programs (e.g., [159]) to the farmers.

Regardless of the benefits, Kamilaris *et al.* [6] also mentioned challenges about farmers' adoption, as the farmers need to understand blockchain before start using it [48]. This issue relates to the cost and risk of blockchain in Section IV-B4.

2) INTERMEDIARIES

Intermediaries refer to people who buy the product from one stakeholder and sell to another, including wholesalers and retailers. Kamilaris *et al.* [6] referred to Sander's survey [49] about positive influences of blockchain on purchasing decisions.

Though the blockchain could help improve sales, limited resources of small and medium enterprises might be a challenge in their blockchain adoption [50].

3) CONSUMERS

Customers refer to people who consume the product. Blockchain could improve consumer's awareness and empowerment [6], as well as improve food safety and quality [3], [8], [51], [55]. Customers could ensure food safety and quality as blockchain-based applications

TABLE 2. The overview of the topics that each review paper discussed and their references to support the discussion. Note that a review paper may discuss the topic without providing a specific reference.

Topic		Galvez et al. [8]	Zhao et al. [7]	Kamilaris et al. [6]	Duan et al. [9]	Feng et al. [4]	Demestichas et al. [5]	Dutta et al. [3]
Stakeholder								
Producers	Benefits			[43]–[46]				[47]
	Challenges			[48]				
Intermediaries	Benefits			[49]				
	Challenges		[50]					
Consumers	Benefits	[51]		[8], [52]–[54]	[55]			
	Challenges			[53]				
Regulators	Benefits				[55], [56]			
	Challenges		[57]–[59]	[7], [60]	[6], [55], [60]	[8], [61], [62]		
Relationship between stakeholders	Benefits			[53], [60], [63]–[67]		[68]		[69]–[72]
	Challenges			[60]				
Business								
Traceability	Benefits				[8], [52], [73], [74]	[75]–[79]		[80]–[82]
	Challenges			[53], [83]	[8], [52], [55], [77]	[57]	[8], [53]	
Efficiency	Benefits	[84]		[65], [85]–[87]	[8], [52], [55], [68], [73], [88]–[91]	[92]		[93]–[95]
Privacy	Challenges		[57], [96]–[101]	[7]			[60]	
Cost and risk	Benefits			[102]				
	Challenges		[97], [103]–[109]	[7], [48], [110]–[112]	[6], [55], [60], [102], [113], [114]	[57], [115]	[6], [71], [80], [116]	
Sustainability	Benefits			[64], [90], [117]–[119]	[7], [120]	[8], [61], [76], [108], [121]–[125]		[8], [60], [126]–[130]
	Challenges	[131]–[133]						
Technology								
Scalability	Challenges		[57], [68], [101], [103], [106], [134]–[139]	[60], [111], [140]	[60], [141]	[57], [125], [142], [143]	[60]	
Security	Benefits					[144]–[146]		
	Challenges					[147]–[149]		
Infrastructure	Benefits				[91]			
	Challenges			[60], [68], [150]–[153]	[55], [102], [154]	[6], [57], [62], [142], [143], [155]–[157]		

provide real-time monitoring of biological, chemical, and physical hazards [52]. Blockchain could facilitate reliable food exchange through higher traceability to achieve food integrity [8], [53]. As blockchain applications could quickly identify and link outbreaks back to specific sources [54], it could mitigate food fraud.

Galvez *et al.* [8], however, raised challenges about rapidly changing consumer preferences and confidence due to product recalls and social networks. Also, as products with traceability typically come with higher prices, they could become a target of food fraudsters [6], [53].

4) REGULATORS

Regulators and authorities refer to people who verify and enforce regulations of the supply chain to, for example, ensure food safety. Blockchain applications could facilitate supply chain auditing [3] and reduce food risks [9], [56]. For example, the Accenture Traceability report [55] discussed a pilot study of blockchain with smart tagging to prevent illegal tuna fishing. Trust audit checking was supported by tamper-proof and traceable properties of blockchain [4].

Interestingly, all seven reviews discussed challenges in regulation, including regulation uncertainty, the role of governments, and conflicting between national regulators.

One reason could be that regulation is one of the most underexplored areas [52]. As a central authority is inessential in a blockchain system, it prevents interventions like censorship as well as creates many uncertainties [57]. There are no legal regulations and standards to follow [61]. For instance, Lucena *et al.* [59] proposed blockchain-based grain quality assurance tracking but acknowledged that they did not prove their application in complex scenarios involving international trade and arbitration laws. This lack of policy and regulation leads to an adoption barrier [6]. Regulators should develop new policies or regulations to monitor and regulate the blockchain [58] to protect users [55], [60] and reduce the barrier for its wider adoption [7], [60].

5) RELATIONSHIP BETWEEN STAKEHOLDERS

Blockchain provides a secure distributed means for transactions, connecting stakeholders from different locations, rules, or applications together [6], [53], [60], [63], [64]. Blockchain technology has the potential to provide a solid end-to-end connection between farmers and large buyers [70]–[72]. Participating parties could increase their reliability, responsibility, and commitment [66], [67]. Functioning as a digital institution of trust [65], the blockchain could enhance trust of customers [69] and collaboration between supply chain partners [4], [68]. This benefit could reduce dependency or remove intermediaries [3], [6].

Blockchains could both bring benefits and raise challenges related to each stakeholder. In practice, however, analyzing the benefits and challenges could be complicated due to the diversity and conflicts between stakeholders in the chain [3], [5], [8]. Different stakeholders in different sectors or industries or countries could have different objectives and practices. While blockchain could remove intermediaries, the perception that blockchain could lead to job loss is one challenge in blockchain adoption [3]. Also, as blockchain connects stakeholders together, there is an important question about who should own the blockchain [6], [60].

B. BUSINESS

This section discusses benefits and challenges that apply to actors across a supply chain, which affect the business of buying and selling agri-food products. We classify them into traceability, efficiency, privacy, cost and risk, and sustainability.

1) TRACEABILITY

Blockchain allows users to follow agri-food products between stakeholders in a supply chain. Feng *et al.* [4] analyzed the traceability issues that blockchains could address, including how to coordinate, verify, link, and record transactions. The blockchain allows origin tracing of products from farms to consumers [3], [4], [77]–[80]. Chan *et al.* [82] proposed a blockchain-based agri-food supply chain management framework for traceability and transparency, which allows information disclosing to stakeholders in a supply chain, so it addresses information asymmetry [9], [52]. In addition to transparency, blockchain allows stakeholders to audit transactions [9], [73]. As the blockchain is immutable, it ensures that information will not be tampered [75], [76]. All valid users can examine and have a copy of the transaction history [74]. Galvez *et al.* [8] also discussed the potential of blockchain in food authenticity, which ensured no alteration of information that could happen when it was under the control of a specific party. Thus, blockchains may be used to tackle food fraud and increase traceability performance.

Traceability, however, relies on data collection. A lack of records is simply a challenge of food traceability [8]. Products can be purposely damaged without notifying blockchain users [77]. Furthermore, it is difficult to ensure the authenticity, security, and integrity of raw input data [4], [8], [9], [57]. The data accuracy, either from sensors or persons, cannot be guaranteed [5], [8]. Furthermore, analytical methods cannot monitor all parameters of food products, especially the environmental parameters [5], [6], [53], [83]. To address this data manipulation issue, third parties such as governments could make regular checks in the blockchain network [9], [52], [55].

2) EFFICIENCY

Blockchain could enhance business performance with less effort. Dutta *et al.* [3], Leng *et al.* [93], and Hasan *et al.* [94] argued that blockchain could enhance the overall efficiency, throughput, and credibility of the related platforms, which could ease business expansion. Blockchain with digitized product movement and certifications provides real-time information of food products [9], [52], [68] and could reduce time to trace from nearly a week to few seconds [6], [9], [85], [88]. This property allows a quick trace of contaminated products when there is an outbreak of an animal or plant disease [6], [65]. Trust and self-organized nature could reduce human intervention [9], [89]. Integration with IoT devices makes the supply chain more efficient [4], [8], [9], [52], [55], [68], [89]–[92]. Ferrer [87], for example, leveraged blockchain to enhance the security, autonomy, and flexibility of agricultural robotic swarm operations. Thiruchelvam *et al.* [95] leveraged blockchain to facilitate data recording and automatic payment transfer. Blockchain with smart contracts can automatically execute and evaluate transactions [8], [84], which can prevent further damage with warnings [9], [52], [73]. Participants can evaluate the assertions made and notify interested parties according to conditions such as quality, timing, or quantity. Smart contracts could lead to scalable and flexible businesses at a lower cost, thus improve the overall effectiveness of manufacturing services [6], [86].

There is no specific challenge regarding business efficiency.

3) PRIVACY

Anonymity and security property of blockchain could support keeping personal and business matters and relationships secret. Dutta *et al.* [3] suggested that blockchain could increase the privacy of enterprise information. Transaction visibility and anonymity of blockchain could ensure the traceability, reliability, security, and information timeliness of agri-food products [4].

Compared to the benefits that were briefly mentioned, blockchain raises more privacy problems. Permanent data visibility and transparency could compromise privacy [6], [7], [57]. Zhao *et al.* [7] discussed several works that raised the privacy leakage issue and efforts for protecting privacy. For example, some stakeholders might not want to share information to maintain business competitiveness. Private or permissioned blockchain might be preferred over public blockchains. The selection of the proper type was not sufficiently discussed and seen as one challenge in blockchain implementation [5]. Even with privacy management, transactional privacy can still not be guaranteed because all participants in the network can access all information [7], [96], [97], and some participants might be competitors [98]. There is still no method to hide all involved parties and transaction amount at the same time [7], [100]. Privacy is one of the two major drawbacks of blockchain [7], [101]. There is a need to consider these issues on data management, particularly data ownership and data retention [5], [60].

4) COST AND RISK

Kamilaris *et al.* [6] suggested that blockchain could help reduce transaction fees and facilitate fairer pricing through the whole chain.

The cost of computing and censoring the equipment required to run the system was deemed as a challenge in adopting blockchain (e.g., [3], [5]–[7]). Adopting blockchain could require many product transformations and organizational changes [5], which needs a lot of money and time [3], [7], [103], [108]. The cost of implementing blockchain could be a barrier for adopting [6], [9], [55], [60], [102]. Developing countries may find difficulties because of the high degree of computing equipment required [6], [7]. Hence, Duan *et al.* [9], [55], [60] suggested that the blockchain should be more "SME friendly."

As the technology was still in the early stage, high uncertainties and market volatility could also be challenges in the adoption. Many stakeholders have old mindsets as well as a lack of awareness of blockchain technology and its advantages (e.g., [6], [7], [9], [114]). There exists an idea that blockchain may deskill workers and organizations [6], [111]. Furthermore, convincing business cases are still limited. [6], [48]. The high volatility of cryptocurrencies could reduce the public trust of the blockchain technology [6], [112]. Many stakeholders may have limited education and required skills to adopt a blockchain-based application [3], [5]–[7]. The training platforms are still inadequate [6], [110].

Regardless of these costs and risks, the benefits of blockchain make the costs sustainable [6], [9], [102]. Requirements of adoption could be varied by stages of the supply chain [9], [55]. Perboli *et al.* [102] encouraged the partial implementation of blockchain instead of replacing the whole system. Other technologies can be more suitable in some cases [9], [55], [114]. Improving users' familiarity with blockchain could improve adoption attitude [9], [113]. Finally, governments should play a role in reducing adoption barriers by setting examples [5], [6].

