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Distributed Ledger Technologies for Smart Digital Economies

Welcome to the June issue of the Technology Innovation Management Review. We invite your comments on the articles in this issue as well as suggestions for future article topics and issue themes.

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The Technology Innovation Management Review (TIM Review) provides insights about the issues and emerging trends relevant to launching and growing technology businesses. The TIM Review focuses on the theories, strategies, and tools that help small and large technology companies succeed.

Our readers are looking for practical ideas they can apply within their own organizations. The TIM Review brings together diverse viewpoints —from academics, entrepreneurs, companies of all sizes, the public sector, the community sector, and others —to bridge the gap between theory and practice. In particular, we focus on the topics of technology and global entrepreneurship in small and large companies.

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Editorial: Distributed Ledger Technologies for Smart Digital Economies

Guest Editors: Steven Muegge & Gregory Sandstrom

Welcome to the June issue of the Technology Innovation Management Review. This edition returns to explore the topic of blockchain (distributed ledger) technology, which the TIM Review began publishing about in the October 2017 edition.

The reasons for focusing on the combination of "DLTs for smart digital economies" in this edition are multiple. The World Economic Forum in 2015, predicted that "10% of global gross domestic product (GDP) [would be] stored on blockchain technology" by 2027 (WEF, 2015). A 2019 Gartner industry report predicted that blockchain industry will deliver business value that reaches over $3.8 trillion CAD by 2030. Likewise, job growth in the DLT sector is expected to increase significantly in the coming years, including business, finance, legal, and management, beyond only computer science and software engineering positions. A 2020 Price Waterhouse Cooper industry report predicted that "blockchain technology could enhance around 40 million jobs globally by 2030" (PwC, 2020). Where these predictions meet with actual market-sized realities, since the previous TIM Review edition on blockchain, from October 31, 2017 to July 1, 2021, the total market cap of "cryptocurrencies" grew from $255 billion CAD to over $1.73 trillion CAD, at hour of publication. In the research arena, with scholarship picking up at universities and independent thinks tanks, publications about blockchain technology have increased significantly. Research output in the healthcare field alone between 2016 and 2021 had a huge compound annual growth rate of 254.4% (Hau & Chang, 2021).

"Blockchain", and the distributed ledger systems behind it, is nevertheless still a concept poorly understood, both in theory and in practise. Many people who are not early adopters of blockchain thinking, or "edge users" of volatile and sometimes risky cryptocurrencies, are unable to give a basic direct answer demonstrating that they have knowledge or awareness about current distributed ledger systems in action, that is, real world use cases. Blockchain thus currently seems to be one of the now popular "unknown knowns" for many people, while the distributed ledger industry nevertheless picks up steam, while a public relations problem holds its adoption back from being palatable for many mainstream users.

This special edition attempts to face this communications challenge, which ultimately expands into a broader conversation than "just blockchain" in attempting to better understand the digitalization path we are currently on. One way that blockchain has been defined is as "a peer-to-peer, distributed ledger that is cryptographically-secure, append-only, immutable (extremely hard to change), and updateable only via consensus or agreement among peers (power of decentralization)" (Bashir, 2018). Yet while informative on a technical level, this type of definition sounds like too much jargon for most people; academics, entrepreneurs, and businesspersons are no different in this regard. The default withdrawal from too much jargon tends to be: "blockchain —so what?" "What's the big deal about distributed ledgers - isn't it just a slow dynamic database?" Or simply, "It's interesting, but come back to me when the technology is more mature". A general lack of recognition thus remains across a range of likely users, involving what this technology is, what it does, and what it will require of us, both in theory and practise, including the impact it seems set to make on society in the near coming years.

Unless more awareness raising happens through education and research dissemination, it remains among blockchain's greatest current problems: a major social breakthrough that would "put blockchain on the map" with the ubiquity of the internet, has not yet happened on the global scale. That is, aside from the rise of "cryptocurrencies" starting in 2009 with Bitcoin, up to the more recent rise of central bank digital currencies (CBDCs), starting in 2018, most recently with the Chinese digital renminbi (e-yuan, e-CNY, 2021), as a digital currency electronic payment, and the government of El Salvador (2021) now accepting Bitcoin as legal tender. In another example of turning a new page, the government of Nigeria, which not long ago issued a moratorium on "crypto" in financial institutions, recently announced it is now exploring and potentially considering a future CBDC, while also preparing to put in place a national blockchain adoption strategy for the country (Nigerian Federal Ministry of Digital Communications and Digital Economy, 2020).

Considering these developments in the digital transformation of societies and economies around the world, this special issue additionally addresses the concept of "smart", and the process of "smartification"

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involving the use of DLTs. This is meant in the context of how we see the term "smart" paired with others on the topic of digital transformation: contracts, devices, labelling, technologies, storage, cities, and machines. From that, the issue presents a series of lessons through the articles that follow on how building DLT-based solutions is becoming part of a process that creates "smarter" digital economies.

The issue opens with **Mika Westerlund, Soham Nene, Seppo Leminen,** and **Mervi Rajahonka**'s research article, "An Exploration of Blockchain-based Traceability in Food Supply Chains", with a survey of contemporary uses cases. Their aim is to identify "the benefits of distributed digital records from farm to fork". The paper's findings suggest that blockchain-based traceability in food supply chains "can provide cost savings, reduced response time to food scandals and food-borne illness outbreaks, improved security and accuracy, better compliance with government regulations, and thus increase consumer trust" (pg. 6). They acknowledge that research on blockchain in supply chains is still emerging and that there is a "growing need for more scholarly studies on the topic" (pg. 13). With Mika Westerlund set as the incoming Editor-in-Chief of the TIM Review, perhaps this article and general edition on DLTs for smart digital economies will serve as a springboard for more of that to come in future editions of the journal.

In the next paper, **Sevda Dede, Mesut Can Köseoğlu,** and **H. Funda Yercan** continue the exploration of blockchains in supply chains. They provide an overview for "Learning from Early Adopters of Blockchain Technology", in making "a systematic review of supply chain case studies". The article starts by looking generally at use cases driving adoption of blockchain in terms of its potential impact on GDP. It then turns specifically to focus on blockchain adoption in supply chains, through an analysis of articles in the Web of Science Core Collection. The paper explores the rationale behind adopting DLTs for supply chains, including the pros and cons, benefits and challenges. The authors note the suitability of blockchain features to the "complex network structure comprising of multiple stakeholders, eliminating intermediaries and paperwork, and increasing transparency, traceability, and efficiency" (pg. 26). For these reasons, blockchain makes immediate sense when hearing how it is being applied and adopted for supply chain uses cases. The addition of a brief use case discussion of the global Trade Lens, dealing with traceability or provenance, adds value for understanding how a network effect can be achieved globally with a mutually agreeable consensus use case.

Turning from supply chains, while maintaining the focus on distributed and decentralized systems thinking and market solutions, **Michel Legault** presents "A Practitioner's View on Distributed Storage Systems: Overview, Challenges and Potential Solutions". The paper identifies how distributed storage is being applied in the "information lifecycle" involving the retention and disposition of business records, in the face of legal and regulatory requirements. It compares five current distributed storage solutions, according to features of the information lifecycle, regarding the creation/modification, classification, storage, retrieval/use, retention, and disposition of data. The paper provides advice on managing content involved in data transactions with respect to personally identifiable information (PII), which the author recommends should be stored "off-chain" for safety and security purposes.

To provide context or the special edition on DLTs and smart digital economies, the TIM Review Managing Editor, **Gregory Sandstrom** draws on a key trio of concepts in "Distributed Ledger Technologies and Social Machines". A basic question frames the background to the paper: "How to 'smartify' the economy with blockchain-based digital extension services?" The paper presents a broad approach to "distributed ledger" thinking by invoking the notion of "distributed ledger communities", as crucially involved in creating a DLT scaleup strategy that aims to achieve a network effect that is humanizing rather than mechanizing. By conceptualizing DLCs as "social machines", the paper expands the topic initially explored by Tim Berners-Lee and Mark Fischetti in their work Weaving the Web (1999). By connecting this conceptualization with the notion of "digital extension services", the paper aims to move ahead the now global humanitarian and educational tradition of "extension services", which formed the basis of both the "Green Revolution" of the 1950s and 60s, and the university and agricultural extension movements of the 1860s and 70s in the UK and USA. The paper in this way feeds into discussions and planning around the world on the topic of digital transformation and DLTs that aim to "smartify" a variety of sectors, leading to

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economic development.

The issue closes with a report from **Victoria L. Lemieux, Atefeh Mashatan, Rei Safavi-Naini,** and **Jeremy Clark**, that provides a summary of insights from the top distributed ledger-oriented conference in Canada, the recently held Blockchain Technology Symposium (BTS'21). The report reveals "A Cross-Pollination of ideas about Distributed Ledger Technological Innovation through a Multidisciplinary and Multisectoral lens". Having invited a variety of contributions to be shared in a kind of "laboratory" environment, the report draws on the four main themes of this year's event: (1) decentralized finance (DeFi), (2) decentralized identity, (3) decentralized health and (4) decentralized supply chain management. On the topic of DeFi, presentations were delivered on the current state of central bank digital currencies (CBDCs), as well as the design of a digital Canadian Loonie (dollar denomination). The decentralized identity presentations addressed the push for creating a "self-sovereign identity", several of which noted that the COVID-19 pandemic has accelerated the attitudes of Canadians towards greater readiness to adopt a secure, trusted, and privacy-enhancing "digital ID" (DID). The DID topic continued in the session on decentralized health, with additional focus on accuracy and fairness in representing and accessing individuals' health data records, including permissioned access for caregivers, and those involved in guardianship of patients in need of additional care and coordinated attention. Regarding decentralized supply chain management, event speakers promoted incentive-driven participation, as well as resilience in supply chains through decentralization. One use case example of mining and minerals management involved efficiency, coordination, and provenance, in ways that hold promise also for "green" or "fair trade". The papers in the current TIMR edition by both Legault and Sandstrom were presented for the first time at BTS'21. Overall, the report sets the stage for further advances and greater collaboration within and across the Canadian university blockchain community.

For future issues, we invite general submissions of articles on technology entrepreneurship, innovation management, and other topics relevant to launching and scaling technology companies, and for solving practical business problems in emerging domains such as artificial intelligence and blockchain applications in business. Potential contributors could also consult the TIM Review topic model (https://topicmodeling.timreview.ca/#/model) to examine the dominant publication themes so far, which might help with ideas for valuable future contributions. Please contact us with potential article ideas and submissions, or proposals for special issues.

This edition also marks the last in the 2-year tenure of Prof. Stoyan Tanev as Editor-in-Chief of the TIM Review. We wish to thank Prof. Tanev for his service to the journal, in engaging and promoting the international network of scholars and practitioners that the journal serves, published in association with the Technology Innovation Management (TIM) Program at Carleton University, where he continues to serve as a member of the TIM Faculty.

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An Exploration of Blockchain-based Traceability in Food Supply Chains: On the Benefits of Distributed Digital Records from Farm to Fork

Mika Westerlund, Soham Nene, Seppo Leminen, Mervi Rajahonka

"Companies are increasingly taking responsibility for the safety of the food they sell, rather than risk their brand on a large recall."

Andy Kennedy
Co-founder of FoodLogiQ

There are growing internal and external pressures for traceability in food supply chains due to food scandals. Traceability refers to tracking food from the consumer back to the farm and vice versa for quality control and management. However, many traceability solutions have failed to meet the needs of supply chain stakeholders. Blockchain is a novel distributed database technology that could solve some issues of traditional traceability systems, such as cost of adoption and vulnerabilities to hacking and data tampering. This study aims to gain insights on the benefits of applying blockchain technology for traceability in food supply chains through literature review and an investigation of five companies that are experimenting with blockchain-based food traceability. Our findings suggest that, upon implementation and contribution by all supply chain participants, blockchain-based traceability can provide cost-savings, reduced response time to food scandals and food-borne illness outbreaks, improved security and accuracy, better compliance with government regulations, and thus increase consumer trust.

Introduction

In recent years, various food scandals have damaged consumer trust in the food industry across the world (Sarpong, 2014; Garaus & Treiblmaier, 2021). In 2011, China witnessed a massive pork mislabeling scandal along with food fraud, which led to recalling donkey meat products that included fox meat (Kamath, 2018). In 2013, several meat suppliers in Europe replaced lamb and beef with horsemeat, which affected 4.5 million processed products, equaling 1,000 tons of food (Kamath, 2018). In 2017, papayas in the US market were linked to a multi-state outbreak of Salmonella (Kamath, 2018). Meanwhile four million Canadians are affected by domestically acquired foodborne illnesses each year, which resulted from food contamination (Astill et al., 2019).

Both food companies and consumers would benefit from faster response times to food scandals and outbreaks of foodborne illnesses (Aung & Chang, 2014; Astill et al., 2019). Typically, food incidents are slow in being handled due to low transparency and inefficient batch sorting, which leads to an inability to trace food items in the supply chain (Sarpong, 2014; He et al., 2018). Further, the complexity and dynamics of modern food supply chains, along with large distances between supply chain entities, make it an ongoing challenge to ensure food safety and quality (He et al., 2018; Behnke & Jansson, 2020). Hence, traceability has become paramount in global food supply chains because consumers expect higher levels of reliability and safety (Casino et al., 2019; Behnke & Janssen, 2020; Tayal et al., 2021).

"Traceability" refers to the ability to track an item in the supply chain from producer to user, enabled by rapid access to relevant and reliable information (Bhatt et al.,

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2013; Xiong et al., 2020). It helps to ensure food safety and quality, as food is a perishable product and foodborne illnesses can originate from mishandling anywhere in a supply chain (Yon & Woo, 2018). That said, retailers are often inundated with data, while suppliers are reluctant to waste valuable transport time completing checklists and audits (Sarpong, 2014). Hence, automated data gathering and storage might be preferable to human data entry practices, and a distributed system solution with the option of data mining could be a more feasible solution than relying on a single centralized database (Bhatt et al., 2013; Bumblauskas et al., 2020; van Hilten et al., 2020).

As a meta-technology, blockchain allows for improved traceability in food supply chains (Kramer et al., 2021). Being built on a decentralized and distributed database (Vu et al., 2021), blockchain enhances transparency, accountability, trust, and traceability in supply chains (Kim & Laskowski, 2017; Gurtu & Johny, 2019; Behnke & Jansson, 2020). Kshetri (2018) also argues that it contributes to cost, quality, speed, dependability, risk reduction, sustainability, and flexibility goals. Nonetheless, the adoption of blockchain technology in food supply chain management is still in its infancy, thus allowing us only a limited understanding of its potential (Treiblmaier, 2018; Müßigmann et al., 2020; Lim et al., 2021). More research is needed on the benefits and challenges of blockchain-based traceability in food supply chains.

This study aims to provide insights mainly about the benefits of blockchain-based traceability in food supply chains. In so doing, the article first reviews recent literature on blockchain technology and traceability in supply chain management, and then discusses five industry cases on blockchain-based traceability in food supply chains. The insights derived from the cases contribute to our extant body of knowledge on the application of blockchain in the supply chain management field, by outlining how blockchain helps to improve food product traceability. The article concludes with implications for practice and suggestions about potential future research avenues.