5) SUSTAINABILITY

Blockchain could improve the ability to maintain the business in economic, environmental, and social aspects [6]. Blockchain could aid supervision and management [3], [130], which helps eliminate food adulteration, improve food safety and quality, and reduce uncoordinated issues, thus increasing sustainability (e.g., [3], [8], [60], [126]–[129]). Blockchain could help in resource allocation [3] as well as enhance demand and quality prediction [4], [9], [76], [120]–[122]. Better management could reduce economic loss and product waste [4], [61], [108], [123] as well as provide support for emission reduction [6]. Blockchain for recording water quality data could lead to sustainable water management [6], [7], [9], [119]. Socially, blockchain could empower the poor in developing countries [118] and provide food security (e.g., by providing a food coupon to refugees [117]).

Consumers became more interested in environmental impact and ethical working conditions [8], [131], [132]. Lee *et al.* [64] suggested blockchain as a tool for monitoring social and environmental responsibility. Similarly, Rejeb [90] suggested blockchain as a framework for environmental, social, and economic regulatory, as well as corruption mitigation. Wrongdoings outside the organization could be held accountable [8], [133].

C. TECHNOLOGY

This section discusses technology advantages and challenges brought by blockchain, including scalability, security, and infrastructure.

1) SCALABILITY

Dutta *et al.* [3] discussed blockchain for supply chain functions that addressed many traditional supply chain issues and improved scalability, which could enable a business or a system to grow larger.

Scalability, however, was deemed an important challenge in blockchain applications. Main issues include transaction speed, latency, and storage capacity of blockchain and IoT devices [4]–[8].

Latency refers to the delay between a user's actions and the system's responses. Four papers ([4], [6]–[8]) discussed latency issues with reference to various works such as [57], [142], [143]. Network delays can necessitate additional computational resources and processing time [7], [139].

Transaction speed is one of the two main challenges of blockchain applications [7], [101]. Information transparency and immutability could lead to performance issues in supply chains [6], [111]. Ethereum, for example, could handle 15 transactions per second, which was very slow compared to 45,000 transactions per second in traditional platforms [9], [141]. Large transaction volumes require more time and mechanisms to validate large blocks [7], [136], [138].

Storage requirements of blockchain are significant [7], [57]. Any individual in a supply chain must have all transaction records on hand at all times [7], [103], thus the blockchain could become voluminous [135].

Pearson *et al.* [60] suspected that these scalability issues lead to limited usage of blockchain.

2) SECURITY

Blockchain could enhance data integrity and transaction security through digital fingerprint [3], [4], [144]–[146]. Such fingerprint could be stored in a local file, local hash tree, external hash tree, distributed ledger, public database, or hybrid distributed ledgers [8].

Although blockchain is secure by design, ensuring security is challenging and data security is still an issue [4], [149]. Programming bugs could also introduce vulnerability in smart contracts [4], [147].

3) INFRASTRUCTURE

Overall infrastructure was also a challenge in blockchain adoption.

Duan *et al.* [9], Perboli *et al.* [102], and Ometoruwa‘ [154] suggested difficulties in realizing decentralization, scalability, and security at the same time. Different ways to balance the three features might be needed for different stages of the food supply chain [9], [55]. Design limitations constrained the choice of consensus algorithm, transaction capacity, and data accessibility [4], [142], [143], [155].

As traceability requires information exchange between stakeholders, which could adopt different systems, interoperability and standardization were challenges discussed in [3]–[5]. Blockchain was often combined with IoT to offer scalability, security, auditing, efficiency, interoperability, and quality solutions [9], [91]. Nonetheless, the capability of IoT-based devices is less than that needed by blockchain [4], [57], [155]. Moreover, complex underlying digital technology that incorporates sensors or other third-party tools might compromise the decentralized trust [6], [68], [150]–[152].

There exists a digital gap between developed, developing, and underdeveloped countries [5], [6], [153]. Poor infrastructure, such as an absence of public key infrastructure, would not be sufficient to satisfy the needs of a blockchain-based system [4]. New users might find a barrier to market due to this issue [6], [60], especially if large companies implement private and permissioned blockchain [6], [60].

V. USER INTERFACE

This section reviews articles that included screenshots of user interfaces for 14 blockchain-based and 10 non-blockchain-based agri-food applications. We also considered articles that did not include screenshots or included screenshots of blockchain-based applications in other domains as well since some of them could benefit from designing blockchain-based agri-food applications.

The following subsections summarize the target users and purpose of the interfaces, how such interfaces were designed to support traceability, as well as other aspects of user interfaces that facilitate traceability applications.

A. TARGET USERS AND PURPOSES

Table 3 and Table 4 provide the list of blockchain-based and non-blockchain-based agri-food applications, respectively. The tables include title, year of publication, as well as an indication of whether the paper included a screenshot of user interfaces for each stakeholder, discussed model or architecture, or involved users in development or testing. Note that the lack of a checkmark means unclear whether the interface is for a corresponding user.

We categorize target users of agri-food applications based on stakeholders. Similar to the stakeholders discussed in IV-A, the target users include producers, intermediaries, and customers. The target users also include *processors* who transform the product into other forms, such as egg packagers or food processing industries, and *distributors* who transfer and/or distribute the product between stakeholders. The purpose of a user interface generally varies by the target users.

1) PRODUCERS

Screenshots of user interfaces for producers were mostly presented in early works on agri-food applications, which did not leverage blockchain. Only a few blockchain-based research works provided screenshots for producers. The purposes were mostly to support decision making, which we found in a livestock management system [174], a decision support system for identification of genetically modified food or feed products [176], a weather forecast information dissemination system [177], a decision support system for choosing the priority of corporate social responsibility (CSR) program [173], and a credit evaluation system [130]. Only two works provided an interface to load information to a system, i.e., registering crops [164] and loading information into RFID tags for identifying and verifying agrochemicals [171]. This trend could be influenced by the usage of sensors to automatically input information to a system. Section V-B will discuss the input methods in more detail.

2) PROCESSORS

Similar to user interfaces for producers, user interfaces for processors aimed at updating information [167] and supporting decision making [172]. Cong An *et al.* [167] built a supply chain management system based on blockchain technology for tracking the origins of agriculture products. Ali and Bahnasawy [172] purposed a decision support system for food processing industries.

3) DISTRIBUTORS

Palacio *et al.* [175] interviewed 50 people to understand the requirements in medicinal product transportation, then provided screenshots of the user interface for logistics personnel and messengers. The paper focused on monitoring temperature in the cold chain, which proper temperature control in logistics was essential.

TABLE 3. List of 14 articles focusing on blockchain-based applications for agri-food supply chain. The list includes the title, year of publication, as well as an indication of whether the paper discussed models or architecture, involved users in development or testing, and included a screenshot of a user interface for each stakeholder. Note that the lack of a checkmark means unclear whether the interface is for a corresponding user.

Title	Year	Screenshot of a user interface for					Model	User Involved
		Producer	Processor	Logistic	Intermediary	Customer		
Credit evaluation system based on blockchain for multiple stakeholders in the food supply chain [130]	2018	✓			✓	✓	✓	
Exploring machine autonomy and provenance data in coffee consumption: A field study of bitbarista [27]	2018					✓		✓
Using blockchain technology in human food chain provenance [160]	2018						✓	
A Blockchain-based decentralized system to ensure the transparency of organic food supply chain [161]	2019						✓	
A simulated organic vegetable production and marketing environment by using Ethereum [162]	2019						✓	
A traceability method based on blockchain and internet of things [163]	2019					✓	✓	
AgroVita using Blockchain [164]	2019	✓					✓	
An information system to track data and processes for food quality and bacterial pathologies prevention [165]	2019					✓		
Blockchain-Driven IoT for Food Traceability with an Integrated Consensus Mechanism [166]	2019					✓	✓	
Building a Product Origins Tracking System Based on Blockchain and PoA Consensus Protocol [167]	2019		✓			✓	✓	
Thai agriculture products traceability system using blockchain and Internet of Things [168]	2019					✓	✓	
A blockchain use case in food distribution: Do you know where your food has been? [126]	2020					✓	✓	✓
A framework for food traceability: Case study-Italian extra-virgin olive oil supply chain [169]	2020					✓	✓	
Blockchain-based safety management system for the grain supply chain [170]	2020						✓	
	Total	2	1	0	1	9	12	2

4) INTERMEDIARIES

There are more user interfaces targeted intermediaries. Three of them also provided user interfaces for the producers [130], [173], [176], where another one was a system for the distribution process of regional products [179]. All interfaces aimed at providing information and visualization for decision-making. Although some papers (e.g., [162], [180]) mentioned updating functionality, they did not provide screenshots nor discuss in detail.

5) CUSTOMERS

User interfaces for agri-food applications mostly focused on customers, especially for blockchain-based traceability applications. Customer's user interfaces primarily visualize information for decision making. Two works [130], [167] also targeted producers, processors, or intermediaries. Other works allow customers to trace food products [126], [163], [166], farmland products [165], agriculture products [168], and specific agri-food products (i.e., coffee [27] and Italian extra-virgin olive oil [169]). Section V-C will discuss the visualization methods in more detail.

In addition to user interfaces for specific target stakeholders, some works provided user interfaces for system administrators or did not explicitly state target users [160]–[162], [164], [165], [167], [170], [178]. Interestingly, neither processors nor distributors were discussed as targets of benefits or source of challenges in the review papers. On the other hand, no work explicitly provided a screenshot for *regulators* or *authorities* though some articles included them as a stakeholder. The lack of exploration was in line with the finding when we reviewed the review articles.

Overall, as counted in the Table 3 and Table 4, the target users of blockchain-based agri-food applications concentrated on the customers, shifting from the non-blockchain-based applications where the target users leaned to the producers. This trend could probably influence by the benefit of blockchain in providing traceability and transparency to the supply chain, so the customers could access and trust the information.

Another trend is that the researches on blockchain mostly discussed and focused on the model or architecture to implement the applications, with little user involvement during the application designing or testing. We discuss the user involvement in the following subsections when we discuss the user interface.

TABLE 4. A list of 10 articles focusing on non-blockchain applications for agri-food supply chain. The list includes the title, year of publication, as well as an indication of whether the paper discussed models or architecture, involved users in development or testing, and included a screenshot of a user interface for each stakeholder. The lack of a checkmark means unclear whether the interface is for a corresponding user.

Title	Year	Screenshot of a user interface for					Model	User Involved
		Producer	Processor	Logistic	Intermediary	Customer		
RFID tags for identifying and verifying agrochemicals in food traceability systems [171]	2009	✓						✓
Decision support system for technical management of food processing industries [172]	2011		✓					
Developing an agri-food supply chain application for determining the priority of CSR program to empower farmers as a qualified supplier of modern retailer [173]	2013	✓			✓		✓	
Development of graphical user interface (GUI) for livestock management system [174]	2013	✓						
A novel ubiquitous system to monitor medicinal cold chains in transportation [175]	2017			✓			✓	✓
SIGMO: A decision support System for Identification of genetically modified food or feed products [176]	2017	✓			✓			
Weather forecast information dissemination design for low-literate farmers: An exploratory study [177]	2017	✓						✓
Postharvest supply chain with microbial travelers: A farm-to-retail microbial simulation and visualization framework [178]	2018							
Dynamic model and graphical user interface: A solution for the distribution process of regional products [179]	2020				✓			
User Experience in Kiosk Application for Traceability of Fishery Products [180]	2020					✓	✓	✓
	Total	5	1	1	3	1	3	4

B. HOW TO COLLECT THE DATA

We categorize how a traceability application gathers information into three methods: form entry, label scanning, and sensor transmission, as summarized in Table 5.

1) FORM ENTRY

Form entry gets information through, for example, text fields or buttons. A user manually inputs information to a system. The system could leverage the input form at any stage of a supply chain, such as crop registration [164], livestock management [174], logistics [175], or purchasing [126]. The form could be used as a basis or in conjunction with other methods. Peets *et al.* [171], for example, proposed a user interface consisting of retrieved data as well as confirm and manual entry buttons to assist information loading to a label. They also conducted an experiment with 10 commercially active sprayer operators and interviewed participants for an opinion about the size of the screen, instructions, and the flow of the program. However, they only mentioned that the user interface was well received by the participants, without the detail of their findings.

2) LABEL SCANNING

Label scanning loads information from a piece of material attached to an object. One common way is a QR code (Quick Response code), which can be printed on a container for a customer to access product traceability information [126], [161], [164]–[166], [168], [169]. The label usually appears as a way to access information gathered via other methods. A user needs a reader to read the embedded information for the label to a system. A label could also leverage other technologies, such as a barcode, Near-Field Communication (NFC), or Radio Frequency Identification (RFID). Violino *et al.* [181] compared NFC, RFID, and blockchain-based gamification QR code. Their questionnaire and interview found that the QR appeared more attractive, probably due to transparency, incentive, and gamification. Bumblauskas *et al.* [126] put a QR on egg packages sold in four retailers. They found a 21.2% scan rate with 2 minutes 48 seconds visiting duration on average, which exceeded their goals in their proof of concept phase. This finding led to interest for further development of the system from their stakeholders.

3) SENSOR TRANSMISSION

Sensor transmission leverages devices to automatically gather information such as temperature, humidity, fertilizer concentration of the soil, or location, as seen in [126], [160], [163], [166], [168], [175], [180]. A system could use one or multiple sensors to reduce the time taken and human error when entering data. The sensor is seen as a way to address inaccurate data issues, which is one challenge in the blockchain application discussed in Section IV-A. The usage of sensors and IoT in blockchain applications was reviewed in [13], [14], [35].

TABLE 5. Input methods with description and examples.

Method	Description	Blockchain-based examples	Non-blockchain examples
Form	Manual inputting information through, for example, text fields or buttons	[126], [164]	[171], [174], [175]
Label	Gathering information from a piece of material attached to an object such as NFC, RFID, QR code, or bar code	[126], [161], [164]–[166], [168], [169], [181]	
Sensor	Automated information gathering via sensors and IoT devices such as temperature sensor or GPS	[126], [160], [163], [166], [168]	[175], [180]

TABLE 6. Visualization methods with description and examples.

Method	Description	Blockchain-based examples	Non-blockchain examples
Formatted text	Presenting information using text that could be structured into, for example, list or section	[160], [161], [167]	
Table	Presenting information in rows and columns	[27]	[174]
Timeline	Presenting information as an time-ordered list where items are connected by one vertical or horizontal line	[126], [166], [169]	
Graph	Presenting information as a diagram showing the relation between items		[180]
Map	Presenting information on a drawing showing geographical location features such as cities or roads	[165]	[175], [180]

C. HOW TO VISUALIZE THE DATA

We categorize how traceability applications present information into five types: formatted text, table, timeline, graph, and map, as summarized in Table 6. In some cases, additional information could be visualized using other representations. We also found cases where a system uses multiple types of visualization.

1) FORMATTED TEXT

Formatted text presents information using texts that are arranged or structured into some patterns. Basnayake and Rajapakse [161], for instance, simply provided a history of organic food by listing the contract and owner identification number. Others grouped information based on stakeholders, then listed each property as a text label with detail, as visualized in Figure 4. The screenshot of agriculture product origins tracking system by Cong An *et al.* [167] showed information groups including product overview information (identifier and involved stakeholders), farmer (e.g., fertilizer and pesticides), importer (e.g., amount and storage address), and processor (e.g., expiry day and packing address). Similarly, Guo *et al.* [160] grouped information based on stakeholders. However, instead of displaying all information on one page as Tran's, they showed only one stakeholder per page.

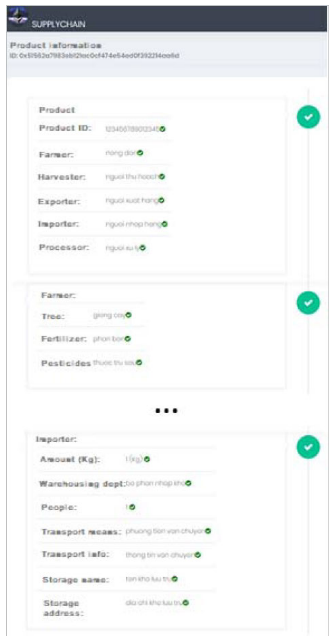

FIGURE 4. An example of a user interface with formatted text visualization from Cong An *et al.* [167]. The screen shows the label and detail of each property, grouped by stakeholders. (Reproduced with permissions from the authors).

2) TABLE

Table presents information in rows and columns. The table could either be with borders such as in a livestock management system [174] (see Figure 5) or without borders such as in an autonomous coffee machine [27]. Both examples have transactions or products as rows and properties in columns.

3) TIMELINE

Timeline presents information as a time-ordered list where items are connected by a line, as visualized in Figure 6. Mobile traceability applications, such as egg tracking application [126] and olive oil traceability application [169], vertically list events with a brief summarization. Alternatively, events could be arranged horizontally, as seen in the food traceability web application [166], which allows access from any device.

4) GRAPH

Graph presents information as a diagram showing the relation between items. We found one paper, a kiosk application for fishery product traceability [180], that represented supply chain events in an oriented graph. The author also compared the graph with the map representation, as discussed in the next paragraph.

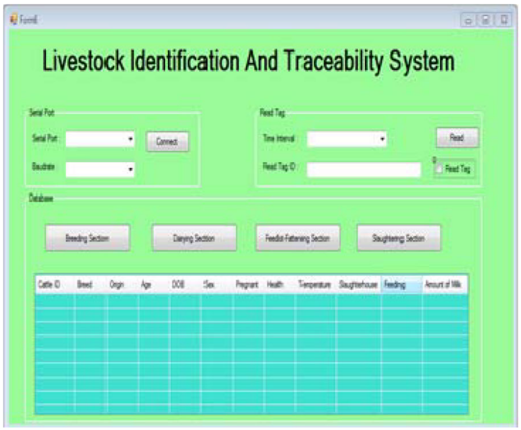

FIGURE 5. An example of a user interface with table visualization from Ismail and Ismail [174]. The screen shows each property in a column and each transaction in a row. (Reproduced with permissions from the authors).

FIGURE 6. An example of a user interface with timeline visualization from Bumblauskas *et al.* [126]. The screen displays transactions in order and connects them with a line. (Reproduced with permissions from the authors).

5) MAP

Map presents information on a drawing showing geographical location features such as cities or roads, as visualized in Figure 7. Details on a map can be varied. For instance, Tradigo *et al.* [165] only pinned a production location on a map. Oliveira *et al.* [180] pinned and linked locations of each stage in a supply chain, whereas Palacio *et al.* [175] plotted the route that the logistics personnel took. Palacio's proposed system was validated in real conditions in a local laboratory. However, the case study presented no details about the usability of the system. On the other hand, Oliveira *et al.* tested the usability of their system as well as compared the graph and map representations with 35 customers. They found that the participants preferred the map over the graph since the graph could be confusing for some users. The participants also asked for details on the map itself rather than the graph.

We also found systems that used other visualizations to display additional information. For instance, Surasak *et al.* [168] visualized the temperature and humidity in a virtual gauge. Lagarda-Leyva *et al.* [179] displayed route completion time in a chart and vehicle capacity usage in a virtual gauge. These visualizations provided additional information for justifying food quality or improving supply chain processes, which could be a complement of our five visualization types.

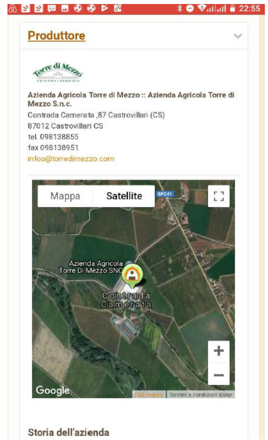

FIGURE 7. An example of a user interface with map visualization from Tradigo *et al.* [165]. The screen displays the location of the producer on a map showing land features. (Reproduced with permissions from the authors).

In case of a lot of information exist, either with one or multiple types of visualization, proper information organization should be considered. The usability study with 35 customers by Oliveira *et al.* [180] found some customers asking for sections of, for example, traceability or recipes, instead of only having one big page with all content.

D. OTHER ASPECTS OF USER INTERFACE

In this section, we revisit the benefits and challenges discussed in Section IV and see how user interfaces relate to or address other points from stakeholders and traceability. We also include articles without screenshots or in non-agri-food supply chain domains, which could be a complement or potentially useful for agri-food traceability applications.

1) PRIVACY

Designing blockchain-based traceability systems generally includes determining the privacy level - whether they are private, permission, or public blockchains. Still, the discussion about the selection of privacy level is not sufficient nor does the privacy level reflects in the user interface.

In a general blockchain application, Cabinakova *et al.* [182] compared user acceptance of centralized and decentralized identity management systems, in which the decentralized system includes buttons to toggle disclosed personal information. They found that this control was a strong predictor of perceived transparency as well as user willingness to disclose data and users' attitude. More consideration of privacy control of stakeholders in a supply chain could be beneficial to the traceability system.

2) EFFICIENCY

While Galvez *et al.* [8] and several works (e.g., [163], [164]) mentioned or used smart contracts as a way to improve efficiency in an agri-food supply chain, we found no works that discuss a user interface for a smart contract in this domain.

Research of blockchain in general presents few works regarding user interface for smart contracts. Gul *et al.* [183] designed a smart contract interface for a user-centric business model in the blockchain. They suggested using a menu-based and filled form-based approach to create a smart contract for productivity and ease of use. Created contracts are immutable as they are based on blockchain technology. In practice, however, applications sometimes require updating of such immutable contracts. Hence, Kafeza *et al.* [184] proposed a versioning system of smart contracts using rental agreement smart contract as a case study. The interface included a simple form to upload the contract as well as a list of contract names and action buttons to, for example, deploy or terminate a contract. Nissen *et al.* [185] addressed another possibility of smart contracts by excluding the underlying contract from a user interface. They attached smart contract logic to physical locations, and the users only observed the result of the executed contracts through physical exploration and the changes to their balance.

3) SUSTAINABILITY

Sutopo *et al.* [173] provided a user interface to input farmer and retailer data. Based on their computation, they then used data tables and charts to show details for improving vegetable quality and farmers' abilities. Tallyn *et al.* [27] proposed autonomous coffee machines that allowed provenance of purchasing data, reducing intermediaries, and options to vote for future supplies. For voting, the screen showed results of supply chain analysis and used text, grouped as cards, to display the best supply for each criterium: "Best Quality", "Low Environmental Impact", "Best Social Responsibility", and "Best Price." They deployed the system in 3 offices and conducted a user study with 13 participants in the office. Their main conclusions included (1) minimizing the use of monetary rewards, (2) providing adequate information about the state of the machine, and (3) situating information about long-term thinking (such as provenance, environment, or value) in time and people's routines. These findings provided implications for blockchain in everyday life as well as wider social structures and values.