Literature Review

The impacts of blockchain on supply chain management

Blockchains use a common shared ledger that records transactions made by users (Mansfield-Devine, 2017; Casado-Vara et al., 2018; Kamilaris et al., 2019). A sequential list of timestamped records gets spread among a network of users whose machines are all running the blockchain protocol, in order to be validated by the nodes (Mansfield-Devine, 2017; Kamilaris et al., 2019; Wang et al., 2019). "Blocks" form a linked chain of hashed information, and each block must refer to the preceding block to be valid (Tapscott & Tapscott, 2017). This distributed approach is more secure than earlier technology allowed because it uses cryptography (Casado-Vara et al., 2018; Chang & Chen, 2020; Wang et al., 2020), and more trustworthy because the structure permanently time-stamps and stores the information in blocks, preventing anyone from altering the ledger (Lemieux, 2016; Ying et al., 2018; Behnke & Janssen, 2020).

Indeed, key characteristics of blockchain-based systems include security, reliability, transparency, and immutability (Wang et al., 2020). In a blockchain system, no central authority controls or maintains the network. Instead, the network is maintained by the participating nodes, while updating information in the database requires the consensus of ledger community participants (Ying et al., 2018; Pournader et al., 2020).

Conversely, when using a centralized database, someone must act as a trusted authority (Mansfield-Devine, 2017). This central authority actor, however, for a variety of reasons, may turn out to have a somewhat or very limited view of an entire supply chain, which thus hinders collaboration, delays information processing, and increases the risk of data corruption, as data flows through intermediaries (Apte & Petrovsky, 2016; Mukri, 2018). Thus, a traditional pre- or non-blockchain system is more vulnerable to corruption, hacking, data leaking, contractual disputes, tampering, and fraud (Azzi et al., 2019; Min, 2019; Chen et al., 2021). This makes blockchains for supply chain management a proverbial "game changer", meaning a foundational technological disruption to both global and local current supply chain systems.

Although the potential of distributed ledger technologies extends beyond cryptocurrencies and peer-to-peer (P2P) payment systems (Iansati & Lakhani, 2017; Grecuccio et al., 2020; Teodorescu & Korchagina, 2021), the expected variety of industrial blockchain applications still remains to be seen (Casino et al., 2019; Bumblauskas et al., 2020; Chang & Chen, 2020). The original blockchain design with Bitcoin was as a "permissionless" system open for anyone to use P2P.

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However, industrial applications tend to use "permissioned" systems that allow authorizing only selected users to join a network and controlling user permissions for safety or necessary business privacy purposes (Behnke & Janssen, 2020). Permissioned blockchain systems in the business-to-business context build on business-technology frameworks like Hyperledger (Behnke & Janssen, 2020), which enable permissioned users to have duplicated transactional records, as well as permission access to monitor the movement and progress of supply chain flows (Chang & Chen, 2020).

The transparency of blockchain systems can help establish the authenticity of transactions (Mansfield-Devine, 2017), while removing intermediaries from the old systems can enable transactions to become faster between supply chain actors (van Hilten et al., 2020). In this vein, distributed ledger technology allows supply chain partners to reduce or eliminate transaction costs. It may also allow them to use untrusted external resources, as easily as they currently use trusted internal resources (Tapscott & Tapscott, 2017). Further, blockchain technology improves supply chain dependability by exerting increased pressure on supply chain partners to be more responsible and accountable for their actions (Kshetri, 2018). As a result, both the improved connectivity among supply chain partners and the increased visibility of information flows can offer consumers more detailed information about the origin of products (Casado-Vara et al., 2018). In food supply chains, knowing the origin of products means improved food safety (Casino et al., 2019).

The importance of traceability in food supply chains

The growing public attention to food quality and safety have led to developing food traceability systems (Dabbene et al., 2014; Chen, 2015; Astill et al., 2019). "Traceability" signifies the ability to track a product and its history through a supply chain from harvest through transport, storage, processing, distribution, and retail (Moe, 1998; Kamilaris et al., 2019). This requires significant information sharing about product history, specification, and location, among a network of others (Kumar et al., 2017). Of note, traceability can be classified according to the direction in which information is recalled in a food chain (Aung & Chang, 2014). Similarly but distinctly, "tracking" refers to the ability to follow-up the downstream path of a product along a supply chain, while "tracing" refers to the ability to determine the origin of a product and its ingredients, using records held upstream in the supply chain (Dabbene et al., 2014; Behnke & Janssen, 2020).

Traceability necessitates the engagement of stakeholders along an entire food supply chain (Dabbene et al., 2014). Since traceability systems can yield huge volumes of data, automated data collection, storage, and accessibility become critical (Chen, 2015). According to Dabbene et al. (2014), such automation uses machine-readable optical labels (QR codes) and radio frequency identification devices (RFID) to enhance the precision and reliability of identifying traced units. Tracing focuses on "batches" (products with the same "best before" date and batch number), "trade units" (boxes of products with the same batch numbers, sent along a supply chain), or "truck units" (pallets of products with different batch numbers, for distribution or storage purposes) (Behnke & Janssen, 2020).

With reliable information, traceability can improve food safety through timely identification of food sources and by providing better information about the causes of potential food contamination (Astill et al., 2019; Lin et al., 2021). Ene (2013) noted that the objectives of food supply chain traceability include: 1) contributing to food safety by enabling the identification of outbreak or hazard sources, managing safety alerts, and withdrawing contaminated or dangerous products; 2) providing reliable information to users by guaranteeing product authenticity, and that certain production practices have been followed; and 3) improving overall product quality and processes by identifying sources of non-compliance, while enhancing product flows and stock management.

According to Opara (2003), six key elements of traceability constitute the food supply chain traceability system:

1. *Product traceability*: physical location of a product at any stage in the supply chain, inventory management, product recall, type of product traceability, and type of food to be traced.

2. *Process traceability*: type and sequence of activities affecting the product (cause, location, time; chemical, physical, environmental, and atmospheric factors), compliance standards and regulations with governmental entities, and collaboration among food supply chain entities.

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3. *Genetic traceability*: genetic product constitution, type and origin of ingredients, information on planting materials (seed, stem cuttings, tuber) to create the original product.

4. *Input traceability*: type and origin of inputs such as fertilizers, chemical sprays, livestock, feed, additives, and chemicals for preservation.

5. *Disease and pest traceability*: involving the epidemiology of pests, bacteria, viruses, and emerging pathogens, which may contaminate food.

6. *Measurement traceability*: measurement standards, length, depth, precision to trace, quality control, and type of traceability.

In general, supply chain partners have both internal and external traceability requirements. Internal traceability includes, for example, sharing logistic data, inventory data, contracts, prices, and organic product certification links, while external traceability refers to, for example, providing food origin information and farmer data to consumers (Yon & Woo, 2018; van Hilten et al., 2020; Xiong et al., 2020). Thus, we see consumers calling for food safety, while farmers wish traceability systems that can aid them in crop management that increases their profits (Xiong et al., 2020; Chen et al., 2021). An increasing need therefore exists to provide traceability from “farm to fork”, whereas the current costs of putting traceability systems into place are a major barrier for most supply chain actors (Aung & Chang, 2014; Casino et al., 2019). That said, if the benefits of food traceability come to be seen as outweighing the costs involved, then blockchain-based systems may indeed be a game-changer in this respect.

Blockchain-based traceability in food supply chains

According to Paliwal et al. (2020), improved traceability is one of the key benefits of applying distributed ledger technology. Other benefits of adopting blockchain-based food traceability involve data interoperability, cost reduction, transparency, auditability, integrity and authenticity, as well as improved data accuracy, data management, and prediction through data analytics in food logistics (Casino et al., 2019; Pournader et al., 2020). Further, blockchain-enabled food traceability allows for improved cybersecurity and reduced food fraud, by using strong cryptography (Wang et al., 2020) and by identifying counterfeiting, dilatation, and adulteration, in support of better food security and safety (Etemadi et al., 2021; Garaus & Treiblmaier, 2021; Tayal et al., 2021).

Within a blockchain system, information is tied to each individual product, creating a digital record that proves its provenance, compliance, authenticity, and quality (Bumblauskas et al., 2020). Blockchain systems not only carry information on each transaction, but also associated metadata (origin, contracts, process steps, environmental variations, microbial records) that can be used to connect items across the entire supply chain (Pearson et al., 2019; Wang et al., 2020). Some of the data are collected via sensor networks tracking location, time, temperature, and humidity levels, and are reported on the blockchain in real-time (Grecuccio et al., 2020). Traceability based on such real-time, reliable, and accurate data can increase accountability in a food supply chain, improve shelf life, help prevent food loss, and increase consumer trust in the brand (Kayikci et al., 2020; Shahbazi & Byun, 2021).

Methodology

We selected five companies that have recently experimented or are experimenting with blockchain-based food traceability as case studies to further investigate the benefits of using blockchain technology for traceability in food supply chains. Chang and Chen (2020) argue that the case study method is a highly informative approach to study blockchains in supply chain management. Our case study data were collected in 2018, and include Walmart, Provenance, Carrefour, Foodchain, and Ripe.io. No specific criteria for choosing the cases were used, besides that they needed to address a blockchain-enabled food supply chain management pilot. Data on the cases were found in scholarly and practitioner literatures on innovation management and food business, and we also used online sources such as industry magazines, blogs, news articles, and corporate websites to collect further information.

We utilized a content analysis method for our data collected from the five cases. We examined and analyzed the case data based on traceability elements that were inferred from the literature review (Opara, 2003). Specifically, we looked for information about how the companies involved in each case applied blockchain applications for solving their food supply chain traceability problems according to common traceability elements. Then, we performed a descriptive analysis, which included creating brief case descriptions, and a table that reflected the context of the blockchain

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experiments and summarized key insights from data. These insights highlight how the case companies applied blockchain technology to solve food supply chain traceability problems, as well as what the perceived or pursued benefits of establishing a blockchain-based traceability system were.

Findings

The following sections provide brief case descriptions to understand the context of each case. Thereafter, we summarize key insights from the cases in a table.

Case 1: Walmart – pork and mango pilots with IBM
In 2016, Walmart launched two pilots using IBM's Hyperledger-based blockchain solution to trace the origin of sliced mangoes sold in North America and pork sold in China. Walmart chose IBM's solution as it was not recreating an existing supply chain, but rather leveraging emerging technologies to enhance supply chain traceability. Walmart had to establish trust through its traceability system due to various recent outbreaks of foodborne illnesses, while the resulting traceability included numerous stages from food production through food consumption. The length, depth, and precision of the food supply chain included farm and slaughterhouse tracking, and store tracking with Walmart's distribution center.

Blockchain technology helped Walmart create greater transparency, veracity, and trust in its food information, so that its supply chain partners could act immediately if a problem arose. Also, they found that cooperation with government entities was crucial. The supply chain entities were able to record, trace, and verify the authenticity and quality of their products throughout the product lifecycle, across multiple different authorities. Audits, identification numbers, and safety-protocols were logged in real-time and stored as e-certificates. Notably, Walmart's blockchain enabled tracing at the item level, not just batch level. This allowed officials to determine the origin of a specific mango in just two seconds. Addressing several vulnerabilities in the food supply chain, Walmart's pilots went beyond technology to gain people's trust and confidence in food.

Case 2: Provenance – tracking tuna on the blockchain
Provenance is a UK-based firm behind a digital platform that enables retailers to bring integrity and transparency to their supply chains. Their goals are to track tuna caught by fishermen with verified and sustainable claims, including traceability and compliance to standards at the origin and along the chain, as well as preventing the "double spend" of product certificates and identification tags. Provenance chose to first understand the key supply chain problems in tuna fishing and then assess the technology opportunities in Indonesia, the largest tuna producing country in Southeast Asia.

Some of the problems were human rights abuses, overfishing, fraud, and illegal, unreported, and unregulated fishing. The firm made use of a hybrid blockchain solution, allowing them to trace the source of tuna in minutes, rather than days or weeks as had been usual previously. In the pilot, fishermen sent SMS messages to register their catch on the Provenance blockchain. Information on the origin and supply chain journey of the fish could be accessed and verified by consumers using their smartphones. In this vein, Provenance could provide a robust proof of compliance to standards by government authorities at the origin and along the entire food supply chain.

Case 3: Carrefour – tracing of chickens, cheese, milk, oranges, and salmon
Carrefour is a European retailer experimenting with food supply chain traceability through blockchain technology. The pilot involved IBM to create a food trust platform aimed at providing better transparency, traceability, and efficiency in food supply chains from farm to fork. Carrefour aimed to track free-range chickens, eggs, cheese, milk, oranges, tomatoes, salmon and ground beef steak, among others, with an objective of implementing a global food traceability standard across all links of its supply chain.

Carrefour's solution is based on Ethereum. It helped them to accurately record events along the supply, processing, packaging, and distribution chain. However, for tomatoes and eggs, they began experimenting with Hyperledger Fabric, because it includes the concept of information "channels", which are equivalent to having multiple separate blockchains at the same time. In other words, the firm can have one channel per product line. Carrefour's perception is that this facilitates the multiplication of different blockchains on a single common core. They consider this as a major enabler of industrializing blockchains.

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Case 4: Foodchain – creating stories from farm to fork
Foodchain S.p.A. is an Italian start-up company with a blockchain-based traceability service. The company strives to use blockchain technology to gain a competitive advantage in food supply chain transparency and traceability. The first phase was identifying and registering raw materials and producers in the blockchain. Thereafter, each food item was recorded on a blockchain using a "smart label", such as a unique QR code. The entire process was monitored, while quality control of the product was tracked in real-time and shareable between all stakeholders of the food supply chain through computer or smartphone.

Given the immutability of data stored on a blockchain ledger, Foodchain S.p.A. believes that it will help food brands to increase trust and loyalty among their customers. In other words, the company's QR codes allow consumers to access the full and immutable story of a food product and learn about all the steps made by the product before landing on their table. Thus, Foodchain enables the monitoring of the entire food supply chain, which aids in improving food quality control and traceability. Their blockchain implementation is private and permissioned, built on Ethereum, but the company has also launched its own public, permissionless blockchain infrastructure called Quadrans.

Case 5: Ripe.io – The internet of tomatoes
Ripe.io is a blockchain start-up company that showcases the value of distributed ledger technology in agriculture by collecting data throughout the entire food supply chain. Its pilot project was called the "Internet of Tomatoes", in which Ripe.io used a blockchain to compile a wealth of data from the farm and apply it to growing better tomatoes. It allowed data to be recorded of every single tomato produced by growers and share that information with the supply chain and consumers using blockchain technology. The objective of Ripe.io was to enable data transparency and traceability from farm to fork, by providing information on an individual tomato, including not only its origin with a farm and producer, but also its sweetness, texture, size, variety, nutritional value, how it was grown, and its ripening record.

For this purpose, Ripe.io collected data from each tomato produced by given growers, and shared the information with restaurant purchasers of tomatoes. Using blockchain technology allowed them to monitor every detail, such as temperature, humidity, and colour, and store the information digitally and securely. Ripe.io is attempting to create a system that can help firms save money through efficiency gains and remove adulterated food quickly and efficiently. Also, blockchain-based traceability allows retailers and authorities to trace and track every item in real time for more accurate monitoring and prediction of shipping and delivery.

Summary of key insights from the cases
Summing up the findings on blockchain-based traceability and its benefits in our five use cases, most value came from cost savings and reduced time for tracing food items through a food supply chain. Due to this, food data were digitally stored on a blockchain, and time to access information about a specific food product only took minutes, compared to weeks in previously-used traditional traceability systems. The new system helped the companies studied in our cases to achieve cost savings, as well as time savings when solving food crises. Table 1 summarizes the key insights gathered from our use cases.

Another key benefit of operating with a shared distributed ledger is automatically achieving compliance with government standards. Prior to having a blockchain-based food traceability system, compliance with government requirements were often challenging due to disparate record-keeping and paper-based documents. Blockchain solved this problem by digitally and securely storing all compliance-based documents, thus eliminating the need for any paper documents. In the case of Walmart, it became easy for all supply chain entities to comply with government standards. Hence, the blockchain system helped firms to achieve better quality control over food, making it possible to trace the product from farm to fork, which in turn helped them to build increased trust with consumers as supply chain operations and management became more transparent.

Some traceability elements, such as product and process traceability appear to be common across the cases studied. For example, case companies attempted to trace individual items and promote enhanced coordination between supply chain entities to achieve better control over the supply chain. That said, only Carrefour covered all six traceability elements in its offering. Specifically, the category of "disease and pest traceability" was not seen consistently across the cases, as only Carrefour put special effort on it. In fact,

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Table 1. Summary of key insights

Case	*Insight 1*	*Insight 2*	*Insight 3*	*Insight 4*	*Insight 5*
Walmart	Hyperledger Fabric and modular architecture provide a robust system for traceability	Blockchain based traceability can solve the major challenge of compliance and documentation	Value of traceability is stronger if it includes non-perishable, perishable, and extra-perishable food products	Top management's commitment is crucial for the adoption of blockchain technology	Time to trace food items is significantly reduced due to the blockchain technology
Provenance	Hybrid blockchain provides a more customized implementation of traceability	Collaboration between all supply chain entities helps to gain more control over the supply chain	Individual fish traceability helps stakeholders to achieve individual item tracking	Blockchain traceability system is integrated downstream	Integration of blockchain with RFID technology helps to achieve the best results
Carrefour	Compliance with government authorities is essential	Quality monitoring is easier with the blockchain-based system	Information about adulterated products can be found easily	Product recall in case of any food crisis is fast and efficient	Both forward and backward traceability are important
Foodchain	Ethereum platform and QR codes help the company with efficient tracing	Certification of farms producing coffee and authentication is necessary	Traceability analysis reports help to improve efficiency over the supply chain	Blockchain-enabled system helps to gain better transparency	Enhanced trust throughout the food supply chain is ensured
Ripe.io	Information to tomato producing farmers is important	Data transparency and traceability from farm to fork is achieved	Real-time analysis and status of tomatoes can be made	Data immutability enables credible details of each tomato's growth	Non-tampering of data can be easily ensured

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Carrefour attempted to predict not only pathogens, but also allergens through the traceability system, which would help in disease and pest traceability. Allergens are not discussed in the previous literature as a traceability element.

The insights from our study also highlight that simply comprehending blockchain technology and how it creates ledger communities for supply chains is important because comprehension is the key to implementing an efficient DLT-based food traceability system. Understanding the advantages (and disadvantages) of public, private and hybrid blockchains helps firms to implement and choose the technology specific to their needs. Except for Foodchain, all firms we studied were leaning to implement a hybrid blockchain solution, due to its flexible modular architecture and enhanced security that includes permissioning. Backend modularity of blockchain systems saves the cost of entirely replacing the existing supply chain, so that the new system can be incorporated on top of and together with the existing supply chain itself. Finally, due to their high data accuracy, companies such as Provenance that traced tuna fish and Ripe.io that traced tomatoes were benefitted far more by blockchain-based traceability systems compared with traditional pre-blockchain systems. Information related to an individual tuna fish or single tomato, rather than merely being faced with information about the whole batch it was in, or having to deal with another unit, was obtained rapidly, making more efficient the tracing of its origin.

Discussion and Conclusion

This article aimed at contributing to the field of supply chain management innovation by investigating the benefits of blockchain-based traceability in food supply chains. While blockchain technology has begun to demonstrate how it can transform industries and enhance business model innovation (Zhao et al., 2016; Tandon et al., 2021), it also constitutes a managerial challenge for incumbents (Beck & Muller-Bloch, 2017). To more fully leverage the potential of blockchain technology, engagement is needed throughout the supply chain. Blockchain-based traceability provides value only if all supply chain partners adopt and actively contribute to it (Gurtu & Johny, 2019). Thus, adoption of blockchain technology may be hindered by various issues involving usage by personnel, technical aspects, education, policies, and local regulatory frameworks (Kamilaris et al., 2019).

Contribution to theory

One of the overall findings of our study was that research involving blockchain-based applications in supply chain management is still emerging. There is a growing need for more scholarly studies on the topic. Also, common practices in blockchain-enabled food traceability systems have often not yet been operationalized, as companies are still experimenting and implementing what they have been learning from individual pilot projects. That said, our results contribute to the widening body of literature on blockchain-based traceability in several ways. In particular, the traceability elements identified by Opara (2003) provided a feasible framework to analyze cases of firms experimenting with blockchain-based traceability in the food supply chain context. However, our findings go further, for example noting the traceability of allergens, which was not discussed in Opara's (2003) framework, likewise recognizing that blockchain enables a more detailed approach to data traceability than was previously possible.

Traceability is important in preventing and responding to food crises such as food contamination. We agree with Dabbene et al. (2014) that blockchain-based solutions can be used effectively for food traceability because of their ability to better address length, depth, and precision in supply chains. Internal traceability attributes such as lot number, pack date, and order number, which have already been used, can now be recorded on a blockchain digitally and dynamically at each stage of the food supply chain. On the other hand, blockchain solves a social problem, in addition to a technical problem (Kamath, 2018). We agree with Azzi et al. (2019), Gurtu and Johny (2019) and Behnke and Janssen (2020) that by adopting blockchain technology, firms can create more reliable, transparent, and secure traceability systems, which contributes to food safety and quality, and thus to consumer trust, provided that all food supply chain entities contribute to the system.

The results also confirm that a hybrid blockchain may provide robustness and cost-savings in traceability due to its modularity benefits (Tapscott & Tapscott, 2017). Such a system will not require replacing or reconstructing the entire supply chain, but rather allows for leveraging already available technology such as QR

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codes (Yoo & Won, 2018). This will bring value to food businesses that do not have to face the unbearable costs of reconstructing their whole supply chain to accommodate a new technology that is supposed to save them time and money. Given the successful implementation of a blockchain-based traceability system, food supply chain entities can rapidly and accurately record, authenticate, and ensure the status of an individual food product, tracking its movement and quality throughout the product lifecycle. We argue that such as system can provide benefits to all stakeholders in a food supply chain, by helping them to produce and gain more detailed data analysis reports.

Implications to practice

This study also provides managers in the food industry with some recommendations. First, blockchain technology is increasingly demonstrating its potential for providing greater transparency, veracity, and trust in food traceability. With it involved, supply chain partners can act immediately if problems such as food scandals appear. We therefore encourage managers in food companies to experiment with blockchain technology as potentially a way to gain competitive advantage, better comply with regulations, and respond to rising consumer concerns surrounding food safety and quality.

Second, building and managing a blockchain-based food traceability system should be done in collaboration with governments to meet international compliance standards and cultivate societal knowledge about food safety. Such a system for any society will attempt to solve the problem of documentation and compliance with local and global regulatory systems involving food supply chains. This can be achieved by recording supply chain-relevant government data such as standards, regulatory guidelines, and corporate registries on a permissioned public blockchain, and comparing them with data and metadata from each supply chain transaction. This would provide secure and trustable compliance for government agencies related to food supply, agriculture, health, infrastructure, natural resources, economy, employment, and others.

Third, experimenting with food-oriented blockchain pilots may result in companies seeking to implement the system more broadly for their food supply chains. While Behnke and Janssen (2020) list scalability as one of technical hindrances for blockchain systems, they also argue that current blockchain-based food traceability pilots indicate that scaling can, and indeed will eventually be reached. We therefore suggest that leveraging blockchain technology can help companies that deal with food to identify vulnerabilities in their current food supply chains. This would allow managers of food businesses to better gain the trust of people in regard to their food products, as those vulnerabilities are reduced or removed through a distributed ledger system. Thus, food brand managers should start building stories about their respective brands that engage all supply chain entities, and which can be supported by real-time information obtained from their food supply chain through a blockchain-based traceability system.

Limitations and future research avenues

Limitations to our study are at least two-fold. First, blockchain-based applications are still emerging in the market. We were only able to explore five cases in a specific area of food traceability involving supply chains. Further, each of those cases is recent or involved still in ongoing experimentations. Thus, this paper provided insights on the early experiences and evidence available at the current time involving blockchains in food supply chains. Thus, future research would benefit from analyzing a larger number of cases and focusing on more mature blockchain-based solutions. In particular, the link between blockchain-based tracing and specific broader social sustainability benefits for food should be examined, as also suggested in other recent studies (Paliwal et al., 2020; Lim et al., 2021; Vu et al., 2021).

Second, our case analyses were based on publicly available data, such as academic and practitioner-oriented articles, reports, news, blogs, and corporate websites. Future research would benefit from first-hand investigation of blockchain-based companies currently conducting food traceability system experiments and risk management practices (see Shahbazi & Byun, 2021), as well as exploring the various perceptions currently held about the benefits of blockchain by supply chain entities at different stages from farm to fork. This could be done either through interviews and surveys of various targeted stakeholders, or through action research by scholars participating in designing solution architecture for blockchain-based traceability systems.

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An Exploration of Blockchain-based Traceability in Food Supply Chains: On the Benefits of Distributed Digital Records from Farm to Fork

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"We are not fit to lead an army on the march unless we are familiar with the face of the country - its mountains and forests, its pitfalls and precipices, its marshes and swamps."

Sun Tzu
The Art of War

Blockchain technology is widely seen as a promising technology for global supply chains, though early adoption of the technology is both costly and risky. Along with many other discouraging factors, large investments required to enter or develop a blockchain raise barriers to entry. Concerns about potential benefits, on the other hand, have led to companies questioning whether it is worth it. Consequently, many players in the global arena are still preferring to wait by observing current practices before making investments, while trying to figure out what the technology might bring them. Hence, the main purpose of this paper is to research various implementations of blockchain technology in supply chains, in order to learn from its early adopters. For this purpose, we chose case studies as the research method, which we used in a systematic way. We focused on multiple relevant case studies from previous research concerning the use of blockchain technology in supply chain practices. Through a systematic analysis of case studies, the paper aims at bringing forward different views, approaches, and results about blockchain adoption, as a way to show the pros and cons of adopting the technology under certain circumstances. The research was obtained from the Web of Science Core Collection. This paper contributes to the literature by showcasing the use of blockchain in supply chains via multiple cases to learn from early blockchain adopters in supply chain practices.

1. Introduction

Blockchain technology is expected to contribute to the global economy in many ways. A recent study by PwC (2020) estimates that blockchain technology has the potential to boost the global GDP by $1.76 (USD) trillion by 2030 through five main areas. The following table summarizes the report's findings from the report (PwC, 2020), showing the top five uses that are driveing blockchain adoption and their estimated economic contributions to the global GDP by 2030.

As the emphasis on provenance (that is, verifying the sources of goods, tracking their movement, and increasing transparency) demonstrates, a key area of blockchain applications is global supply chains. Some reasons that make supply chains a potentially high-gain area for blockchain implementation include their complex network structure with several stakeholders, need for information sharing between the parties, difficulty and risk in transfer of documents, time-consuming processes, and lack of trust between parties. Research shows that the number of blockchain

Table 1. Top five uses driving blockchain adoption and their estimated economic contribution to GDP

Uses driving blockchain adoption	Potential boost to global GDP by 2030
Provenance	$962 bn
Payments and financial instruments	$433 bn
Identity	$224 bn
Contracts and dispute resolution	$73 bn
Customer engagement	$54 bn

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engagements per industry is highest in the supply chain industry, constituting 19% of all distributed ledger technology (DLT) implementations worldwide (HFS Research, 2020). Yet, the number and variety of use cases is still limited, while much potential remains to be realized.

1.1 Purpose and structure of the paper

This study aims to research and evaluate various implementations of blockchain and DLT in supply chains in order to provide insights regarding applications currently trending, while also establishing a viable resource to learn from case studies in the related literature. Conforming with this purpose, the study is designed as a systematic literature review of formerly conducted case studies concerning the use of blockchain technology in supply chain practices.

The study has five main sections. The introductory section specifies the scope and structure of the paper, provides a general overview related to the digital economy, and focuses on blockchain implementation in supply chains, setting forth problems in supply chains that the use of blockchain could solve. The second section describes the research methodology, namely research questions addressed in this study, the search process, inclusion and exclusion criteria for the cases, and data collection and analysis procedures. The third section presents the actual case studies used, while the fourth section details the results associated with each research question, along with limitations of the study. Finally, the conclusion draws an application from the search results and findings, while shedding light on future research possibilities.

1.2 Blockchain Implementations in Supply Chains

As challenges and environmental conditions (that is, complexity, intense competition, pressure on lead times, regulations, etc.) push organizations to find novel solutions, many global enterprises are placing emphasis on understanding how blockcain technology can help improve their supply chain operations to reach strategic objectives. Gradually enabled in global supply chains over the years, blockchain technology has a goal of improving efficiency through digitalization. Benefits from blockchain implementation in supply chains include keeping track of cargoes, enchanced visibility, decreased time spent in customs clearance, reduced risk, cost efficiency, and reduction in paperwork (Aich et al., 2019). According to an analysis by the platform Blockdata, six of the companies on Forbes' "Blockchain 50" list (of the largest global brands with an annual revenue of over $1 billion) developed blockchain use cases directly related to supply chain management (Kshetri, 2021). Among these 50, 15 companies, including IBM, Nestlé, Walmart, and Amazon, have used blockchain technology for traceability/provenance purposes, highly related to supply chain management, with one third of these projects in the pilot phase, and the rest already in use.

The beneficial features of distributed ledger technology have opened up many possiblities for improving supply chains. With high trade volumes and a large number of players, the shipping industry is an important component of supply chains worldwide, providing a number of very good examples of blockchain implementation. Maersk and International Business Machines (IBM), for example, have been collaborating for ecosystem-wide blockchain integration in maritime transportation, starting the "TradeLens" project in 2018. The maritime transportation domain constitutes an information structure, when considered as a domain consisting of many actors scattered in a complex supply chain environment, with direct or indirect collaboration (Stopford, 2009). Mike White, Head of TradeLens at Maersk, stated (2019) that in the shipping industry, data gets trapped in organizational silos, operations are complex and costly, processes are time-consuming, clearance can be subject to delays, and collaboration with stakeholders in the industry's external environment is a necessity. Hence, the TradeLens initiative aims to increase transparency and traceability, while eliminating intermediaries and paperwork required for maritime transportation. The platform was designed with accessibility in mind, providing transparency and traceability to shipowners, brokers, customs, port authorities, and insurance companies by tracking cargo for all users in the private blockchain network, from the first port of call to the last.

According to the 2020 Maersk Sustainability Report (2021), TradeLens integration has increased to over 220 organizations, comprising data from more than ten ocean carriers, and 600 ports and terminals, thus covering almost half the world's ocean container cargo. TradeLens will be utilized for developing countries in automation of sea cargo data in a multi-stakeholder project starting from Sri Lanka and Cambodia (Maersk, 2021).