4) COST AND RISK

Stakeholders may have limited education and required skills to use a blockchain-based application. Blockchain education is still immature with a limited number of universities offering blockchain courses [186]. Instead of relying on education, several papers addressed this issue by providing familiar interfaces to users. Bumblauskas *et al.* [126], for example, integrated blockchain with internal traceability software, hardware, and data entry from a system operator. Similarly, Iftekhar *et al.* [187] merged an enterprise-ready blockchain platform with existing conventional infrastructure.

In a general context, Teruel and Trujillo [188] used a conceptual modeling approach and provided a middleware of blockchain-based employee schedule tracker for non-blockchain users. With the middleware, users could use a blockchain-based application as they did with a standard web application, i.e., by using usernames, passwords, and user interface elements instead of addresses, private keys, or transactions. They measured System Usability Score (SUS) with 38 participants and found that the middleware was more usable and reduced task performance time. Rahman *et al.* [189] proposed a gesture-based user interface of a blockchain-based smart health monitoring system for elderly people or people with special needs. Seitz *et al.* [190] used blockchain to trace application installations on edge devices. They proposed an augmented reality that allowed user interaction with devices in an industrial environment.

5) SCALABILITY

One prominent scalability issue that relates to user interface design is latency. The limit for keeping the user's attention is 10 seconds, and the limit for the user to feel instantaneously response is 0.1 second [191]. Cong An *et al.* [167] proposed a system that took 15 seconds to create a block. Compared to the Proof-of-Work consensus protocol that could take 10 minutes, 15 seconds is very fast. Yet, based on the time limit suggestion, a user could notice the latency.

In a general context, Nissen *et al.* [185] discussed that long transaction time disrupted user tasks. To address the issue, they added a "confirmed" for the trusted transaction and an "unconfirmed" for value to be updated. Their solution could be a good complement to only trying to improve the performance of a blockchain application.

6) SECURITY

User interface design related to security generally leads to the choice between public-private key authentication, as seen in the work by Iftekhar *et al.* [187], or username-password authentication, as seen in the work by Shaikh *et al.* [164]. One factor to determine which implementation is education and skills of the target users, as discussed in the cost and risk.

7) INFRASTRUCTURE

Infrastructure could affect user design choices. Idrees *et al.* [177] conducted semi-structured interviews with 16 farmers in Pakistan and found that majority of farmers have access to a smartphone. Hence, they designed an Android application and leveraged SMS to disseminate weather information. The choice of a device implies a screen size, which influences both how to collect and visualize the data. For instance, mobile phones usually come with GPS, which could be used to automatically get location data. Mobile applications typically prefer vertical timelines (e.g., as in [126], [169]) due to limited width.

VI. DISCUSSION

In the previous two sections, we summarize the benefits and challenges of blockchain as well as categorize user interfaces, which briefly correspond to the benefits and challenges. In this section, we connect them together to determine research gaps, which researchers could address to ease the design process of the blockchain-based agri-food traceability applications and increase their usability.

Overall, blockchain for the agri-food supply chain has a lot of potentials, which still need to be confirmed through practical implementations. From Table 2, seven review papers discussed the benefits and challenges of blockchain in agri-food supply chain application based on 119 unique references. Surprisingly, 97 references were not picked up by our queries. A notable number of references came from general or other domains. This finding could imply that convincing cases of blockchain-based agri-food traceability are still scarce. Tribis *et al.* [48] suggested that real performance evaluation is still lacking, and from our point of view, user involvement and evaluation are also lacking. Compared to the traditional applications, fewer numbers of blockchain-based applications involved users (see Table 3 and Table 4).

One common potential benefit and goal of blockchain-based agri-food supply chain applications is to provide trustworthy traceability information to customers. From Table 3 and Table 4, user interfaces for customers came from the blockchain-based applications more than from the traditional applications. Such customer involvement will increase the importance of user interfaces since customers may lack the motivation to be trained how to use the applications. Other stakeholders, who can be motivated by the business advantages, may also find difficulty in adopting this complex technology if the user interfaces are hard to use. Training cost tends to outweigh the design cost for better user interfaces.

Blockchain-based agri-food traceability applications involve a relatively wide range of user types, while the underlying technology is relatively complex compared to other applications. We speculate that its nature requires additional considerations when designing the interface. For instance, one of the usability components involves an easy reversal of user errors [26], which is prevented by the immutability property of the blockchain. More considerations should be put on error prevention, such that farmers with limited knowledge of the technology may not enter incorrect information.

Regardless, we cannot confirm the need for additional considerations. This is because of the relatively limited discussion about the user interfaces in the reviewed literature. Furthermore, most of the reviewed literature did not provide or provided only a limited evaluation of the user interfaces. Though the screenshots provide fairly rich information about the user interfaces, they may not illustrate all of the features of the applications. Due to this limitation, this paper avoids evaluating the interfaces, even by using design heuristics.

With the current state of research, it is difficult to draw out design guidelines specifically for blockchain-based agri-food traceability applications. Thus, we suggest future research efforts to include details on user interface and design decisions in their works, involve users in development and evaluation, and consider user interfaces to enhance benefits and address challenges of the applications.

A. MORE DETAILS ON USER INTERFACE AND DESIGN DECISIONS

We found that papers rarely explain their user interfaces and why they designed those user interface features. We speculate each input and visualization type to be useful in different situations. For instance, five visualization types could emphasize different aspects of information: the formatted text could be just a simple way to present all information; the table could facilitate a detailed comparison of data, which may be suitable for supply chain management but too excessive for customers; the timeline could emphasize time, which should be useful for the products with a short or sensitive shelf-life; the graph could emphasize steps, which could be useful to oversee the supply chain process; the map could emphasize locations, which could be used to promote local specialty or detect area-based issues such as water pollution. Still, we lack the detailed explanation to confirm these suggestions. We encourage researchers to include the user interface details and design decisions so that others could justify whether the features are useful for their applications.

B. MORE USER INVOLVEMENT AND EVALUATION

We found that relatively few works reported details of user opinions regarding user interface or usability, though many applications originated from analyzing business case studies that involved stakeholders in their development. There are very limited evaluations and guidelines to tell how features should be designed. For instance, designers may want to emphasize locations on a map, but the information to be displayed on the map will require preferences from the target users. Business entities may prefer all data visible for management while customers may overwhelm by those data. The designers may need to evaluate different types of map representations (e.g., satellite and road map), similar to Violino *et al.* [181] that evaluated the label types (NFC, RFID, and QR code). As users in an agri-food supply chain have different backgrounds and skills, we believe that user study is important to find which user interface features are suitable for which users in which context.

C. MORE CONSIDERATIONS OF USER INTERFACES

Our analysis in Section V could serve as a starting point for considering user interfaces in blockchain-based agri-food traceability applications. For instance, gathering inputs through forms should be more flexible but more time-consuming and error-prone compared to other methods. Proper form design, e.g., with autocompletion and validation, could reduce error and time taking to enter the information. While visual feedback such as percent-done indicator [192] is not the solution to latency issues, it helps users understand the waiting and reduce frustration. Designers may follow learnability guidelines (e.g., [193]) to reduce costs related to limited education and required skills. We believe that better user interface design could enhance the benefits and address the challenges of the blockchain-based agri-food traceability applications, thus easing the adoption of the blockchain-based agri-food traceability applications.

VII. CONCLUSION

Blockchain technology is seen as a way to improve agri-food supply chain traceability and deliver food quality, safety, and nutrition information to stakeholders. While there are a lot of works on blockchain-based agri-food traceability, relatively few works paid attention to user interfaces. Limited knowledge on how to design the user interface for the traceability application could lead to usability issues. As a step towards more usable blockchain-based agri-food traceability applications, this paper reviewed existing works from a user interface perspective. We examined 7 review papers to understand the benefits and challenges that the blockchain brings to stakeholders, businesses, and technology for the agri-food supply chain. We analyzed 24 papers containing user interfaces related to blockchain and/or agri-food traceability for target users and user interface purposes. We summarized three ways to collect the traceability data (form entry, label scanning, and sensor transmission), five ways to visualize the traceability data (formatted text, table, timeline, graph, and map), as well as other aspects of the user interfaces. In the end, we encouraged researchers to include details on user interface and design decisions in their works, involve users in development and evaluation, and consider user interfaces to enhance benefits and address challenges of the applications. We believe that better user interface design is one factor to widen blockchain adoption in the future.

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REFERENCES

[1] M. Iansiti and K. R. Lakhani. (2017). *The Truth About Blockchain*. [Online]. Available: https://hbr.org/2017/01/the-truth-about-blockchain

[2] O. Ahumada and J. R. Villalobos, "Application of planning models in the agri-food supply chain: A review," *Eur. J. Oper. Res.*, vol. 196, no. 1, pp. 1–20, Jul. 2009. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0377221708001987

[3] P. Dutta, T.-M. Choi, S. Somani, and R. Butala, "Blockchain technology in supply chain operations: Applications, challenges and research opportunities," *Transp. Res. E, Logistics Transp. Rev.*, vol. 142, Oct. 2020, Art. no. 102067.

[4] H. Feng, X. Wang, Y. Duan, J. Zhang, and X. Zhang, "Applying blockchain technology to improve Agri-food traceability: A review of development methods, benefits and challenges," *J. Cleaner Prod.*, vol. 260, Jul. 2020, Art. no. 121031.

[5] K. Demestichas, N. Peppes, T. Alexakis, and E. Adamopoulou, "Blockchain in agriculture traceability systems: A review," *Appl. Sci.*, vol. 10, no. 12, pp. 1–22, 2020.

[6] A. Kamilaris, A. Fonts, and F. X. Prenafeta-Boldú, "The rise of blockchain technology in agriculture and food supply chains," *Trends Food Sci. Technol.*, vol. 91, pp. 640–652, Sep. 2019.

[7] G. Zhao, S. Liu, C. Lopez, H. Lu, S. Elgueta, H. Chen, and B. M. Boshkoska, "Blockchain technology in Agri-food value chain management: A synthesis of applications, challenges and future research directions," *Comput. Ind.*, vol. 109, pp. 83–99, Aug. 2019.

[8] J. F. Galvez, J. C. Mejuto, and J. Simal-Gandara, "Future challenges on the use of blockchain for food traceability analysis," *TrAC Trends Anal. Chem.*, vol. 107, pp. 222–232, Oct. 2018.

[9] J. Duan, C. Zhang, Y. Gong, S. Brown, and Z. Li, "A content-analysis based literature review in blockchain adoption within food supply chain," *Int. J. Environ. Res. Public Health*, vol. 17, no. 5, p. 1784, Mar. 2020.

[10] C. Elsden, A. Manohar, J. Briggs, M. Harding, C. Speed, and J. Vines, "Making sense of blockchain applications: A typology for HCI," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, Apr. 2018, pp. 1–14, doi: 10.1145/3173574.3174032.

[11] M. Foth, "The promise of blockchain technology for interaction design," in *Proc. 29th Austral. Conf. Comput.-Hum. Interact.*, Nov. 2017, pp. 513–517, doi: 10.1145/3152771.3156168.