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2. Research Method

This study was designed as a systematic review of case studies that rigorously reviews several formerly conducted case studies. Through a systematic analysis of these case studies, our study aims at presenting different views, approaches, and results in relation to blockchain implementation in supply chains, thus giving readers a chance to grasp the pros and cons of adopting the technology under certain conditions.

In carrying out the systematic review, this study follows guidelines as proposed by Kitchenham (2004) who described a systematic review as "a means of identifying, evaluating and interpreting all available research relevant to a particular research question, or topic area, or phenoenon of interest". Systematic reviews require a well-defined methodology in order to decrease the probability of being biased in examining the related literature. Further, the methodology should be made transparent to readers through detailed explanation and documentation about the search process (Kitchenham, 2004). To this end, the research questions addressed in this study, search process, inclusion and exclusion criteria for the cases, procedures for data collection, and analysis are explained in detail.

2.1 Research Questions

This study aims to answer the following research questions (RQ):

RQ1: *What blockchain features regarding blockchain implementation in supply chains are addressed in case studies?*

RQ2: *Which sectors are leading case study research on blockchain implementation in supply chains?*

RQ3: *What benefits of adopting blockchain technology are improving supply chain operations and helping to achieve supply chain strategies?*

RQ4: *What are the biggest challenges of adopting blockchain technology in supply chains?*

RQ1 intends to analyse blockchain features that are most utilized and, thus, most emphasized, in supply chain case studies. RQ1 provides insight into the needs of supply chains regarding implementation of blockchain technology in currently utilized systems, while emphasizing where most problems in supply chains occur. In RQ2, the analysis of blockchain adoption from a sectoral perspective shows information on sectors that have most utilized blockchain in their supply chains, as well as those needing more research on blockchain adoption. Finally, RQ3 and RQ4 provide analysis regarding advantages and drawbacks, respectively, of blockchain adoption.

2.2 Search Process

The search process of this study was performed electronically using the Web of Science (WoS) database. The cases were obtained from the WoS Core Collection, starting with a broad search with the terms "blockchain" and "distributed ledger" (or DLT) in the title, along with the terms "case study" and "supply chain" in the abstract [TI=(blockchain OR "distributed ledger" OR DLT) and AB=("case study" AND "supply chain")]. Although this paper considers blockchain technology, the researchers consciously did not limit the search terms to "blockchain". On account of the fact that blockchain is a type of distributed ledger technology (DLT), and that both are commonly used interchangeably, the search terms included "distributed ledger" and "DLT", as well. This approach eliminated the risk of missing out on a relevant work simply because it used the term "distributed ledger" instead of "blockchain". Given that not all distrubuted ledgers are blockchains, but that all blockchains are fundamentally distributed ledgers, the main research subject in this study covers a set of case studies on blockchain applications in supply chains.

Because a number of papers phrased the blockchain concept as "block-chain" or "block chain", the initial database search included the terms "block-chain" and "block chain," along with the most commonly used term, "blockchain". Adding them to the database search, however, did not bring up any further relevant results, and thus, the two less common variations of the keyword "blockchain" (that is, "block-chain" and "block chain") were excluded from the search. To direct the search toward a focus on maritime supply chains, the search terms "shipping" and "maritime" were added to the initial search term, "supply chain".

As a default search parameter, we set the timespan for our research from January 1st, 2017 to April 15th, 2021. The initial search with the aforementioned combinations identified 171 results in total, 125 of which were articles published in journals. The remaining 46 search results consisted of 37 conference papers

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(proceeding books included), and 9 books or chapters in a book. For the second step, any duplicates were identified and removed, after which the abstracts were scanned for relevance, and non-relevant papers were also eliminated. The remaining 63 papers were those included in our systematic analysis of case studies.

2.3 Inclusion and Exclusion Criteria
In order to focus the research on case studies that have dealt with blockchain implementation in supply chains, certain papers were excluded from the initial list of results. The exclusion was carried out according to the following criteria:

- Conjectural case studies (case studies that included hypothetical applications)

- Non-relevant case studies (case studies that did not include a supply chain application)

- Technical case studies (case studies that focused mainly on software, but did not include a supply chain application)

Furthermore, certain inclusion criteria were set as:

- Case studies that included real supply chain systems, but only simulated blockchain implementations

- Mathematical approaches that provided supply chain case studies

3. Results

The following table presents the 63 selected case studies relevant to our systematic literature review, along with a summary of each study.

We assigned each case study an identification number in the table (for example, CS1, CS2). In the year of publication column, “EA” in parentheses denotes the publication as an early access publication. Under the type of publication column, journals are indicated by a “J”, books by a “B”, and conference papers by a “C”.

4. Discussion

This section systematically presents answers to our research questions, discussing what may be learned from the literature on blockchain in supply chains.

4.1 What blockchain features regarding blockchain implementation in supply chains are addressed in case studies?
The systematic review demonstrates that a number of blockchain features are specifically addressed in supply chain case studies. *Traceability* (that is, the ability to track goods), for instance, is addressed in 55 of the 63 case studies reviewed. Traceability, combined with

Table 2. Systematic literature review of case studies

CS ID	Author(s)	Year	Main topic	Type of Publcation	No of Citations
CS1	Alles & Gray	2020	Pharmaceutical	J	7
CS2	Bal & Pawlicka	2021	Retail, Finance	J	-
CS3	Baralla et al.	2021	Food SC	J	6
CS4	Bodkhe et al.	2020 (EA)	Food SC, Cyber security	J	9
CS5	Caldarelli et al.	2020	Food SC	J	9
CS6	Casino et al.	2020 (EA)	Food SC	J	7
CS7	Curbera et al.	2019	Healthcare	J	7
CS8	Danese et al.	2021	Food SC	J	-
CS9	Ethirajan et al.	2020	Manufacturing	J	-
CS10	Fu et al.	2020	Food SC	J	4
CS11	Garrard & Fielke	2020	Food SC	J	7
CS12	Gausdal et al.	2018	Maritime	J	60
CS13	Khatoon et al.	2019	Green operations	J	28
CS14	Kshetri	2018	Shipping, Food SC, Military, Pharmaceutical, Retail, Insurance	J	688

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Table 2. Systematic literature review of case studies (cont'd)

CS15	Kumar et al.	2020 (EA)	Logistics	J	-
CS16	Kumar et al.	2020 (EA)	Logistics	J	4
CS17	Li & Zhou	2020 (EA)	Maritime, Food SC, Logistics, Green Operations	J	2
CS18	Li et al.	2020	Retail	J	14
CS19	Maity et al.	2021	Food SC	J	1
CS20	Orjuela et al.	2021	Food SC	J	-
CS21	Park & Li	2021	Food SC, Maritime	J	-
CS22	Patelli & Mandrioli	2020	Food SC	J	7
CS23	Perez et al.	2020	Textile	J	7
CS24	Philipp	2020	Maritime, Green Opeartions	J	2
CS25	Philipp et al.	2019	Maritime	J	18
CS26	Prause	2019	Logistics, Autonomous Delivery	J	10
CS27	Prause & Boevsky	2019	Small and medium enterprises (SME), Food SC, Autonomous Delivery	J	8
CS28	Rijanto, Arief	2020 (EA)	Food SC	J	-
CS29	Rodriguez-Espindola et al.	2020	Humanitarian	J	13
CS30	Roeck et al.	2020	Diamond, Food SC, Pharmaceutical	J	31
CS31	Rogerson & Parry	2020	Food SC	J	25
CS32	Shemov et al.	2020	Construction	J	1
CS33	Sivula et al.	2021	Construction, Regional Development	J	-
CS34	Sternberg et al.	2021	Food SC	J	17
CS35	Stranieri et al.	2021	Food SC	J	11
CS36	Sund et al.	2020	Retail	J	8
CS37	Tan & Sundarakani	2021	Logistics	J	2
CS38	Toennissen & Teuteberg	2020	Shipping, Food SC, Retail, Pharmaceutical, Diamond	J	78
CS39	Tseng & Shang	2021	Healthcare, Accounting, Food SC, Logistics	J	-
CS40	van Hoek	2020	Retail, Logistics	J	16
CS41	Vishnubhotla et al.	2020	Oil Trade	J	1
CS42	Vivaldini	2021 (EA)	Food SC	J	-
CS43	Wamba et al.	2020	Food SC, Consumer Engagement	J	58
CS44	Wang	2019	Construction	J	5
CS45	Wang et al.	2020	Construction	J	43
CS46	Zhou et al.	2020	Maritime	J	5
CS47	Calle et al.	2019	SME, Finance, Logistics	B	-
CS48	Di Ciccio et al.	2018	Pharmaceutical	B	35
CS49	Potancok et al.	2020	Pharmaceutical	B	-
CS50	Aich et al.	2019	Automotive, Food SC, Retail, Pharmaceutical	C	32
CS51	Casado-Vara et al.	2018	Food SC	C	222
CS52	Cui et al.	2019	Food SC	C	1
CS53	Grest et al.	2019	Pharmaceutical	C	-
CS54	Hafizon et al.	2019	Maritime	C	4
CS55	Haroon et al.	2019	Food SC	C	6

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Table 2. Systematic literature review of case studies (cont'd)

CS56	Kanak et al.	2019	Automative, Inner City Transportation, Cyber Security, Green Opeartions	C	2
CS57	Koirala et al.	2019	Reverse Auction Supply Chain	C	2
CS58	Lam & Lei	2019	Textile, Green Opeartions	C	4
CS59	Miehle et al.	2019	Automotive	C	9
CS60	Pundir et al.	2019	Retail	C	19
CS61	Scheid et al.	2019	Cold Chain Supply Chain	C	12
CS62	Wu et al.	2019	Food SC	C	17
CS63	Yusuf et al.	2019	Food SC	C	5

transparency, increases supply chain visibility, while ensuring product quality and safety, thus contributing to profitability. By accessing data records with time stamps, stakeholders can track transactions in an efficient manner. Similarly, transparency provides stakeholders with the ability to monitor and access data on the chain, as addressed in 53 studies. By providing access to the history of activities, transparency also facilitates validating and auditing distributed ledger elements.

Immutability, which involves disabling the ability to make changes to initial or previous data, is another feature commonly addressed in supply chain case studies. This feature is enabled by cryptographic security in distributed ledgers and is considered as the most expensive aspect of blockchains, since it has technological requirements such as databases, distribution, and hashing to ensure the data does not change.

Security, efficiency, and confidentiality are also among the blockchain features addressed in supply chain case studies. *Security* refers to cybersecurity measures that prevent forced or unintentional data access by unwanted parties. The high level of difficulty in changing data on blockchains is essential regarding supply chain processes. *Efficiency* refers to the reduction in cost, paperwork, and unnecessary intermediaries. Faster data handling, easier accessibility, and the elimination of geographical limitations further boosts efficiency in supply chain processes. *Confidentiality*, meanwhile, refers to maintaining the privacy of users and their data, as well as certain aspects of their transactions. This feature is hard to balance with transparency and traceability for supply chain processes, but in blockchains, stakeholders may prefer a private permissioned blockchain option to limit the monitoring and controlling actions in the blockchain.

Finally, the culmination of all the aforementioned features of blockchain use in supply chains is trust. Trust is established by blockchain's ability to remove untrusted parties while providing information sharing, immutability, visibility, and automation. In conventional companies, stakeholder trust develops through transactions themselves, while in blockchain implemented supply chains, trust is established through blockchain distributed ledger accounting. In an environment lacking trust, blockchains carry the potential to fundamentally improve transactions between parties.

4.2 Which sectors are leading case study research on blockchain implementation in supply chains?

Overall, the case studies regarding blockchain implementation in supply chains are dominated by food supply chains. The number of case studies in food supply chains increased substantially in 2020 and 2021, making up 28 of the total case studies examined. Logistics, pharmaceuticals, and retail (for example, Walmart) industries are the next common areas of investigation, but still far behind food supply chains with 10, 8, and 8 cases, respectively. Finally, automotive, maritime, construction, and green operations are found to be the other significant areas for case studies.

4.3 What are the benefits of adopting blockchain technology that are improving supply chain operations and helping to achieve supply chain strategies?

In the case studies reviewed, the benefits of adopting blockchain technology mostly refer to features. One common advantage mentioned in the case studies is the feature of secure, real-time data handling with monitoring and controlling of data in a virtual environment. Reduced (or eliminated) paperwork in supply chain processes increases efficiency through decreased response times. Similarly, traceability

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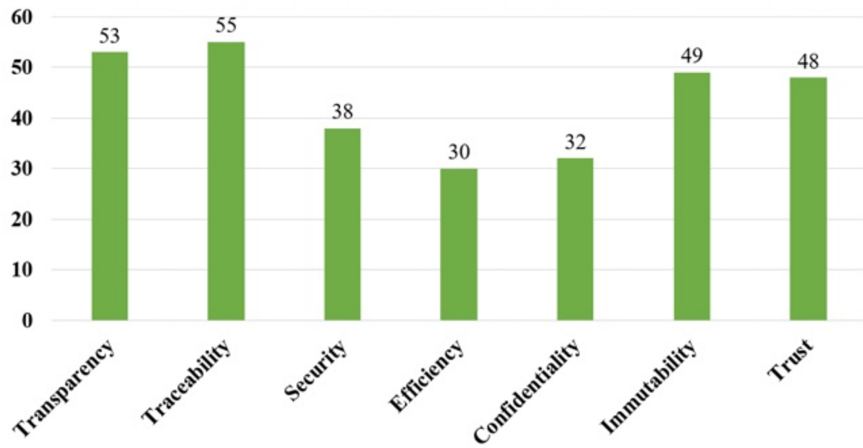

Figure 1. Blockchain features addressed in case studies

increases or goes hand-in-hand with supply chain visibility. Digitalizing the processes also reduces risk of error while removing geographic boundaries and providing easier access from all over the world.

Blockchain technology also enables flexibility in supply chains. Since data is transferred in an automated environment with digital interfaces, instead of through constant physical document exchange with couriers, the data record stored in the blockchain ledger can be available anytime. Data transparency contributes to data accessibility and information sharing among stakeholders, thereby increasing and enabling improved communications. Blockchain systems likewise facilitate interoperability in a way that aims to connect the participants of the ecosystem, while providing secure data exchange and confidentiality through decentralization and data encryption. Since complete transparency may not be desirable for some (or many) transactions in a distributed ledger ecosystem, a private permissioned blockchain option, or cases of semi-transparency for certain parties in a supply chain, may be the appropriate choice.