[12] C. S. Wright. (2019). *Bitcoin: A Peer-to-Peer Electronic Cash System*. [Online]. Available: https://bitcoin.org/bitcoin.pdf

[13] M. Torky and A. E. Hassanein, "Integrating blockchain and the Internet of Things in precision agriculture: Analysis, opportunities, and challenges," *Comput. Electron. Agricult.*, vol. 178, Nov. 2020, Art. no. 105476.

[14] I. Mistry, S. Tanwar, S. Tyagi, and N. Kumar, "Blockchain for 5G-enabled IoT for industrial automation: A systematic review, solutions, and challenges," *Mech. Syst. Signal Process.*, vol. 135, Jan. 2020, Art. no. 106382.

[15] M. Singh, A. Singh, and S. Kim, "Blockchain: A game changer for securing IoT data," in *Proc. IEEE 4th World Forum Internet Things (WF-IoT)*, Feb. 2018, pp. 51–55.

[16] A. Panarello, N. Tapas, G. Merlino, F. Longo, and A. Puliafito, "Blockchain and IoT integration: A systematic survey," *Sensors*, vol. 18, no. 8, p. 2575, Aug. 2018.

[17] WHO. (2015). *WHO | 10 Facts on Food Safety*. [Online]. Available: http://www.who.int/features/factfiles/food_safety/en/

[18] Y. Peng, J. Li, H. Xia, S. Qi, and J. Li, "The effects of food safety issues released by we media on consumers' awareness and purchasing behavior: A case study in China," *Food Policy*, vol. 51, pp. 44–52, Feb. 2015. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0306919214002152

[19] *Traceability in the Feed and Food Chain: General Principles and Basic Requirements for System Design and Implementation*, International Organization for Standardization, Geneva, Switzerland, 2007.

[20] J. Qian, L. Ruiz-Garcia, B. Fan, J. I. Robla Villalba, U. McCarthy, B. Zhang, Q. Yu, and W. Wu, "Food traceability system from governmental, corporate, and consumer perspectives in the European union and China: A comparative review," *Trends Food Sci. Technol.*, vol. 99, pp. 402–412, May 2020.

[21] A. Corallo, R. Paiano, A. L. Guido, A. Pandurino, M. E. Latino, and M. Menegoli, "Intelligent monitoring Internet of Things based system for Agri-food value chain traceability and transparency: A framework proposed," in *Proc. IEEE Workshop Environ., Energy, Structural Monitor. Syst. (EESMS)*, Jun. 2018, pp. 1–6.

[22] M. M. Aung and Y. S. Chang, "Traceability in a food supply chain: Safety and quality perspectives," *Food Control*, vol. 39, pp. 172–184, May 2014.

[23] A. Banterle, "Tracciabilità, coordinamento verticale e governance delle filiere agro-alimentari," *Agriregionieuropa*, vol. 4, p. 15, Dec. 2008.

[24] I. C. Pappa, C. Iliopoulos, and T. Massouras, "What determines the acceptance and use of electronic traceability systems in Agri-food supply chains?" *J. Rural Stud.*, vol. 58, pp. 123–135, Feb. 2018.

[25] Interaction Design Foundation. *Human-Computer Interaction (HCI)*. Accessed: Mar. 5, 2021. [Online]. Available: https://www.interaction-design.org/literature/topics/human-computer-interaction

[26] J. N. Alertbox. (2003). *Usability 101: Introduction to Usability*. [Online]. Available: http://tfa.stanford.edu/download/IntroToUsability.pdf

[27] E. Tallyn, L. Pschetz, R. Gianni, C. Speed, and C. Elsden, "Exploring machine autonomy and provenance data in coffee consumption: A field study of bitbarista," *Proc. ACM Hum.-Comput. Interact.*, vol. 2, p. 170, Nov. 2018.

[28] C. Karunanayaka, K. Vidanagamachchi, and R. Wickramarachchi, "Transforming agriculture supply chain with technology adoption-: A critical review of literature," in *Proc. Int. Conf. Ind. Eng. Oper. Manage.*, Mar. 2020, pp. 1163–1170.

[29] H. Juma, K. Shaalan, and I. Kamel, "A survey on using blockchain in trade supply chain solutions," *IEEE Access*, vol. 7, pp. 184115–184132, 2019.
[30] D. Dave, S. Parikh, R. Patel, and N. Doshi, "A survey on blockchain technology and its proposed solutions," *Procedia Comput. Sci.*, vol. 160, pp. 740–745, Jan. 2019.
[31] V. S. Yadav and A. R. Singh, "A systematic literature review of blockchain technology in agriculture," in *Proc. Int. Conf. Ind. Eng. Oper. Manage.*, Jul. 2019, pp. 973–981.
[32] G. Mirabelli and V. Solina, "Blockchain and agricultural supply chains traceability: Research trends and future challenges," *Procedia Manuf.*, vol. 42, pp. 414–421, Jan. 2020.
[33] W. Lin, X. Huang, H. Fang, V. Wang, Y. Hua, J. Wang, H. Yin, D. Yi, and L. Yau, "Blockchain technology in current agricultural systems: From techniques to applications," *IEEE Access*, vol. 8, pp. 143920–143937, 2020.
[34] A. Rejeb and K. Rejeb, "Blockchain and supply chain sustainability," *Logforum*, vol. 16, no. 3, pp. 363–372, 2020.
[35] M. Wu, K. Wang, X. Cai, S. Guo, M. Guo, and C. Rong, "A comprehensive survey of blockchain: From theory to IoT applications and beyond," *IEEE Internet Things J.*, vol. 6, no. 5, pp. 8114–8154, Oct. 2019.
[36] V. Astarita, V. P. Giofrè, G. Mirabelli, and V. Solina, "A review of blockchain-based systems in transportation," *Information*, vol. 11, no. 1, p. 21, Dec. 2019.
[37] J. Astill, R. A. Dara, M. Campbell, J. M. Farber, E. D. G. Fraser, S. Sharif, and R. Y. Yada, "Transparency in food supply chains: A review of enabling technology solutions," *Trends Food Sci. Technol.*, vol. 91, pp. 240–247, Sep. 2019.
[38] K. Gopi, D. Mazumder, J. Sammut, and N. Saintilan, "Determining the provenance and authenticity of seafood: A review of current methodologies," *Trends Food Sci. Technol.*, vol. 91, pp. 294–304, Sep. 2019.
[39] R. Sharma, S. S. Kamble, A. Gunasekaran, V. Kumar, and A. Kumar, "A systematic literature review on machine learning applications for sustainable agriculture supply chain performance," *Comput. Oper. Res.*, vol. 119, Jul. 2020, Art. no. 104926.
[40] M. Lezoche, J. E. Hernandez, M. D. M. E. A. Díaz, H. Panetto, and J. Kacprzyk, "Agri-food 4.0: A survey of the supply chains and technologies for the future agriculture," *Comput. Ind.*, vol. 117, May 2020, Art. no. 103187.
[41] S. S. Kamble, A. Gunasekaran, and S. A. Gawankar, "Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications," *Int. J. Prod. Econ.*, vol. 219, pp. 179–194, Jan. 2020.
[42] X. Zhang, Z. Cao, and W. Dong, "Overview of edge computing in the agricultural Internet of Things: Key technologies, applications, challenges," *IEEE Access*, vol. 8, pp. 141748–141761, 2020.
[43] (2017). *FarmShare*. [Online]. Available: http://farmshare.org
[44] (2017). *AgriLedger*. [Online]. Available: http://www.agriledger.com/
[45] A. Carbone, D. Davcev, K. Mitreski, L. Kocarev, and V. Stankovski, "Blockchain based distributed cloud fog platform for IoT supply chain management," in *Proc. 8th Int. Conf. Adv. Comput., Electron. Electr. Technol. (CEET)*, Feb. 2018, pp. 51–58.
[46] M. Chinaka, "Blockchain technology—Applications in improving financial inclusion in developing economies: Case study for small scale agriculture in Africa," Ph.D. dissertation, Massachusetts Inst. Technol., Cambridge, MA, USA, 2016.
[47] P. Helo and Y. Hao, "Blockchains in operations and supply chains: A model and reference implementation," *Comput. Ind. Eng.*, vol. 136, pp. 242–251, Oct. 2019. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0360835219304152
[48] Y. Tribis, A. El Bouchti, and H. Bouayad, "Supply chain management based on blockchain: A systematic mapping study," in *Proc. MATEC Web Conf.s*, vol. 200. Les Ulis, France: EDP Sciences, 2018, p. 20.
[49] F. Sander, J. Semeijn, and D. Mahr, "The acceptance of blockchain technology in meat traceability and transparency," *Brit. Food J.*, vol. 120, no. 9, pp. 2066–2079, Aug. 2018.
[50] L. Ge, C. Brewster, J. Spek, A. Smeenk, and J. Top, *Blockchain for Agriculture and Food: Findings From the Pilot Study*. Hague, The Netherlands: Wageningen Economic Research, 2017, p. 112. [Online]. Available: www.wur.eu/economic-research
[51] C. Martin and H. Leurent, *Technology and Innovation for the Future of Production: Accelerating Value Creation*. Geneva Switzerland: World Economic Forum, 2017.
[52] F. Tian, "A supply chain traceability system for food safety based on HACCP, blockchain & Internet of Things," in *Proc. Int. Conf. Service Syst. Service Manage.*, Jun. 2017, pp. 1–6.
[53] M. Creydt and M. Fischer, "Blockchain and more—Algorithm driven food traceability," *Food Control*, vol. 105, pp. 45–51, Nov. 2019.
[54] T. Levitt. (2016). *Blockchain Technology Trialled to Tackle Slavery in the Fishing Industry*. [Online]. Available: https://www.theguardian.com/sustainable-business/2016/sep/07/blockchain-fish-slavery-free-seafood-sustainable-technology
[55] C. Leong, T. Viskin, and R. Stewart. (2018). *Tracing the Supply Chain: How Blockchain Can Enable Traceability in the Food Industry*. [Online]. Available: https://www.accenture.com/t20190115T192110Z__w__/us-en/_acnmedia/PDF-93%/Accenture-Tracing-Supply-Chain-Blockchain-Study-PoV.pdf
[56] D. Tse, B. Zhang, Y. Yang, C. Cheng, and H. Mu, "Blockchain application in food supply information security," in *Proc. IEEE Int. Conf. Ind. Eng. Eng. Manage. (IEEM)*, Dec. 2017, pp. 1357–1361.
[57] A. Reyna, C. Martín, J. Chen, E. Soler, and M. Díaz, "On blockchain and its integration with IoT. Challenges and opportunities," *Future Gener. Comput. Syst.*, vol. 88, pp. 173–190, Nov. 2018.
[58] S. Underwood, "Blockchain beyond bitcoin," *Commun. ACM*, vol. 59, no. 11, pp. 15–17, Oct. 2016.
[59] P. Lucena, A. P. D. Binotto, F. da Silva Momo, and H. Kim, "A case study for grain quality assurance tracking based on a blockchain business network," 2018, *arXiv:1803.07877*. [Online]. Available: http://arxiv.org/abs/1803.07877
[60] S. Pearson, D. May, G. Leontidis, M. Swainson, S. Brewer, L. Bidaut, J. G. Frey, G. Parr, R. Maull, and A. Zisman, "Are distributed ledger technologies the panacea for food traceability?" *Global Food Secur.*, vol. 20, pp. 145–149, Mar. 2019.
[61] M. Risius and K. Spohrer, "A blockchain research framework," *Bus. Inf. Syst. Eng.*, vol. 59, no. 6, pp. 385–409, 2017.
[62] N. M. Kumar and P. K. Mallick, "Blockchain technology for security issues and challenges in IoT," *Procedia Comput. Sci.*, vol. 132, pp. 1815–1823, Jan. 2018.
[63] H. Yuan, H. Qiu, Y. Bi, S.-H. Chang, and A. Lam, "Analysis of coordination mechanism of supply chain management information system from the perspective of block chain," *Inf. Syst. e-Bus. Manage.*, vol. 18, no. 4, pp. 681–703, Dec. 2020.
[64] H. L. Lee, H. Mendelson, S. Rammohan, and A. Srivastava, "Technology in agribusiness: Opportunities to drive value," Stanford Graduate School Bus., CA, USA, White Paper, Aug. 2017. [Online]. Available: https://www.gsb.stanford.edu/faculty-research/publications/technology-agribusiness-opportunities-drive-value
[65] M. Tripoli and J. Schmidhuber, "Emerging opportunities for the application of blockchain in the Agri-food industry agriculture," *Food Agricult. Org. United Nations*, vol. 3, p. 21, Aug. 2018. [Online]. Available: http://www.fao.org/3/CA1335EN/ca1335en.pdf
[66] K. N. Khaqqi, J. J. Sikorski, K. Hadinoto, and M. Kraft, "Incorporating seller/buyer reputation-based system in blockchain-enabled emission trading application," *Appl. Energy*, vol. 209, pp. 8–19, Jan. 2018.
[67] A Saad-Hussein, H. M. El-Mofty, and M. A. Hassanien, "Climate change and predicted trend of fungal keratitis in Egypt," *East Mediterr Health J.*, vol. 17, no. 6, pp. 468–473, 2010. [Online]. Available: http://www.ncbi.nlm.nih.gov/pubmed/21796962
[68] F. Tian, "An Agri-food supply chain traceability system for China based on RFID & blockchain technology," in *Proc. 13th Int. Conf. Service Syst. Service Manage. (ICSSSM)*, Jun. 2016, pp. 1–6.
[69] A. A. Khare and A. Mittal, "Blockchain: Embedding trust in organic products' supply chain," *J. Comput. Theor. Nanoscience*, vol. 16, no. 10, pp. 4418–4424, Oct. 2019.
[70] A. Scuderi, V. Foti, and G. Timpanaro, "The supply chain value of pod and pgi food products through the application of blockchain," *Quality Access Success*, vol. 20, no. S2, pp. 580–587, 2019.
[71] S. Mondal, K. P. Wijewardena, S. Karuppuswami, N. Kriti, D. Kumar, and P. Chahal, "Blockchain inspired RFID-based information architecture for food supply chain," *IEEE Internet Things J.*, vol. 6, no. 3, pp. 5803–5813, Jun. 2019.
[72] N. Kshetri, "Blockchain and the economics of food safety," *IT Prof.*, vol. 21, no. 3, pp. 63–66, May 2019.
[73] M. P. Caro, M. S. Ali, M. Vecchio, and R. Giaffreda, "Blockchain-based traceability in agri-food supply chain management: A practical implementation," in *Proc. IoT Vertical Topical Summit Agricult. Tuscany (IOT Tuscany)*, May 2018, pp. 1–4.
[74] M. M. Queiroz, R. Telles, and S. H. Bonilla, "Blockchain and supply chain management integration: A systematic review of the literature," *Supply Chain Manage., Int. J.*, vol. 25, no. 2, pp. 241–254, Aug. 2019.