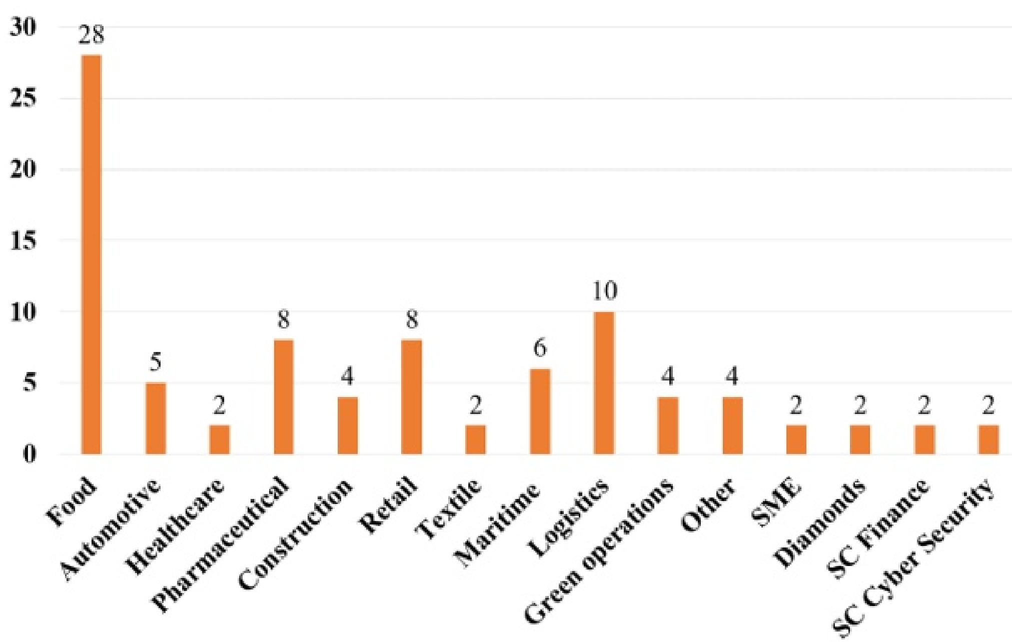

Figure 2. Leading sectors for case studies in the blockchain-supply chain field

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Finally, blockchain technology provides immutability, which prevents counterfeting of documents, and, thus, increasies trust between parties in the supply chain. "Smart contracts" enable more efficient business arrangements by generating automated documentation for use in a supply chain, which are among the most commonly mentioned advantages of blockchain implementation. If records in a supply chain could be immutable and eliminate counterfeting, this would ensure a high level of trust. With need for intermediaries removed, no single company then has control over the entire business process in an ecosystem, thus eliminating issues like disclosure and accountability, while being cost effective.

4.4 What are the biggest challenges to adopting blockchain technology in supply chains?

The most common challenge emphasized in the case studies is the uncertain regulatory environment. Uncertain and divergent laws and regulations negatively impact the efficiency and effectiveness of international trade applications, as organizations have the tendency of being reluctant to adopt blockchain without relevent national or international regulations. This may spread an unhelpful generalization of blockchain systems, causing small and medium enterprises, farmers, and other small scale members of the supply chain to avoid blockchain technology.

A second common challenge is scalability. Although data handling has come a long way and verification durations can be reduced substantially with blockchain accounting, due to complexity of data produced throughout supply chain processes, the amount of time spent data handling and verifying is still not yet acceptable for IoT environments, where timing is crucial. The case studies mention that available DLT systems can be used for small scale operations, whereas it is better with large scale operations for organizations to build their own blockchain system, though this generate additional costs for implementation.

Thirdly, a common challenge is the requirement to technologically and socially understand blockchain systems. With digitally driven global trade, blockchain implementations require considerable network size and speed. Hence, it constitutes a critical problem if only small parts of a supply chain have the required infrastructure, while the rest do not. Simply put, old-fashioned, conservative social mindsets along with lack of current technological understanding for blockchain implementation in supply chains, are challenges which must be faced. Another major challenge refers to one of the main features of blockchain systems, which is transparency. This research shows that complete transparency is not a desirable feature for blockchain implementation in certain sectors. Transperency issues primarily came up under data privacy concerns for pharmaceutical and food supply chains. If blockchain implementation is not successful, disruption in logistics processes creates difficulties with supply chain transparency and traceability. The option of deploying a private permissioned blockchain is an alternative when transparency is a main concern, though it will likely be costly. For implementations that provide their customers direct public access to the blockchain, privacy concerns are more likely to arise.

In addition to these concerns, the risk of cyber attacks appears to be another major challenge for blockchain implementation. Digitalization, while providing many benefits, also opens sectors to cyber crime. Though one of blockchain's main features is security provided by the distributed network structure, the relevant studies deem extra countermeasures necessary regarding cyber attacks.

Finally, adopting blockchain can be a great challenge in itself. While common standards for distributed ledger systems remain elusive, it is unrealistic to think of blockchain as a "one-size-fits-all" type of technology. It is difficult to create a supply chain where all parties, small and big, are users of a blockchain ledger, without a standardized environment, along with sound regulatory, technological, privacy, and scalability strategies. All these unsolved challenges have led people who use and operate supply chains to be reluctant to invest in blockchain technology, which, for certain sectors, is still considered risky.

5. Conclusion

Global supply chains are a key area for applying blockchain distributed ledger technology. The reasons why supply chains are a potentially high-gain area for blockchain implementation include its complex network structure comprising of multiple stakeholders, eliminating intermediaries and paperwork, and increasing transparency, traceability, and efficiency.

The earliest blockchain-supply chain case studies found in the WoS database are from 2018, while the majority of

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studies were published in 2020. While this small time window offers a perspective on trends in these case studies, it also limits the possible scope of the study.

Overall the case studies regarding blockchain implementation in supply chains are dominated by food supply chain cases. Most of the food supply chain case studies sought traceability, efficiency, and transparency enabled by blockchain, as a way to increase efficiency in the supply process while improving cost effectiveness. This tendency was mirrored in case studies of retail, pharmaceuticals, general logistic processes, automotive, maritime, construction, and green operations. In the case studies reviewed, the most commonly mentioned supply chain beneficial features of blockchain were traceability and transparency, while immutability and trust also displayed importantly in the literature.

Benefits of blockchain implementation in supply chains from the case studies mostly refer to the features of distributed ledger systems. The main benefits of using blockchain in supply chains include real time data handling with monitoring and controlling of data in a virtual environment, less paperwork, increased efficiency with faster response time, increased supply chain visibility, and reduced geographic limitations. Blockchains also gain advantage from flexibility, as data transparency provides data accessibility and information sharing among the participants of the ecosystem, increasing communication potential. Interoperability, which connects all network users in a secure environment, increases efficiency and transparency. The immutability feature of blockchain increases trust by preventing counterfeiting, while also eliminating intermediaries, increasing efficiency, improving supply chain operations, and helping achieve supply chain strategies.

Blockchain, however, comes with its own challenges, including the current uncertain regulatory environment, scalability complexities, adequate technological understanding and requirements, issues involving transparency and privacy, as well as cyber threats. Diverse laws and regulations prevent the efficiency of international trade applications, and cause reluctancy to adopt blockchain supply chain solutions. For data handling in small scale operations, available DLT systems can be used, while for large scale operations it is better for organizations to build their own blockchain system, although that generates additional implementation costs. Conservative decision-making processes can make it difficult for an organization to accept technological developments, thus diminishing the impact of blockchain features if not preventing the organization from adoption. Transperency issues have been mentioned involving data privacy concerns, with complete transparency not a desirable feature for blockchain implementations in certain sectors. With a lack of common standards, it is unrealistic to think of blockchain as a "one-size-fits-all" type of technology. Finally, while blockchain digitally speeds up supply chains, it also opens them to the threat of cyber attacks.

Our paper contributes to the literature by showcasing the use of blockchain in supply chains via multiple case studies, by learning from early adopters of blockchain technology in supply chain practices, and by providing information regarding the main expectations supply chain stakeholders bring when considering blockchain implementation for their processes. Though our aim in analyzing multiple case studies for this research was to enable a wider range of analysis and minimize researcher bias, the study still had a number of limitations. These include having analyzed the benefits and challenges captured from cases in specific supply chain domains in a way so as to provide only generalized results, as well as conducting the electronic search only in the Web of Science database.

To conclude, this study was essentially a review of case studies, revolving around a number of research questions that were asked of each case study. Therefore, our learning aim from early adopters was limited to the main trends in blockchain adoption and reasons for organizations to get involved. Building on this, further research should be conducted to understand what the various features of blockchain really mean for organizations and how they function in real life. Traceability, for example, could be a good topical starting point to focus on developing a further understanding of how global supply chains increase traceability using blockchain. An additional research paper might still review several cases, but this time looking at the details of each case for the predefined blockchain feature. A similar approach could be used to examine blockchain implementation in certain sectors. In this manner, focusing on how global food supply chains solve the problem of provenance through blockchain technology, or how global supply chains are increasing the efficiency of their operations through the use of blockchain, could help spread the knowledge gained at global-enterprise level to local players. Better

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understanding "how" blockchain technology contributes to solving certain business problems at this early stage might also require qualitative in-depth interviews.

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A Practitioner's View on Distributed Storage Systems: Overview, Challenges and Potential Solutions

Michel Legault

"Filecoin is a decentralized storage market - think of it like Airbnb for cloud storage - where anybody with extra hard drive space can sell it on the network."

Juan Benet,
Founder/CEO of Protocol Labs and creator of IPFS

This paper provides an overview on how content can be managed with a blockchain or other distributed ledger technology (DLT), and what challenges need to be addressed in managing this content as part of transactions. Transactions on a blockchain may require supporting documents, for example, photos, reference documents, or actual contracts. As DLTs becoming an increasingly popular method to complete transactions and share information, several issues are arising that need to be addressed, such as: Where should this electronic content in documents be stored? Will the storage system have the features and functionality to properly manage this content through the "information lifecycle", including the retention and disposition of business records based on legal and regulatory requirements? The paper presents an overview of the emerging technology involved with distributed storage systems. It presents five solutions currently available, including their designs, how they secure and store files, and whether or not these files can be deleted in order to meet record disposition requirements and regulations. The discussion points out the need for alignment between multiple stakeholders and consortium members in a distributed ledger-based community with shared ecosystem scaling objectives. The challenges of scaling include the need to protect personal and sensitive information, especially when this information should normally be disposed after a record's retention period has ended.

Introduction

The technology now called "blockchain" was originally conceived in Bitcoin as a decentralized e-commerce alternative to "financial institutions serving as trusted third parties to process electronic payments" (Satoshi Nakmoto, 2008). Blockchain was meant to usher in a "trust-less" model, where mechanisms (such as cryptographic proof) could enable all parties in a distributed ledger system to reach a consensus on what the authentic data record was. In addition, the Bitcoin blockchain was meant to allow for completely non-reversible transactions.

Since 2017, Bitcoin and other alternative cryptocurrencies (known as "alt-coins") have seen tremendous growth in their popularity, now with a worldwide audience driving explosive growth in actual monetary value. Bitcoin and other cryptocurrencies have come to be seen increasingly as potential hedges against the risk of inflation and hyper-inflation (see El Salvador making Bitcoin legal tender, 2021). This is happening as fiat currencies reserves have been increased to meet economic challenges from the COVID-19 pandemic and socio-economic lockdowns.

Nevertheless, it is important to note that blockchain systems make it challenging to fully adhere to the "information lifecycle", which refers to the stages information goes through as it is managed by users, including:

- Creation/Modification
- Classification (adding metadata, identifying user access restrictions)
- Storage

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- Retrieval/Use (through search or navigation)
- Retention and Disposition

Information, content, and data are created on blockchains. This information is also classified using the hash function, and stored directly on the blockchain of a ledger community. Information on a shared blockchain ledger is always retrievable, since users can review the details of each transaction on a public blockchain.

The paper summarizes the author's experience and professional engagement with the domain of distributed storage systems. It describes some of the challenges with storing content on blockchains, what potential solutions exist, and how distributed storage systems are part of these solutions. This paper also describes and compares a selected set of distributed storage systems currently available in the public domain, presenting the research results involving their features and approaches to immutable content.

Challenges with Storing Content on Blockchains and DLTs

The main challenge of storing content on blockchains and DLTs presents itself most transparently in the final stage of information retention and disposition. Retention of content or data is not an issue on blockchains and DLTs since this content/data is automatically immutable (that is, cannot be deleted). However, as part of the information lifecycle, a subset of content or data objects are declared as records because they are identified as containing business information that must be retained per legal and/or regulatory requirements that govern that industry or economic sector. The retention periods for records, however, usually have an end date when these records must be disposed of, unless a business record must be retained permanently based on legal and regulatory comments.

The immutability of blockchains make it challenging to destroy distributed on-chain records (Lemieux et al., 2019). Additionally, several technical capabilities that are commonly relied upon in defensible disposition plans are not yet available as part of blockchain systems (Lemieux et al., 2019). These include automated record management and classification, suspension of automated deletion, technology-assisted review (TAR), and content search of records for diligence purposes.

In addition, embedding information on blockchains has given rise to concerns about the use of blockchain recordkeeping in relation to compliance with the European Union's (EU) General Data Protection Regulations (GDPR) (Lemieux et al., 2019). Although blockchain technology enables openness and transparency in public ledgers, at the same time information recorded on-chain is permanently stored. This is the case even if a user deletes their profile, which can contain "personally identifiable information" (PII) (Hofman et al., 2019). As a result, the immutability of data stored on blockchains may conflict with EU GDPR requirements relating to the destruction of information no longer needed to meet the needs for which it was gathered in the first place. In short, blockchain technology is caught in a quandary of how to meet current data privacy rules relating to the "right to be forgotten".

Potential Solutions to these Challenges

One approach to addressing the challenge of immutability and proper records retention and disposition is to store more content off-chain than on-chain. This would allow for a more "traditional" approach where this content (including content with PII) can be stored in a document or content management solution that has functionality to enable the storage, tagging, searching, and retrieval of information, as well as the declaration, retention, and disposition of records, and the deletion of non-records (also referred to as "transitory information").

This content would be linked to related blockchain transactions through a unique URL (to this content) in a transaction's hash. There are three advantages with this approach:

- Version control: As additional versions are added, the original information block with the hash/URL will continually point to the latest version of the file, while the version history is updated and managed.
- PII data: This data, by being stored off-chain, can eventually be deleted (depending on the storage network), rather than being immutable on a blockchain where any personal information linked to the transaction could "not be forgotten".
- Records disposition: If a storage network and system allows for the deletion of files (records), then these files can be disposed of based on their retention schedules, rather than remaining as immutable data on a blockchain.

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The Emergence of Distributed Storage Systems

In addition to traditional content management systems, people have been developing distributed storage systems, whose designs in several keys ways mirror the approach taken by blockchains and other distributed ledger systems.

A distributed or "decentralized" (this paper uses the two terms interchangeably) storage system is designed to store files across multiple file servers or locations. This type of storage system allows programs to access or store files from any network or computer. Alongside of blockchain developments, distributed storage systems are being developed by applying similar algorithms, protocols and encryption to mimic decentralized ledger technologies.

These distributed storage systems are now competing for business with more traditional server- and cloud-based storage and content management systems, such as Amazon Web Services (AWS) Content Management Systems (CMS), and Google Drive, as well as more robust content management systems, such as OpenText and Microsoft SharePoint/365. The distributed storage systems tout several advantages over traditional content management provision, such as:

• **Cost savings**: There are two aspects to cost savings:

- Transaction fees on blockchains result from transactions when increasing amounts of data are stored on a chain or in a block. Higher transaction fees will typically inhibit a blockchain's ability to scale in a way that accommodates a large amount of community data. For example, with the Ethereum network, although it is technically possible to store data on-chain, the high fees involved make doing so impractical for most real-world use cases (Williams & Jones, 2018).

- In terms of general cost savings, some distributed storage systems claim that because they leverage a distributed network of servers and other file storage systems, this means that they can offer storage space at a much-reduced cost compared to a set of servers controlled by centralized storage providers such as AWS.