[75] H. Watanabe, S. Fujimura, A. Nakadaira, Y. Miyazaki, A. Akutsu, and J. J. Kishigami, "Blockchain contract: A complete consensus using blockchain," in *Proc. IEEE 4th Global Conf. Consum. Electron. (GCCE)*, Oct. 2015, pp. 577–578.
[76] G. Liang, S. R. Weller, F. Luo, J. Zhao, and Z. Y. Dong, "Distributed blockchain-based data protection framework for modern power systems against cyber attacks," *IEEE Trans. Smart Grid*, vol. 10, no. 3, pp. 3162–3173, May 2019.
[77] N. Kshetri, "1 blockchain's roles in meeting key supply chain management objectives," *Int. J. Inf. Manage.*, vol. 39, pp. 80–89, Apr. 2018.
[78] M. Thakur and K. A.-M. Donnelly, "Modeling traceability information in soybean value chains," *J. Food Eng.*, vol. 99, no. 1, pp. 98–105, Jul. 2010.
[79] R. Badia-Melis, P. Mishra, and L. Ruiz-García, "Food traceability: New trends and recent advances. A review," *Food Control*, vol. 57, pp. 393–401, Nov. 2015.
[80] K. Behnke and M. F. W. H. A. Janssen, "Boundary conditions for traceability in food supply chains using blockchain technology," *Int. J. Inf. Manage.*, vol. 52, Jun. 2020, Art. no. 101969.
[81] K. Salah, N. Nizamuddin, R. Jayaraman, and M. Omar, "Blockchain-based soybean traceability in agricultural supply chain," *IEEE Access*, vol. 7, pp. 73295–73305, 2019.
[82] K. Y. Chan, J. Abdullah, and A. Shahid, "A framework for traceable and transparent supply chain management for Agri-food sector in Malaysia using blockchain technology," *Int. J. Adv. Comput. Sci. Appl.*, vol. 10, no. 11, pp. 149–156, 2019.
[83] S. Keesstra, G. Mol, J. de Leeuw, J. Okx, C. Molenaar, M. de Cleen, and S. Visser, "Soil-related sustainable development goals: Four concepts to make land degradation neutrality and restoration work," *Land*, vol. 7, no. 4, p. 133, Nov. 2018.
[84] M. Raskin, "The law and legality of smart contracts," Georgetown Law Technol. Rev., Georgetown Univ. Law Center, NY, USA, Tech. Rep., 2017, vol. 1, no. 2, pp. 305–341. [Online]. Available: https://ssrn.com/abstract=2959166, doi: 10.2139/ssrn.2842258.
[85] S. Wass. (2017). *Food Companies Unite to Advance Blockchain for Supply Chain Traceability*. [Online]. Available: https://www.gtreview.com/news/fintech/foodcompanies-unite-to-advance-bl ockchain-for-supply-chain-traceability/
[86] Z. Li, W. M. Wang, G. Liu, L. Liu, J. He, and G. Q. Huang, "Toward open manufacturing: A cross-enterprises knowledge and services exchange framework based on blockchain and edge computing," *Ind. Manage. Data Syst.*, vol. 118, no. 1, pp. 303–320, Feb. 2018.
[87] E. C. Ferrer, "The blockchain: A new framework for robotic swarm systems," in *Proc. Future Technol. Conf.* Cham, Switzerland: Springer, 2018, pp. 1037–1058.
[88] F. Yiannas, "A new era of food transparency powered by blockchain," *Innovations, Technol., Governance, Globalization*, vol. 12, nos. 1–2, pp. 46–56, Jul. 2018.
[89] J. Lin, Z. Shen, and C. Miao, "Using blockchain technology to build trust in sharing LoRaWAN IoT," in *ACM Int. Conf. Proc. Ser.*, 2017, pp. 38–43.
[90] A. Rejeb, "Blockchain potential in tilapia supply chain in ghana," *Acta Technica Jaurinensis*, vol. 11, no. 2, pp. 104–118, Jul. 2018.
[91] A. Rejeb, J. G. Keogh, and H. Treiblmaier, "Leveraging the Internet of Things and blockchain technology in supply chain management," *Future Internet*, vol. 11, no. 7, p. 161, Jul. 2019.
[92] A. Kiayias and G. Panagiotakos, "On trees, chains and fast transactions in the blockchain," in *Proc. Int. Conf. Cryptol. Inf. Secur. Latin Amer.* Cham, Switzerland: Springer, 2017, pp. 327–351.
[93] K. Leng, Y. Bi, L. Jing, H.-C. Fu, and I. Van Nieuwenhuyse, "Research on agricultural supply chain system with double chain architecture based on blockchain technology," *Future Gener. Comput. Syst.*, vol. 86, pp. 641–649, Sep. 2018.
[94] H. Hasan, E. AlHadhrami, A. AlDhaheri, K. Salah, and R. Jayaraman, "Smart contract-based approach for efficient shipment management," *Comput. Ind. Eng.*, vol. 136, pp. 149–159, Oct. 2019.
[95] V. Thiruchelvam, A. S. Mughisha, M. Shahpasand, and M. Bamiah, "Blockchain-based technology in the coffee supply chain trade: Case of burundi coffee," *J. Telecommun., Electron. Comput. Eng.*, vol. 10, nos. 3–2, p. 121–125, 2018.
[96] A. Kosba, A. Miller, E. Shi, Z. Wen, and C. Papamanthou, "Hawk: The blockchain model of cryptography and privacy-preserving smart contracts," in *Proc. IEEE Symp. Secur. Privacy (SP)*, May 2016, pp. 839–858.
[97] Q. Lu and X. Xu, "Adaptable blockchain-based systems: A case study for product traceability," *IEEE Softw.*, vol. 34, no. 6, pp. 21–27, Nov. 2017.
[98] M. El Maouchi, O. O. Ersoy, Z. Erkin, Others, M. el Maouchi, O. O. Ersoy, and Z. Erkin, "TRADE: A transparent, decentralized traceability system for the supply chain," in *Proc. 1st ERCIM Blockchain Workshop*, no. 10. Gurugram, India: European Society for Socially Embedded Technologies (EUSSET), 2018, pp. 1–8.
[99] Q. Feng, D. He, S. Zeadally, M. K. Khan, and N. Kumar, "A survey on privacy protection in blockchain system," *J. Netw. Comput. Appl.*, vol. 126, pp. 45–58, Jan. 2019.
[100] E. B. Hamida, K. L. Brousmiche, H. Levard, and E. Thea, "Blockchain for enterprise: Overview, opportunities and challenges," in *Proc. 13th Int. Conf. Wireless Mobile Commun. (ICWMC)*, 2017, pp. 92–133.
[101] K. Biswas, V. Muthukkumarasamy, and W. L. Tan, "Blockchain based wine supply chain traceability system," in *Proc. Future Technol. Conf. (FTC)*, Dec. 2017, pp. 56–62. [Online]. Available: https://www.researchgate.net/publication/321474197
[102] G. Perboli, S. Musso, and M. Rosano, "Blockchain in logistics and supply chain: A lean approach for designing real-world use cases," *IEEE Access*, vol. 6, pp. 62018–62028, 2018.
[103] I.-C. Lin and T.-C. Liao, "A survey of blockchain security issues and challenges," *IJ Netw. Secur.*, vol. 19, no. 5, pp. 653–659, 2017.
[104] J. Yli-Huumo, D. Ko, S. Choi, S. Park, and K. Smolander, "Where is current research on blockchain technology?—A systematic review," *PLoS ONE*, vol. 11, no. 10, Oct. 2016, Art. no. e0163477.
[105] S. F. Papa, "Use of blockchain technology in agribusiness: Transparency and monitoring in agricultural trade," in *Proc. Int. Conf. Manage. Sci. Manage. Innov. (MSMI)*, 2017, pp. 1–3.
[106] T. M. Fernández-Caramés and P. Fraga-Lamas, "A review on the use of blockchain for the Internet of Things," *IEEE Access*, vol. 6, pp. 32979–33001, 2018.
[107] H. F. Atlam, A. Alenezi, M. O. Alassafi, and G. B. Wills, "Blockchain with Internet of Things: Benefits, challenges, and future directions," *Int. J. Intell. Syst. Appl.*, vol. 10, no. 6, pp. 40–48, Jun. 2018.
[108] K. Korpela, J. Hallikas, and T. Dahlberg, "Digital supply chain transformation toward blockchain integration," in *Proc. 50th Hawaii Int. Conf. Syst. Sci.*, Jan. 2017, pp. 1–10.
[109] A. Banafa, "IoT and blockchain convergence: Benefits and challenges," *IEEE Internet Things Newslett.*, Jan. 2017. Accessed: Mar. 15, 2021. [Online]. Available: https://iot.ieee.org/newsletter/january-2017/iot-and-blockchain-convergence-benefits-and-challenges.html
[110] ICT4Ag. (2017). *Perspectives for ICT and Agribusiness in ACP Countries: Start-up Financing, 3D Printing and Blockchain*. [Online]. Available: http://www.fao.org/e-agriculture/events/cta-workshop-perspectives-ict-and-agribusiness-acp-countries-start-financing-3d-printing-and
[111] K. S. Hald and A. Kinra, "How the blockchain enables and constrains supply chain performance," *Int. J. Phys. Distribution Logistics Manage.*, vol. 49, no. 4, pp. 376–397, Jun. 2019.
[112] L. H. White, "The market for cryptocurrencies," *Cato J.*, vol. 35, no. 2, p. 383, 2015.
[113] N. Hackius and M. Petersen, "Blockchain in logistics and supply chain: Trick or treat," in *Proc. Hamburg Int. Conf. Logistics Digitalization Supply Chain Manage. Logistics, Smart Digit. Solutions Ind. 4.0 Environ. (HICL)*, vol. 23, W. Kersten, T. Blecker, and M. C. Ringle, Eds. Berlin, Germany: Epubli GmbH, 2017, pp. 3–18. [Online]. Available: http://hdl.handle.net/10419/209299
[114] P. Verhoeven, F. Sinn, and T. Herden, "Examples from blockchain implementations in logistics and supply chain management: Exploring the mindful use of a new technology," *Logistics*, vol. 2, no. 3, p. 20, Sep. 2018.
[115] A. Dorri, S. S. Kanhere, R. Jurdak, and P. Gauravaram, "Blockchain for IoT security and privacy: The case study of a smart home," in *Proc. IEEE Int. Conf. Pervas. Comput. Commun. Workshops (PerCom Workshops)*, Mar. 2017, pp. 618–623.
[116] T. Burke, "Blockchain in food traceability," in *Food Traceability*. Cham, Switzerland: Springer, 2019, pp. 133–143.
[117] WFP. (2017). *WFP Building Blocks: Blockchain for Zero Hunger*. [Online]. Available: https://innovation.wfp.org/project/building-blocks
[118] J. Thomason, M. Ahmad, P. Bronder, E. Hoyt, S. Pocock, J. Bouteloupe, K. Donaghy, D. Huysman, T. Willenberg, B. Joakim, L. Joseph, D. Martin, and D. Shrier, "Blockchain-powering and empowering the poor in developing countries," in *Transforming Climate Finance Green Investment With Blockchains*. Amsterdam, The Netherlands: Elsevier, 2018, pp. 137–152.
[119] E. Weisbord. (2018). *Demystifying Blockchain for Water Professionals: Part 1*. [Online]. Available: https://iwa-network.org/demystifying-blockchain-for-water-professionals -part-1/