The following table provides a cost comparison between IPFS/Filecoin and Amazon s3 infrequent access tier storage costs. It shows that IPFS/Filecoin data storage costs 38% (less than half) of the cost of Amazon's S3 — Infrequent Access per gigabyte per month. A comparison with Google cloud storage (60 TB of Google storage, which comes out to USD $0.026 per gigabyte, for example) demonstrates its costs are twice as much as Amazon's, which was already more than double that of IPFS/Filecoin (Alpha Gnome, 2021)

• Security: Distributed storage systems encrypt their data files, and store these files across the entire decentralized network, making the hacking of files and data a greater challenge compared to centralized storage and content management systems.

• Reliability: As files get distributed across a decentralized network, the risk of a single controlling "node" (more below) going down that makes files unavailable is minimized.

• Authenticity: With file storage being treated as a transaction, provenance and the authenticity of the origins of these files gets strengthened.

• Immutability: According to a review of their white papers, like blockchains and DLTs, files that are stored on these systems are immutable, meaning they are permanently stored on these systems. Although this is presented as an advantage (that is, a permanent store of knowledge that can never be lost), as previously mentioned in this paper, immutability is already a challenge for DLTs since

Table 1. Cost comparison of non-distributed and distributed storage systems

Storage Costs per GiB	IPFS/Filecoin	Amazon S3 – Infrequent Access Tier
Per Day	$0.0000018	$0.0004385
Per Month	$0.0000549	$0.0134217
Per Year	$0.0006674	$0.1603822
Average cost per deal	$0.0025003	$0.0580808

they cannot fulfill the disposition of records as part of their legal and regulatory requirements within the current framework.

The following section provides an overview of selected distributed storage systems with a summary of their designs and characteristics.

Examples of Distributed Storage Systems

The following distributed storage systems (platforms) were selected for this paper: InterPlanetary File System (IPFS), Arweave, SIA, Storj, and Filebase.

The InterPlanetary File System, or IPFS (https://ipfs.io/), is a peer-to-peer (P2P) distributed file system that seeks to connect all computing devices with the same system of files. While IPFS is in some ways similar to the Web, in comparative platform language, it can be viewed "as a single BitTorrent swarm, exchanging objects within one Git repository" (Benet, 2015). IPFS has content-addressed hyperlinks, encrypted content, and a data structure that allows for versioned file systems, blockchains, and even a "permanent web", which acts as a store of global knowledge. (Benet, 2015). IPFS is described by Protocol Labs itself as having "no single point of failure" and as a "trust-less" ecosystem (Benet, 2015).

IPFS is a P2P ecosystem in which no nodes are privileged (Benet, 2015). A node in IPFS means a personal computer/server that has signed up/agreed to be an IPFS storage location for content. IPFS nodes store IPFS objects in local data storage, that is, on these personal computers and servers. Nodes connect to each other and transfer objects. The objects stored and sometimes transferred include files and other data structures (Benet, 2015). The IPFS protocol is divided into a stack of sub-protocols responsible for various aspects of the system's functionality:

- Identities: manages node identity generation and verification

- Network: manages P2P connections, using various underlying network protocols

- Routing: maintains information to locate specific peers and objects

- Exchange: a novel block exchange protocol (BitSwap) that governs block distribution, modelled as a market which weakly incentivizes data replication

- Objects: encrypted content-addressed immutable objects with links

- Files: versioned file system hierarchy inspired by Github

- Naming: a self-certifying mutable name system

Although IPFS envisions a decentralized internet infrastructure upon which many different kinds of applications can be built, it currently serves the purpose being a next generation file sharing system (Benet, 2015). One notable use of IPFS was during the government's Wikipedia banning in Turkey. In this case, IPFS was used to create a Wikipedia mirror, which allowed access to Wikipedia content despite the ban (Dale, 2017).

IPFS also addresses the issue of latency, that is, delays in transmitting and/or processing data, by using the Coral distributed sloppy hash table (DSHT). Coral organizes a hierarchy of separate DSHTs into clusters depending on region and size. This enables its nodes to query peers in their local region first, thus finding nearby data without querying distant nodes (Freedman et al, 2004). This greatly reduces the latency of lookups (Benet, 2015).

IPFS recognizes that it publishes and retrieves immutable objects that are "permanent" in a digital sense. Although IPFS can track the version history of each object in the system, mutable naming of objects is not available, resulting in communication of new content happening off-band by sending IPFS links (Benet, 2015). At the same time, the IPFS console allows for users to delete files, although it is unclear if both the file and its bookkeeping information have been deleted from the storage node, or if the link has only been deleted from the console. The ambiguity involves whether or not the actual file exists in some form of limbo that, since no one else has the key to decrypt it, is essentially lost to everyone.

In its whitepapers, *Arweave* (https://www.arweave.org/) states clearly that although they have built a "monumental system of de-centralised information dissemination, we have yet to build the corresponding system of permanent knowledge storage" (Williams & Jones, 2017). Arweave thus shows its goal of creating immutable content in order to avoid failures of the past where stores of knowledge have been destroyed or become un-recoverable. Arweave also refers to ongoing efforts involving censorship or manipulation of news stories by media outlets or governments after an original version is published. This might be done, for example, in order to create a “memory hole” for certain facts that may not fit a given regime’s or organization’s political narrative, where they are easy to conveniently forget.

Arweave acts as a browsable sister network to the internet, by providing long-term knowledge storage features that the internet needs, but currently lacks. Any web browser with the Arweave extension installed will be able to seamlessly navigate between pages stored on servers on the normal internet, and resources stored on Arweave. When pages on the normal internet are not found, the browser extension will search the “Archain” for archived copies of the page. Furthermore, Arweave is also being built to allow users to “rewind” the state of a web page and see what it looked like at a previous moment in time.

Arweave is based on a protocol where once a piece of data is stored in the data structure, it is cryptographically entangled with every other previous block in the network (Williams & Jones, 2018). This ensures that any attempt to change the contents of a document will be automatically detected and consequently rejected by the network. This allows for Arweave’s claim of being able to permanently store data on-chain, “beyond the reach of accidental or intentional data loss or manipulation” (Williams & Jones, 2018).

Arweave's novel data structure, a blockweave, does not require miners to store every previous block. To achieve this, all data required to process new blocks and new transactions is “memoised” (regarding a “shadow” or slimmed-down version of the full block where the removed data can be reconstructed from other data) into the state of each individual block (Williams & Jones, 2018). Two components of a blockweave include:

- Wildfire - a system that provides for the rapid fulfilment of data requests on the network as a necessary part of participation. Wildfire works by creating a ranking system local to each node that determines how quickly new blocks and transactions are distributed to peers, based on how quickly they respond to requests and accept data from others. Peers are served by order of their rank, with poorly performing peers being blacklisted from the network entirely (Williams & Jones, 2018). This aims to address latency issues so that the Arweave solution has response speeds comparable to traditional, centralized storage providers.

- Blockshadowing - this component works by partially decoupling transactions from blocks, and only sending a minimal block “shadow” between nodes that allows peers to reconstruct a full block, instead of transmitting the full block itself (Williams & Jones, 2018).

Arweave also supports two types of archiving:

- Unverified data archiving - users can submit arbitrary information to the weave, with an associated name (an Archain Resource Locator, or ARL).

- Verified internet archiving - an internet URL is submitted to the network and a de-centralised consensus protocol is employed to agree upon its contents before storage. Verified internet archiving allows submitters to easily ensure that important information hosted on the internet will be available and accessible to them and others in the future. These backups are expected to be trustable by others in the future, as they will be guaranteed to be faithful representations of an internet URL's contents at a given time (Williams & Jones, 2018).

Arweave states that it places high value on the authenticity of the data it archives. Arweave clearly recognizes that litigation can be tied up over the authenticity of documents. In addition, in 2017, the U.S. state of Delaware signed into law amendments to Delaware's General Corporation Law to account for the use of blockchain technology in corporate recordkeeping (Lucking, 2017), which also means blockchain evidence is now admissible in court proceedings according to U.S. law (Williams & Jones, 2018). Arweave recognizes that its data archiving could speed up the verification process for authenticating records and avoiding frivolous litigation, but they do not appear to recognize the flipside of this ruling, which is that these records are immutable and can never be disposed of as part of a defensible position for records management.

The third platform, *Sia* (https://sia.tech/), has positioned itself as a “decentralized cloud storage platform that intends to compete with existing storage solutions, at both the P2P and enterprise level” (Vorick & Champine, 2014). Sia also highlights the fact that with existing centralized storage solutions, a single company owns user storage data. This can in unfortunate cases lead it to "abuse privacy in the pursuit of higher profits" (Sia, 2016).

Instead of renting storage from a centralized provider, peers on Sia rent storage from each other. Sia itself stores only the "smart" storage contracts formed between parties, defining the terms of their arrangement. A blockchain is used by Sia to store these smart storage contracts. By forming a smart contract, a storage provider (also known as a host) agrees to store a client's data, and to periodically submit proof of their continued storage until the smart contract expires (Vorick & Champine, 2014).

A file that is uploaded to the Sia network is encrypted and then spread to multiple nodes across the globe. No single node contains a majority of the content of the file, but rather only small fragments. This approach, according to Sia, reduces storage costs compared to a central cloud storage provider and improves access speed and reliability (Sia, 2016).

To address potential latency issues, Sia takes a two-pronged approach:

- Clients can use regenerating codes to safeguard against hosts going offline. These codes typically operate by splitting a file into n pieces, such that the file can be recovered from any subset of m unique pieces (these values vary based on the specific code). Each piece is then encrypted and stored across many hosts, which allows a client to attain high file availability and reduced latency — for example, downloading from the closest 10 hosts, or increase download speed by downloading from the 10 fastest hosts (Vorick & Champine, 2014).

- Incentivizing hosts to maximize uptime and collect as many rewards as possible, or even larger rewards via cryptocurrency payments (Vorick & Champine, 2014).

Sia also runs into the same issue regarding immutability of files and data. In fact, Sia states that contracts do not require hosts to transfer files back to their client when requested; instead, they reward hosts for uploading files and data P2P (Vorick & Champine, 2014). Although this approach helps to bolster content in Sia's P2P network, no provisions appear to have been taken to develop a consensus that completely disposes of files and data records based on the most recent legal and regulatory requirements.

Storj Decentralized Cloud Storage (DCS) (https://www.storj.io/) describes itself as "the world's first open-source, distributed cloud storage layer that's private by design and secure by default - enabling developers to build in the best data protection and privacy into their applications as possible" (Storj, 2021). The components of Storj's framework in order to store, retrieve and maintain data include:

- Storage nodes: these distributed nodes are located across the globe, where data is reliably stored, and network bandwidth provided with appropriate responsiveness. The nodes are selected based on various technical criteria (for example, ping time, throughput, bandwidth, sufficient disk space, geographic location, uptime, history of responding accurately). A node that meets these criteria reduces latency throughout in the network and ensures high response and uptimes for users. In return for their valuable network service for the platform, nodes are paid.

- P2P communication and discovery - all peers communicate via a standard protocol where each peer provides authentication (by cryptographically proving their identity). There is complete privacy, along with the ability to look up peer network addresses by a unique identifier so that, given a peer's unique identifier, any other peer can connect to it. This creates a "trust-less" data storage and sharing network.

- Redundancy - a strategy where data is stored in a way that provides access to the data with high probability, even though any given number of individual nodes may be in an offl¬ine state. This ensures there is no single point of failure, thereby minimizing outages, downtime, bitrot, ransomware, and data breaches.

- Metadata - to track which storage nodes contain what data.

- Encryption - data is encrypted and split into 80 or more pieces, which are then stored across multiple storage nodes. If a single node goes offline, this does not block access to data, as any file sought can be reconstituted from as few as 29 of its distributed pieces that can be found in other online nodes.

- Audits and reputation - audits are used to determine a node's degree of stability. Failed audits result in a storage node being marked as bad, which means redistributing data to new nodes and avoiding that node altogether in the future. Such audits in turn, determine the reputation of each node. This approach also works to minimize the need for data repair.

In their whitepaper, Storj indicated that in addition to uploading, downloading, copying, and moving files, users also have the option to delete files (Storj Labs, 2018). When a user wants to delete a file, the delete operation is made, received and validated, and a signed message is returned indicating either that the storage node received the delete operation and will delete both the file and its bookkeeping information, or that it was already removed. The segment pointers to this file (regarding the metadata or key to find and open this file in the decentralized storage network) are then removed and the customer will stop being charged for that data storage.

Filebase (https://filebase.com/) is a Simple Storage Service (S3)-compatible object storage platform that allows users to "store data in a secure, redundant, and performant manner across multiple decentralized storage networks" (Filebase, 2021).

Filebase has taken a different approach compared to other distributed cloud storage (DCS) networks. Filebase allows users to select a DCS - either the Sia, Storj, or Skynet DCS —as their storage layer. Filebase leverages unused storage capacity and rents storage from these DCS networks, managing all smart storage contracts on behalf of users, which serves as a cryptographic Service Level Agreement (SLA).

The Filebase platform includes mechanisms for high-availability, redundancy, and privacy. When servers on these networks go offline, data is automatically repaired and uploaded to new hosts, providing for minimal latency and interruptions. Filebase claims it can achieve 3x redundancy for every object (Filebase, 2021).

Unlike other leading DCS networks, Filebase has no requirement to generate or purchase cryptocurrency as part of its service since it has no token. Filebase appears to be positioning itself as an intermediary between the DCS networks for users seeking distributed storage for their files.

From a retention and disposition perspective, Filebase allows users to delete uploaded files in their folders ("buckets"). Based on a review of documentation available on their website, Filebase does not appear to clearly explain anywhere if requests are sent to the selected DCS network to permanently delete a file, along with its "bookkeeping information". At the same time, if the only link to this file in the DCS is the link provided on the Filebase interface and console, this file may be forever "lost" without the ability to decrypt it or to identify its owner. This scenario for Filebase as a DCS network intermediary needs to be better understood to see if a defensible position for records disposition can be established.

Comparison of Distributed Storage Systems across the Information Lifecycle Stages

The following table provides a comparison of the distributed storage systems reviewed above, including how they relate to the "information lifecycle" stages, as well as specific attributes within each of these stages.

After having made this comparison, I make no recommendation in this paper for any one of these distributed storage solutions as optimal for content storage off-chain. Each has their own strengths that favour different uses:

- IPFS is one of the original protocols and has the size and features to be leveraged by larger organizations. Sia, Storj, and Filebase are also vying for market share with organizations (from small to large) and not just individual users, but they are relative newcomers compared to IPFS.

- Arweave has positioned itself as a permanent store of knowledge, and organizations should consider this solution particularly for data that requires permanent archiving of content.

Users and organizations must clearly define and document their content management requirements and compare these to the features of each solution in order to select the right solution for their unique needs.