[120] Y. Wang, M. Singgih, J. Wang, and M. Rit, "Making sense of blockchain technology: How will it transform supply chains?" *Int. J. Prod. Econ.*, vol. 211, pp. 221–236, May 2019.
[121] L. E. Cartier, S. H. Ali, and M. S. Krzemnicki, "Blockchain, chain of custody and trace elements: An overview of tracking and traceability opportunities in the gem industry," *J. Gemmology*, vol. 36, no. 3, pp. 212–227, 2018.
[122] S. Ølnes, J. Ubacht, and M. Janssen, "Blockchain in government: Benefits and implications of distributed ledger technology for information sharing," *Government Inf. Quart.*, vol.34, no. 3, pp. 355–364, 2017.
[123] B. K. Mohanta, S. S. Panda, and D. Jena, "An overview of smart contract and use cases in blockchain technology," in *Proc. 9th Int. Conf. Comput., Commun. Netw. Technol. (ICCCNT)*, Jul. 2018, pp. 1–4.
[124] J. Hong, Y. Zhang, and M. Ding, "Sustainable supply chain management practices, supply chain dynamic capabilities, and enterprise performance," *J. Cleaner Prod.*, vol. 172, pp. 3508–3519, Jan. 2018.
[125] S. E. Chang, Y.-C. Chen, and M.-F. Lu, "Supply chain re-engineering using blockchain technology: A case of smart contract based tracking process," *Technol. Forecasting Social Change*, vol. 144, pp. 1–11, Jul. 2019.
[126] D. Bumblauskas, A. Mann, B. Dugan, and J. Rittmer, "A blockchain use case in food distribution: Do you know where your food has been?" *Int. J. Inf. Manage.*, vol. 52, Jun. 2020, Art. no. 102008. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S026840121930461X
[127] P. Kittipanya-Ngam and K. H. Tan, "A framework for food supply chain digitalization: Lessons from thailand," *Prod. Planning Control*, vol. 31, nos. 2–3, pp. 158–172, Feb. 2020.
[128] N. Kshetri, "Can blockchain strengthen the Internet of Things?" *IT Prof.*, vol. 19, no. 4, pp. 68–72, 2017.
[129] S. S. Kamble, A. Gunasekaran, and R. Sharma, "Modeling the blockchain enabled traceability in agriculture supply chain," *Int. J. Inf. Manage.*, vol. 52, Jun. 2020, Art. no. 101967.
[130] D. Mao, F. Wang, Z. Hao, and H. Li, "Credit evaluation system based on blockchain for multiple stakeholders in the food supply chain," *Int. J. Environ. Res. Public Health*, vol. 15, no. 8, p. 1627, Aug. 2018.
[131] P. Loop, "Blockchain: The next evolution of supply chains," *Mater. Handling Logistics*, vol. 71, no. 10, pp. 22–24, 2016.
[132] S. New, "The transparent supply chain," *Harvard Bus. Rev.*, vol. 88, no. 10, pp. 76–82, Oct. 2010.
[133] A. Parmigiani, R. D. Klassen, and M. V. Russo, "Efficiency meets accountability: Performance implications of supply chain configuration, control, and capabilities," *J. Oper. Manage.*, vol. 29, no. 3, pp. 212–223, Mar. 2011.
[134] B. Koteska, E. Karafiloski, and A. Mishev, "Blockchain implementation quality challenges: A literature review," in *Proc. SQAMIA 6th Workshop Softw. Qual., Anal., Monitor., Improvement, Appl.*, 2017, pp. 11–13.
[135] Z. Zheng, S. Xie, H. Dai, X. Chen, and H. Wang, "An overview of blockchain technology: Architecture, consensus, and future trends," in *Proc. IEEE Int. Congr. Big Data (BigData Congr.)*, Jun. 2017, pp. 557–564.
[136] T. Aste, P. Tasca, and T. Di Matteo, "Blockchain technologies: The foreseeable impact on society and industry," *Computer*, vol. 50, no. 9, pp. 18–28, 2017.
[137] X. Xu, I. Weber, M. Staples, L. Zhu, J. Bosch, L. Bass, C. Pautasso, and P. Rimba, "A taxonomy of blockchain-based systems for architecture design," in *Proc. IEEE Int. Conf. Softw. Archit., (ICSA)*, 2017, pp. 243–252.
[138] A. Jindal, G. S. Aujla, and N. Kumar, "SURVIVOR: A blockchain based edge-as-a-service framework for secure energy trading in SDN-enabled vehicle-to-grid environment," *Comput. Netw.*, vol. 153, pp. 36–48, Apr. 2019.
[139] P. K. Sharma, N. Kumar, and J. H. Park, "Blockchain-based distributed framework for automotive industry in a smart city," *IEEE Trans. Ind. Informat.*, vol. 15, no. 7, pp. 4197–4205, Jul. 2019.
[140] I. Eyal, A. E. Gencer, E. G. Sirer, and R. Van Renesse, "Bitcoin-NG: A scalable blockchain protocol," in *Proc. 13th USENIX Symp. Netw. Syst. Design Implement., (NSDI)*, 2016, pp. 45–59.
[141] Coindesk. (2019). *How Will Ethereum Scale*. [Online]. Available: https://www.coindesk.com/learn/ethereum-101/ethereum-mining-works
[142] P. Zheng, Z. Zheng, X. Luo, X. Chen, and X. Liu, "A detailed and real-time performance monitoring framework for blockchain systems," in *Proc. 40th Int. Conf. Softw. Eng., Softw. Eng. Pract.*, May 2018, pp. 134–143.
[143] Z. Zheng, S. Xie, H.-N. Dai, X. Chen, and H. Wang, "Blockchain challenges and opportunities: A survey," *Int. J. Web Grid Services*, vol. 14, no. 4, pp. 352–375, 2018.
[144] D. Puthal, N. Malik, S. P. Mohanty, E. Kougianos, and C. Yang, "The blockchain as a decentralized security framework [future directions]," *IEEE Consum. Electron. Mag.*, vol. 7, no. 2, pp. 18–21, Mar. 2018.
[145] S. Ølnes, "Beyond bitcoin enabling smart government using blockchain technology," in *Proc. Int. Conf. Electron. Government*. Cham, Switzerland: Springer, 2016, pp. 253–264.
[146] M. Conoscenti, A. Vetro, and J. C. De Martin, "Blockchain for the Internet of Things: A systematic literature review," in *Proc. IEEE/ACS 13th Int. Conf. Comput. Syst. Appl. (AICCSA)*, Nov. 2016, pp. 1–6.
[147] M. Alharby and A. van Moorsel, "Blockchain-based smart contracts: A systematic mapping study," 2017, *arXiv:1710.06372*. [Online]. Available: http://arxiv.org/abs/1710.06372
[148] X. Li, P. Jiang, T. Chen, X. Luo, and Q. Wen, "A survey on the security of blockchain systems," *Future Gener. Comput. Syst.*, vol. 107, pp. 841–853, Jun. 2020.
[149] M. A. Khan and K. Salah, "IoT security: Review, blockchain solutions, and open challenges," *Future Gener. Comput. Syst.*, vol. 82, pp. 395–411, May 2018.
[150] S. Figorilli, F. Antonucci, C. Costa, F. Pallottino, L. Raso, M. Castiglione, E. Pinci, D. Del Vecchio, G. Colle, A. Proto, G. Sperandio, and P. Menesatti, "A blockchain implementation prototype for the electronic open source traceability of wood along the whole supply chain," *Sensors*, vol. 18, no. 9, p. 3133, Sep. 2018.
[151] M. Kim, B. Hilton, Z. Burks, and J. Reyes, "Integrating blockchain, smart contract-tokens, and IoT to design a food traceability solution," in *Proc. IEEE 9th Annu. Inf. Technol., Electron. Mobile Commun. Conf. (IEMCON)*, Nov. 2018, pp. 335–340.
[152] K. Rabah, "Convergence of AI, IoT, big data and blockchain: A review," *lake Inst. J.*, vol. 1, no. 1, pp. 1–18, 2018.
[153] A. Maru, D. Berne, J. de Beer, P. G. Ballantyne, V. Pesce, S. Kalyesubula, N. Fourie, C. Addison, A. Collett, and J. Chavez, "Digital and data-driven agriculture: Harnessing the power of data for smallholders," in *Global Forum on Agricultural Research and Innovation*. Rome, Italy: The Global Forum on Agricultural Research and Innovation, 2018.
[154] T. Ometoruwa. (2018). *Blockchain Trilemma: Decentralization, Security & Scalability*. [Online]. Available: https://www.coinbureau.com/analysis/solving-blockchain-trilemma/
[155] Y.-P. Lin, J. Petway, J. Anthony, H. Mukhtar, S.-W. Liao, C.-F. Chou, and Y.-F. Ho, "Blockchain: The evolutionary next step for ICT E-Agriculture," *Environments*, vol. 4, no. 3, p. 50, Jul. 2017.
[156] H. Min, "Blockchain technology for enhancing supply chain resilience," *Bus. Horizons*, vol. 62, no. 1, pp. 35–45, Jan. 2019.
[157] M. Andoni, V. Robu, D. Flynn, S. Abram, D. Geach, D. Jenkins, P. McCallum, and A. Peacock, "Blockchain technology in the energy sector: A systematic review of challenges and opportunities," *Renew. Sustain. Energy Rev.*, vol. 100, pp. 143–174, Feb. 2019.
[158] Soil Association. (2020). *Soil Association Certification*. [Online]. Available: https://www.soilassociation.org/certification/
[159] (2019). *ArbolMarket*. [Online]. Available: https://www.arbolmarket.com
[160] M. Guo, X. J. Liu, and W. Zhang, "Using blockchain technology in human food chain provenance," *WIT Trans. Built Environ.*, vol. 179, pp. 391–396, Aug. 2018.
[161] B. M. A. L. Basnayake and C. Rajapakse, "A blockchain-based decentralized system to ensure the transparency of organic food supply chain," in *Proc. Int. Res. Conf. Smart Comput. Syst. Eng. (SCSE)*, Mar. 2019, pp. 103–107.
[162] D.-H. Shih, K.-C. Lu, Y.-T. Shih, and P.-Y. Shih, "A simulated organic vegetable production and marketing environment by using ethereum," *Electronics*, vol. 8, no. 11, p. 1341, Nov. 2019.
[163] X. Dong, X. Zheng, X. Lu, and X. Lin, "A traceability method based on blockchain and Internet of Things," in *Proc. IEEE Intl Conf Parallel Distrib. Process. With Appl., Big Data Cloud Comput., Sustain. Comput. Commun., Social Comput. Netw. (ISPA/BDCloud/SocialCom/SustainCom)*, Dec. 2019, pp. 1511–1518.
[164] S. Shaikh, M. Butala, R. Butala, and M. Creado, "AgroVita using blockchain," in *Proc. IEEE 5th Int. Conf. Converg. Technol. (I2CT)*, Mar. 2019, pp. 1–5.
[165] G. Tradigo, P. Vizza, P. Veltri, and P. H. Guzzi, "An information system to track data and processes for food quality and bacterial pathologies prevention," in *Proc. CEUR Workshop*, vol. 2400, 2019, pp. 1–10.