Conclusion

With the rise of blockchain and DLTs, an increasing need has arisen to understand what data should be stored on-chain and what data is best stored off-chain. Data that contains personal identifiable information (PII) and/or needs to be disposed of after a defined retention period should not be stored on-chain whenever possible. This is because that data will then

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Table 2. A comparison of distributed storage systems

Information Lifecycle Stage	IPFS	Arweave	Sia	Storj	Filebase
Creation/ Modification (including version control)	No barriers to content creation; allows for version control when updating files	No barriers to content creation; separate files need to be added for manual tracking of versions to maintain the immutability of each version	No barriers to content creation; no indication that version control exists (re: allowing for previous versions to exist as part of a version history for the file)	No barriers to content creation; no clear indication on the ability to manage versions of files	No barriers to content creation; no clear indication on the ability to manage versions of files
Classification (including metadata)	Metadata captured for pointers; no other indication of being able to add metadata beyond the file name	No other indication of being able to add metadata beyond the file name	No other indication of being able to add metadata beyond the file name	Metadata captured for pointers to the file in the network; no other indication of being able to add metadata beyond the file name	User-defined metadata can be added to a file
Storage (including security and authenticity)	Protocol ensures encryption of files for secure storage and unique identifier to confirm authenticity	Protocol ensures encryption of files for secure storage and unique identifier to confirm authenticity	Protocol ensures encryption of files for secure storage and unique identifier to confirm authenticity	Protocol ensures encryption of files for secure storage and unique identifier to confirm authenticity	Protocol ensures encryption of files for secure storage and unique identifier to confirm authenticity; also allows for content to be either Private or Public
Retrieval/Use	Unique URL for a file can be shared with other users	Users can share and link to Arweave resources like	Files can be downloaded; files can be shared publicly and privately; user needs	Files can be downloaded; user can share a bearer credential with other	In addition to the ability to set content as either Private or Public, a

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Table 2. A comparison of distributed storage systems (cont'd)

Information Lifecycle Stage	IPFS	Arweave	Sia	Storj	Filebase
		normal web addresses (provided Arweave is enabled on the user's web browser)	to share the "siafile" (which includes metadata pointers for the file) with others so they can download the file	users to provide them access to a file	unique URL for a file can be shared with other users
Retention/ Disposition	Console allows for the deletion of files; unclear if file is also deleted from the nodes or just from the console	Files are permanently stored	Console allows for the deletion of files; unclear if file is also deleted from the nodes or just from the console	Ability to delete a file and its bookkeeping information	Console allows for the deletion of files; unclear if file is also deleted from the nodes or just from the console

become immutable, which in turn makes it more difficult for someone to have the ability to "be forgotten" in cyberspace.

For users and organizations that want to extend the paradigm of "decentralization" to file storage, the development of distributed storage systems offers an interesting alternative to traditional, more centralized on-premise and cloud storage providers. Distributed storage systems are based on blockchain protocols. These systems offer interesting alternatives to more traditional content management and storage systems, as they offer more secure storage and authentication through encryption and pointer metadata, respectively. They also promise reduced costs by leveraging a network of distributed nodes, such that no new hardware or server costs are needed for these systems to provide storage.

At the same time, these new distributed storage systems have their own challenges. If one of these systems also creates immutable copies of files, it presents a challenge to protect PII and dispose of records. In addition, with these being relatively new systems, other aspects of information management are still maturing at the same time, such as user-provided metadata on files, version control, and seamless user access for multiple users.

File storage will continue to be a topic of interest in the blockchain and DLT space. In particular, the recent growth of non-fungible tokens (NFTs), which are now associated with content such as books, music, and artwork, attests to the need for secure storage of these tokens. Distributed storage systems have an important role to play in developing decentralized ecosystems. Their increasing technological maturity is likely to continue to disrupt the file storage and content management industry.

Additional discussions need to be held to better vet the requirements that organizations have for the storage, retention and disposition of their content, and how these distributed storage solutions either meet or do not meet these requirements. Meeting both the institutional requirements as well as the social preconditioning for onboarding new technologies will be key for distributed storage solutions to become serious rivals to existing and well-established content management systems.

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Distributed Ledger Technologies and Social Machines: How to "Smartify" the Economy with Blockchain-based Digital Extension Services?

Gregory Sandstrom

"*The future masters of technology will have to be light-hearted and intelligent. The machine easily masters the grim and the dumb.*"

Marshall McLuhan (1969)

This paper examines the broad impact of digitalization on economic development. More specifically, it addresses the computer science-derived notion of "social machines", along with the invention of distributed ledger technologies (DLTs) (or blockchain), as potential signposts on the pathway to "smart(er) digital economies". The paper investigates blockchain-based ecosystems as examples of social machines that assist in economic "smartification" and development. It looks at distributed ledger-based communities (DLCs) that provide examples of functioning social machines for a variety of business and personal network communications purposes. It then analyses the scaleup of DLT-based social machines by comparison with "extension services", largely in education and agriculture, which are currently undergoing processes of digitalization. Overall, this conceptual study examines the general horizons and potential impact of blockchain and social machines on the provision of online products and services, across a range of sectors and industries. The paper offers interpretative assistance to managers, entrepreneurs, technology experts, and academics with lingering questions about blockchain in and for business and economic development.

Introduction

What are now called "social machines" have been around for decades as part of a computer-driven wave of digitalization that has taken over developed societies around the world, including but not limited to the invention of the Internet. People and machines are becoming increasingly integrated through computing power, data processing and storage, information management, and Artificial Intelligence (AI), which are all included in the study of "web science" (Shadbolt & Berners-Lee, 2008, Hall et al. 2016). Economic development now hinges significantly on digitalization and the digital economy, while early mover high tech companies can develop and use advanced technologies to gain strategic advantages over competitors, potentially for years to come.

Berners-Lee and Fischetti coined the term "social machine" in 1999. It joined a language constellation with "social computing" and "cyber-physical systems" to help imagine the future of web-connected societies, or what Wellman (2001) called "networked individualism". The Internet and world wide web, from Web 1.0, to Web 2.0, and the "semantic web" (Hendler & Berners-Lee, 2010), look set to combine with a new distributed ledger technology (DLT), sometimes known as "blockchain", which was invented at the same time as Bitcoin. Bitcoin itself was invented, coded, and released into the wild in 2009 as "a peer-to-peer electronic cash system with no central mint or trusted third party" (Nakamoto, 2008).

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The trend of using social machines more widely in the electronic-information era coincides with the push in recent decades towards digitalization, and more recently towards the so-called "smartification" (promoting smarter cities, smarter economies, smarter devices). One way to consider it is that "[s]martification refers to the digital refinement of an existing product by embedding digital technologies and smart services" (Schuh et al., 2019). These processes of smartification thus both require improving technology design "intelligently", in a way that includes strategic planning for niche market acquisition, along with broader economic development. Schuh et al. correspondingly acknowledge that, "[t]he designation 'smart' is common to describe a product that is extended with digital functions and customer-oriented services" (2019).

Considering the relatively new terminology, this paper explores the potential for smartification in the context of entrepreneurial and business activities that are arising from the use of DLTs to create "ledger communities" (LCs). As DLTs make use of the Internet, information services, big data, encryption, and "smart devices" (which may hold digital wallets), some have even suggested this powerful mixture of technological capabilities has brought us now to the brink of a "blockchain revolution" (Tapscotts, 2016, 2016a & 2017, 2017a). This language contrasts with speaking less abruptly about "the rise of social machines" (Shadbolt et al., 2016), and more gradually about how their development is transforming the human/digital ecosystem globally.

Practically no studies have investigated the interface or potential synergy between DLTs and social machines, and none considering smartification trends. Thus, the paper addresses an existing gap in the literature between DLTs and social machines, with only one paper found that combined the terms "blockchain" and "social machines", and not in a significant way. The starting premise of the study is that such synergy would be valuable to consider. It goes further than the currently available literature by using "scalability" as a comparable point of reference. Scalability involving distributed ledgers refers to increasing the throughput of the system via distributed computing processes for use, service, or production across a range of features. Its applicability as a comparable point of reference is demonstrated via a 20th century and contemporary example ([cooperative] extension services).

The paper thus brings together language that is already familiar within the innovation literature (for example, Roger, 1962; Rogers & Valentine, 1995), and adds new literature involving social machines and smartification (for example, Shadbolt et al., 2019, 2016, 2013; Smart & Shadbolt, 2014, O'Hara, 2013), together with recent literature on DLTs (Nakamoto, 2008; Orcutt, 2015; Swan, 2015; Urgessa & Vigna, 2015; Pilkington, 2016; Tapscott, 2016; Tapscotts, 2016, 2016a; UK Government Chief Scientific Adviser, 2016; Boucher, 2017; Calvo, 2017; Casey & Vigna, 2017; Narayanan & Clark, 2017; Tapscott, 2017; Werback, 2018; DuPoint, 2019; Zhu et al. 2019). The purpose of doing this is to raise awareness for researchers and technology entrepreneurs seeking to build or improve innovative infrastructure for social machines that will help smartify local and global economies. Both roles are important for economic development in laying a foundation for DLCs of the future. At the same time, both may benefit from comparing social machines and DLCs, in light of the scalable notion of "extension services", which may aid in conceptually approaching both how to innovate DLTs, as well as diffuse them in DLCs through digital extension activities that aim at smartification.

The conceptualization of DLCs as social machines allows us to formulate important interrelated questions. *First, does such conceptualization help in our understanding of how to "smartify" an economy by using digital DLT-based tools, products and services? Second, how does considering the "smartification" process as happening through "digital extension services" help in answering the first question?*

The paper considers "extension" as the driving source of "innovation diffusion" (Rogers, 1962). This simply means that innovation diffusion extends first from innovations themselves (Thiel & Masters, 2014), which likewise extend from innovators, inventors, and entrepreneurs (Argabright et al., 2012). Innovation itself serves as an indicator in the process of digitally "smartifying" an economy, which requires concentrating digital resources and following the lead of innovative technology-led entrepreneurial startup ventures that strive to reach global, in addition to local, markets.

The paper traces a brief history of both social machines and DLTs through their similar time frames. A comparative literature review considers the two streams - by framing DLTs and social machines in their common context of striving towards "smartification". It then

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applies some of the insights to a use case analysis focusing on the historical growth of "extension services" as an example ripe for comparison within the lenses of "digitalization" and "smartification", and thus to the growth of "digital extension services" in general.

A Descriptive Analysis of Social Machines

The initial meaning of "social machines" (1999) comes from computer scientist and inventor of the world wide web, Tim Berners-Lee, with Mark Fischetti, current editor of Scientific American, who stated: "Computers can help if we use them to create abstract social machines on the Web: processes in which the people do the creative work and the machine does the administration". From this, we see a conversation has grown up that involves human-machine interaction, human and social computing, as well as "collective intelligence", which means different things to people coming from different fields.

Berners-Lee and Fischetti (1999) identified "interconnected groups of people acting as if they shared a larger intuitive brain," in defining social machines on the world wide web. This was picked up more than a decade later by Shadbolt (2013), along with Smart et al. (2013), who provided an updated definition: "Social Machines are Web-based socio-technical systems in which the human and technological elements play the role of participant machinery with respect to the mechanistic realisation of system level processes". Hooper et al. (2016) defined a "social machine" as "a socio-technical construct by which a human-machine collective achieves greater things than would be possible of the individual 'parts' working alone". Donath more recently widened the meaning of a social machine away from a mechanistic view, in speaking generally of "a communication medium and a setting for interactions, an electronic place to see and be seen" (2020). These definitions all relate to how digitalization impacts our daily activities, both mechanically and organically, as it enables new forms of "socialization" mediated in some cases by social machines.

A project named "SOCIAM" (https://sociam.org/) ran from 2012 to 2018, with funding by the U.K.'s Engineering and Physical Sciences Research Council. It linked three top universities in the U.K. to produce interdisciplinary web science research insights into social machines. In 2014, the project leaders pointed out that, "Social Machines are a characterization of technology-enabled social systems, seen as computational entities governed by both computational and social processes". The distinction between computational entities, and social systems/processes meanings was important to highlight regarding what is "technology-enabled" and what isn't. Following Berners-Lee and Frischetti's new term, earlier philosophers Deleuze and Guatarri (2004) noted that,

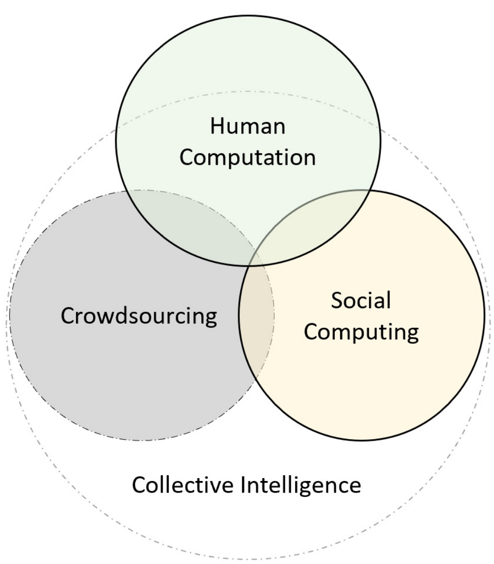

Figure 1. The intersection of human computation and social computing (adapted from Quinn & Bederson [2011], and Romani & Baranauskas [2013])

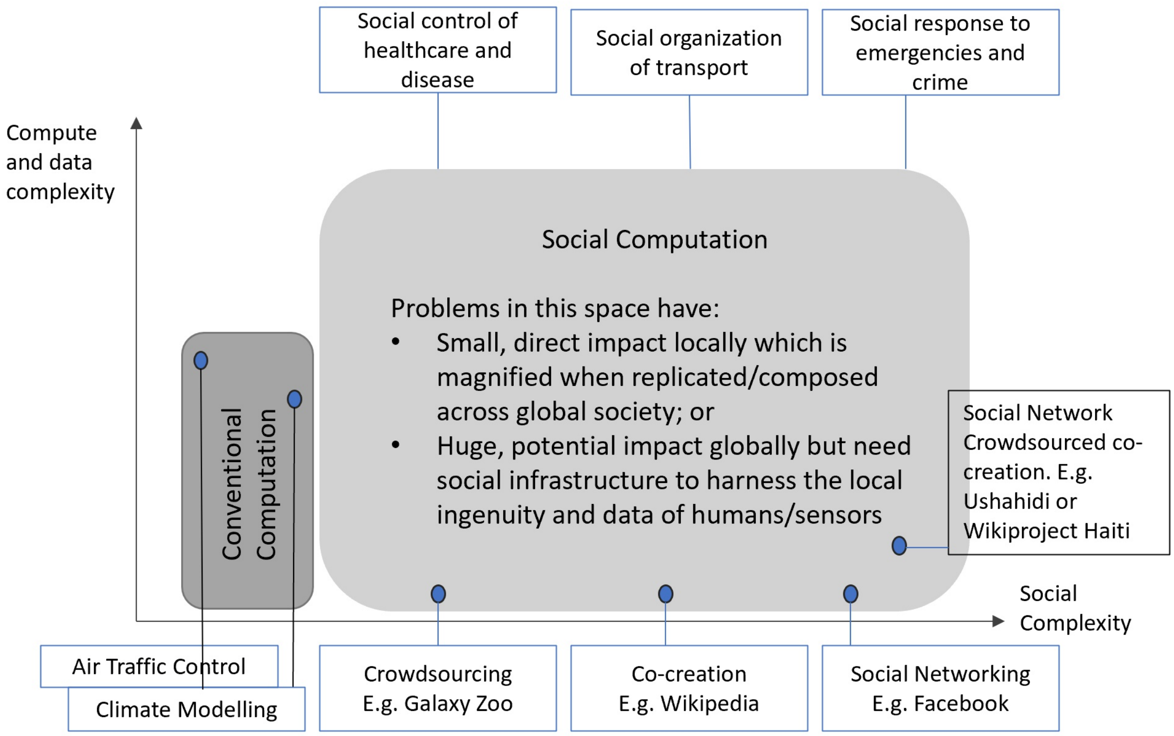

Figure 2. A space for social machines (adapted from O'Hara et al. 2013)

"The same machine can be both technical and social, but only when viewed from different perspectives: for example, the clock as a technical machine for measuring uniform time, and as a social machine for reproducing canonic hours and for assuring order in the city".