[166] Y. P. Tsang, K. L. Choy, C. H. Wu, G. T. S. Ho, and H. Y. Lam, "Blockchain-driven IoT for food traceability with an integrated consensus mechanism," *IEEE Access*, vol. 7, pp. 129000–129017, 2019.

[167] A. C. An, P. T. X. Diem, L. T. T. Lan, T. Van Toi, and L. D. Q. Binh, "Building a product origins tracking system based on blockchain and PoA consensus protocol," in *Proc. Int. Conf. Adv. Comput. Appl. (ACOMP)*, Nov. 2019, pp. 27–33.

[168] T. Surasak, N. Wattanavichean, C. Preuksakarn, and S. C. H. Huang, "Thai agriculture products traceability system using blockchain and Internet of Things," *Int. J. Adv. Comput. Sci. Appl.*, vol. 10, no. 9, pp. 578–583, 2019.

[169] R. Guido, G. Mirabelli, E. Palermo, and V. Solina, "A framework for food traceability: Case study-Italian extra-virgin olive oil supply Chain," *Int. J. Ind. Eng. Manage.*, vol. 11, no. 1, pp. 50–60, Mar. 2020.

[170] X. Zhang, P. Sun, J. Xu, X. Wang, J. Yu, Z. Zhao, and Y. Dong, "Blockchain-based safety management system for the grain supply chain," *IEEE Access*, vol. 8, pp. 36398–36410, 2020.

[171] S. Peets, C. P. Gasparin, D. W. K. Blackburn, and R. J. Godwin, "RFID tags for identifying and verifying agrochemicals in food traceability systems," *Precis. Agricult.*, vol. 10, no. 5, pp. 382–394, Oct. 2009.

[172] S. A. Ali and A. H. Bahnasawy, "Decision support system for technical management of food processing industries," in *Proc. Int. Conf. Internet Comput. Inf. Services*, Sep. 2011, pp. 20–24.

[173] W. Sutopo, M. Hisjam, and Yuniaristanto, "Developing an Agri-food supply chain application for determining the priority of CSR program to empower farmers as a qualified supplier of modern retailer," in *Proc. World Congr. Eng. Comput. Sci.*, vol. 2, 2013, pp. 1180–1184.

[174] R. Ismail and I. Ismail, "Development of graphical user interface (GUI) for livestock management system," in *Proc. IEEE 4th Control Syst. Graduate Res. Colloq.*, Aug. 2013, pp. 43–47.

[175] M. G. Palacio, L. G. Palacio, J. J. Q. Montealegre, H. J. O. Pabon, M. A. L. Del Risco, D. Roldan, S. Salgarriaga, P. Vasquez, S. Hernandez, and C. Martinez, "A novel ubiquitous system to monitor medicinal cold chains in transportation," in *Iberian Conf. Inf. Syst. Technol., (CISTI)*, Jun. 2017, pp. 1–6.

[176] M. Bohanec, B. M. Boshkoska, T. W. Prins, and E. J. Kok, "SIGMO: A decision support system for identification of genetically modified food or feed products," *Food Control*, vol. 71, pp. 168–177, Jan. 2017.

[177] F. Idrees, A. Batool, and J. Qadir, "Weather forecast information dissemination design for low-literate farmers: An exploratory study," in *Proc. ACM Int. Conf. Proc. Ser.*, 2017, pp. 1–5.

[178] C. Zoellner, M. A. Al-Mamun, Y. Grohn, P. Jackson, and R. Worobo, "Postharvest supply chain with microbial travelers: A farm-to-retail microbial simulation and visualization framework," *Appl. Environ. Microbiol.*, vol. 84, no. 17, Jun. 2018.

[179] E. A. Lagarda-Leyva, A. Bueno-Solano, H. P. Vea-Valdez, and D. O. Machado, "Dynamic model and graphical user interface: A solution for the distribution process of regional products," *Appl. Sci.*, vol. 10, no. 13, p. 4481, Jun. 2020.

[180] J. Oliveira, P. M. Faria, and A. M. R. da Cruz, "User experience in kiosk application for traceability of fishery products," in *HCI International 2020—Late Breaking Papers: User Experience Design and Case Studies* (Lecture Notes in Computer Science), vol. 12423. Cham, Switzerland: Springer, 2020, pp. 740–751.

[181] S. Violino, F. Pallottino, G. Sperandio, S. Figorilli, F. Antonucci, V. Ioannoni, D. Fappiano, and C. Costa, "Are the innovative electronic labels for extra virgin olive oil sustainable, traceable, and accepted by consumers," *Foods*, vol. 8, no. 11, p. 529, 2019.

[182] J. Cabinakova, N. K. Ostern, and J. Krönung, "Understanding preprototype user acceptance of centralised and decentralised identity management systems," in *Proc. 27th Eur. Conf. Inf. Syst. Inf. Syst. Sharing Soc., (ECIS)*, 2020, pp. 1–18.

[183] M. J. J. Gul, A. Paul, A. Ahmad, M. Khan, and G. Jeon, "Smart contract's interface for user centric business model in blockchain," in *Proc. 34th ACM/SIGAPP Symp. Appl. Comput.*, Apr. 2019, pp. 709–713, doi: 10.1145/3297280.3297347.

[184] E. Kafeza, S. J. Ali, I. Kafeza, and H. Alkatheeri, "Legal smart contracts in Ethereum block chain: Linking the dots," in *Proc. IEEE 36th Int. Conf. Data Eng. Workshops, (ICDEW)*, Apr. 2020, pp. 18–25.

[185] B. Nissen, L. Pschetz, D. Murray-Rust, H. Mehrpouya, S. Oosthuizen, and C. Speed, in *GeoCoin: Supporting ideation Collaborative Design With Smart Contracts*. New York, NY, USA: Association for Computing Machinery, Apr. 2018, pp. 1–10, doi: 10.1145/3173574.3173737.

[186] M. Themistocleous, K. Christodoulou, E. Iosif, S. Louca, and D. Tseas, "Blockchain in academia: Where do we stand and where do we go?" in *Proc. 53rd Hawaii Int. Conf. Syst. Sci.*, 2020, pp. 1–10.

[187] A. Iftekhar, X. Cui, M. Hassan, and W. Afzal, "Application of blockchain and Internet of Things to ensure tamper-proof data availability for food safety," *J. Food Qual.*, vol. 2020, pp. 1–14, May 2020.

[188] M. A. Teruel and J. Trujillo, "Easing DApp interaction for non-blockchain users from a conceptual modelling approach," *Appl. Sci.*, vol. 10, no. 12, p. 4280, Jun. 2020.

[189] M. A. Rahman, K. Abualsaud, S. Barnes, M. Rashid, and S. M. Abdullah, "A natural user interface and blockchain-based in-home smart health monitoring system," in *Proc. IEEE Int. Conf. Informat., IoT, Enabling Technol. (ICIoT)*, Feb. 2020, pp. 262–266.

[190] A. Seitz, D. Henze, D. Miehle, B. Bruegge, J. Nickles, and M. Sauer, "Fog computing as enabler for blockchain-based IIoT app marketplaces—A case study," in *Proc. 5th Int. Conf. Internet Things: Syst., Manage. Secur., (IoTSMS)*, Oct. 2018, pp. 182–188.

[191] J. Nielsen, *Usability Engineering*. San Mateo, CA, USA: Morgan Kaufmann, 1994.

[192] B. A. Myers, "The importance of percent-done progress indicators for computer-human interfaces," *ACM SIGCHI Bull.*, vol. 16, no. 4, pp. 11–17, Apr. 1985.

[193] T. Grossman, G. Fitzmaurice, and R. Attar, "A survey of software learnability: Metrics, methodologies and guidelines," in *Proc. 27th Int. Conf. Hum. Factors Comput. Syst. (CHI)*, 2009, pp. 649–658.

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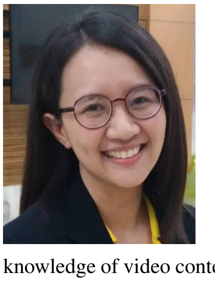

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