In a nutshell, what do social machines do? Crowdsourcing, collective intelligence, supply chain monitoring, file sharing, and citizen science, to name a few activities. What are examples of social machines? Wikipedia, Facebook, Twitter, Instagram, Duolingo, Zooniverse, Flickr, Patientslikeme, and Last.fm. How do people interface with social machines? Shadbolt et al. (2016) noted that, "[c]onsumer electronics in their current form of smartphones, wearables, and sensors, along with other devices yet to be envisioned, will power this next generation of systems, providing the key mechanisms that people will use to leverage a new type of social computational power. We refer to these as social machines". The trend in device innovation supports people making more and more frequent use of social machines with administration (automation, calculation, scheduling, etc.) done by computers, while creative work (networking, symbolic value-adding, trust-building, moral, ethical, and cultural aspects) is driven by (still-human) people.

According to Hendler and Mulvehill (2016) a social machine "represents the concept at the nexus of the increasing convergence of artificial intelligence, social networking, and human cognition". They believe that an "ability to easily communicate with others in our society regardless of time, geographical location, and social or economic status is the basis of the social machine" (Ibid). In short, they believe that social machines "enable humans and computers to work together as powerful teams" (Ibid). For some contemporary entrepreneurs who aren't on the cutting edges of web and information science, this may sound too futuristic. While for others, that time is already here, as we work out and discover new vocabularies for machine-human interaction on-line and with the Internet of Things.

Concerns remain, however, regarding dangers, warnings, and possible pitfalls arising from issues involving control over the machines that we are now creating. "The emergent Internet of Things and the

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application of AI and blockchain technologies", wrote Hall et al. (2016), "promises much in terms of smarter everything but we can also see a nightmare world of control by a network of machines and devices that we have little control over". This nightmare scenario may be considered when thinking of "societal machines" as tools of elite power over entire societies, rather than as "social machines" that facilitate digitally-mediated relationships and transactions between people in and across a range of societies. Hendler and Mulvehill (2016) instead took a more positive, constructive approach, saying, "we can continue to create and refine social machine technologies that can increasingly take advantage of the way that large numbers of people can network together to support real-world problems. With the help of other humans interacting with increasingly smart machines, we will be able to achieve many things that we cannot currently do". Similarly, Shadbolt et al. (2016) suggested that they "see a future where consumer electronic devices are not just personal accessories but rather the nodes that embed individuals within a variety of social machines".

In their book on social machines that resulted from the SOCIAM project, Shadbolt et al. (2019) stated that,

> "[s]ocial machines should prompt neither optimism nor pessimism; they will enable new types of problem-solving and new types of mischief alike. To the academic community, our message is that social machines and CPSMs [cyber-physical social machines] deserve recognition and new types of interdisciplinary research. To policymakers, we say that social problems and the responses to them can productively be viewed through the social machine lens. To the technology industry, we argue that social machines are one of the chief social goods of platforms and other means of connecting people, and that the flourishing of sociality and communication within social machines should be a key part of the industry's contribution to societal welfare".

One of the challenges, as Hooper et al. note, is that "[m]ost if not all issues that social machines respond to have multiple stakeholders" (2016). This feature of social machines as involving multiple stakeholders is what makes the similarities most striking with blockchain DLCs, which also require multiple stakeholders to function. The reason for this is similar to what makes a "social machine" social, instead of just a "technical machine"; the technology is built in such a way that it requires a "community", meaning a big enough (mass) active user or member base for the logic of the system's benefits to become apparent.

Comparing Distributed Ledger Communities (DLCs) and Social Machines

One way to conceptualize "social machines" is through the recent rise of "blockchain" ("chain of blocks" in Nakamoto, 2008) DLTs, which do the accounting and some of the administration for DLCs (Sandstrom, 2017). These communities use informational (accounting) "ledgers" shared across a network of multiple (hundreds, often times thousands) of computers, according to protocols developed by "Satoshi Nakamoto" (Bitcoin), Hal Finney (Bitcoin), Gavin Andresen (Bitcoin), Vitalik Buterin (Ethereum), Gavin Wood (Ethereum, Polkadot), and many other software developers and engineers that have followed since.

Canadian business executive Don Tapscott (2016) suggested that, "the blockchain, the underlying technology [behind Bitcoin], is the biggest innovation in computer science– the idea of a distributed database where trust is established through mass collaboration and clever code rather than through a powerful institution that does the authentication and the settlement". To on-board people, one must therefore convince them that a DLC can deliver trust (Casey & Vigna, 2017; Truong et al., 2018; Werbach, 2018) between human beings while enabling new or improved transactions involving value. The peer-to-peer (P2P) features of making direct transfers between members, and the possibility of anonymous (or pseudonymous) transactions, ratings, and exchanges, make DLTs suitable tools for a variety of industries and business interactions. DLTs thus lead to ledger communities (LCs) (Sandstrom, 2017) of people (users) who agree to the terms and conditions of the "Genesis Block" of that particular LC, and thus gain a measure of mutual trust in making transactions with others there.

These communities of mutually involved participant agents are the key drivers for people to adopt DLTs in "smarter city" environments (see Figure 3). All of the transactions take place, are recorded, and time-stamped between registered DLC members, who either transfer digital assets, tokens, points, credits, or information to

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other members (or member "wallets") in the system. This enables "common pools of resources" (CPRs) and sense of trust based on participatory understanding to form around shared activities, purposes, transactions, and roles in a digital ecosystem.

Economist Elinor Ostrom described CPRs this way, outside of a DLT context:

> "We have learned that citizens do play an essential role in the governance of common pool resources and that efforts to turn over all of the responsibility for governing these resources to external experts are not likely to protect them in the long run. The complexity of the resources at local, regional, national, and global levels do require complex governance systems involving citizen input in diverse fashions" (In Helfrich, 2009).

With the need for a similarly diverse governance system, DLCs as social machines constitute online networks of trading, sharing, and value exchange that use a digital platform for activating fast and secure transactions and services enabled by DLTs (see Figure 4), sometimes involving CPRs. The incentive structure of DLCs, as Jose Luis Calvo suggests (2017), thus becomes quite attractive in that "participants of the system have more benefit working in favour of the system than against them [it]".

The emergence of DLT-based DLCs thus portend a massive re-classification and re-organisation of society, economics, and culture along new lines, networks, organizations, and communications channels. This will likely bring with it a different structure of power and governance than we have seen before, just as the internet changed the previous electric ecology in a profound way. This makes it humbling and precautionary to do origins and processes thinking about the complexity of DLTs at this early stage in their development. We need to look more closely into the "Genesis Block" (original first block) in every blockchain to find the "governing ideology" of each DLC, as this determines who its insiders and outsiders are, and how its rules and regulations govern, guide, assist, connect, and evaluate members.

It would be nearly impossible to understate the pent-up potential that this technology contains in terms of societal reconstruction, restrictions, inclusions, exclusions, and overall reorganisation along digital access and denial lines (what is a digital queue in DLT-space?). One need only recognise the power of "[a] cryptocurrency that's not based on nation-states" (Tapscott, 2016) to consider the foundationally disruptive potential of digital currencies as an alternative to nation-state backed "fiat currencies". The question now seems not to be if states will act to produce their own DLT-based platforms and systems, including potentially Central Bank digital currencies (CBDCs), but rather when, how, and in what order (see Estonia's X-Road platform). The halls of political and economic power around the world are now faced urgently with choices about what to do with DLTs, when applied broadly in/to economics, culture, language, politics, religion, education, and other areas (Swan, 2015; Urgessa & Vigna, 2015; Tapscott, 2016; Tapscotts, 2016, 2016a; Casey & Vigna, 2017; Tapscotts, 2017, 2017a). We ought to seek answers that draw out the ideas of academics, along with technologists, entrepreneurs, and community leaders so that we may "think things out before we put them out", a well-heeded McLuhan warning at obsessing in a Narcissus-like state with technology to our own detriment and loss of self-identity.

DLTs seem aimed to eventually create societies that have new "communities of identity permission", wherein some people volunteer and can enter a ledger community, while other people do not wish to, or because of their already-made and indicated public preferences, are not allowed to. In other words, DLT social machines herald an era of "Are you in or are you out?", meaning "Do you hold certain principles of transacting in common with us according to your voluntarily published identity?", based on community-market membership and secure identity with "digital keys and signatures". Making decisions to be part of DLCs or not may become a significant feature of DLC-driven societies in the coming years.

Key issues involve "permissions" in a DLC, digital identity, access to digital assets, as well as voting rights, secure storage, information sharing opportunities, and other features. Thus, the question of whether a DLC is "permissionless" (one does not need permission to access it, or to interact with other members) or "permissioned" (permission is needed to access it, and

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to interact with other members) is crucial for businesses and entrepreneurs to answer if they are thinking about building a DLT-backed product or service offering.

Discussion: How to Smartify Social Machines with Digital Extension Services?

According to the interpretation of "social machines" by Berners-Lee and Fischetti (1999), "The stage is set for an evolutionary growth of new social engines. The ability to create new forms of social process would be given to the world at large, and development would be rapid". While we can speak of an "evolutionary growth" when the topic is biological forms, in contrast, the growth of technological forms requires alternative language that specifically addresses and includes the "human factor". This is because social machines are "artificial" or "technological", rather than "natural" or "organic" entities. They thus do not "evolve" in the way biological organisms do. For this, an alternative language for change involving design and planning of digital platforms and ecosystems seems valuable, as social machines (or "engines") aim for both innovative simplicity and coherent design principles (Dorst, 2015).

The language of "extension" offers a direct channel to "agency", design, and planning in the study of economic development, being present in one way or another throughout economic theory. Each social machine has its own history that involves both economic and non-economic decisions and actions that extend from human agents and institutions. Thus, we can think about social machines as "extending" directly from community leadership, along with entrepreneurial activities, principles, innovations, and enterprises, both social and business in orientation. Ultimately DLT social machines extend to and from their users.

Social machines enabled by DLTs seen this way break new ground through the work of "digital extension agents" (compare with validators, endorsers, witnesses, node leaders, oracles). They may thus gradually or rapidly achieve a "network effect" by attracting smaller or larger communities of users. This reveals not only what (or who) the entrepreneurial activity extends *from*, but rather also and more importantly, what it extends *to*: a unique distributed market niche and an active, growing user community of networked individuals, yet without a single central source of control, just socially-accepted "rules of the game" in a DLC.

A social machine's smartification is partially demonstrated in its roll-out plan about how to scale. This means targeting "extensive growth", in addition to the "intensive growth" that comes already from possibilities present with the invention of "blockchain". Taking the combined extensive and intensive growth approach to DLTs, we can then consider, with greater foresight and accuracy than "evolutionary economics" allows, what impacts DLC social machines are likely to have on economic development, as well as how, where, and why they can be built.

Considerable work has been done applying "extension" thinking to a variety of technological innovations (McLuhan, 1964; Brey, 2000; Lawson, 2010; Steinert, 2015), and even to the consumer world (Belk, 1988, 2013). This provides entrepreneurs with an accessible language for describing both innovation conceptualization and product or service diffusion. Entrepreneur and venture capitalist Peter Thiel (with Blake Masters, 2014) most recently applied the notions of extensive and intensive growth specifically to innovation and development in *Zero to One*. The book showed that while both "intensive" and "extensive" thinking are needed for successful innovation diffusion, the core of innovative thinking is "intensive" in orientation. Innovations can be produced and potentially diffused (extended) from "one to infinity (∞)", as a principle, yet the harder part in the task of generating meaningful disruptive change through innovation comes from making a(n intensive) breakthrough from "0 to 1", and thus the title of the book (see image below in Appendix).

Further good reasons exist to adopt "extension" language to address the rise of social machines given the importance for DLTs of navigating to scale globally. The historical diffusion of public cooperative extension services (mainly in education and agriculture) in multiple countries around the world, establishes them as arguably the single most influential and significant "social machine" to achieve mass scale created in world history, prior to the Internet. The role of extension services in the 1950s-60s "Green Revolution" through agricultural extension, and earlier with the university extension movement (see "distance education" or "life-long learning") starting in the 1860s and 70s in the UK, and a bit later in the USA (Chapin, 1894; Chapple 1896; Moulton 1897), provide significant cases in point. The examples of "extension" that bridge (academic) theory with practise (education and technology diffusion) may serve to help us now look more closely at what "digital extension services" might mean in the 21st century.

The question is still open how DLTs may be used to increasingly coordinate, grow, and serve globally online and connected users, given the current state of the technology. Without scaleup potential, DLT social machines face the risk of collapse and LC desertion, as has happened with many DLT projects already. This is where the addition of "extension" thinking and extension services becomes most appropriate, as a way of providing scale-ready thinking for DLT projects in quest of appropriate business and governance application.

The main challenge of scalability for DLCs is one of how to extend, that is, to experience and achieve scaleup. The question we can ask, following Thiel and Masters (2014), is: how to intentionally and with purpose build a DLT-backed DLC that attracts and enables "1 to n" growth of users and transaction to achieve a "network effect"? Deciding on how to create a DLC's extension services and network effect strategy thus enables DLTs to move from design and planning with theories into practise where active users are involved as participants in the decision-making process, or otherwise quickly to irrelevancy and to the community's quick collapse.

Digital extension services maintained over time provide examples of community generated and guaranteed leverage; a community "market voice". They draw on collective volunteer improvement though minimal provision of education and services that help local Users improve their earning, producing and basic living conditions or opportunities. DLCs similarly enable a process of to building new digital extension services upon already existing social machines, even while some principle of proportionality is needed in caution against over-extension.

With DLC social machines, the intensification of information matching and filtering opportunities across mutually "permissioned" datasets translates into finding ways to connect Members with others who can add values to the network. Some of these values are currently "invisible", according to the way the financial system is now configured. It will be up to new DLCs to make these values visible, beyond only financial applications via "cryptocurrencies" (Orcutt, 2015; UK Government Chief Scientific Adviser, 2016).

Looking at the origins of technology-driven companies and the discovery or achievement of innovations as examples of McLuhan's "extensions of man[kind]" helps us as to make sense of social machines using an inherently teleological term. The opportunity of taking on board this language of "intensive and extensive" thinking, where culture, media, technology, economy, and business meet, seems to be ripe for exploration regarding DLTs, given the planning and design that goes into business modelling and value proposition identification. Our team planning and design themselves take an "extension" thinking approach in community. It remains to be seen, however, if thinking about social machines using teleological language will help focus attention on some of the ethical, moral, economic, and political issues that currently face us as they rise to prominence, in ways that allow us to react to the pressing changes in technology happening around us.

Some of the key similarities and differences between social machines, DLCs and digital extension services are summarized in Table 1.

Conclusion

This paper involving conceptualization of DLCs as social machines aimed to address the following interrelated research questions: *First, does such conceptualization help in our understanding of how to "smartify" an economy by using digital DLT-based tools, products and services? And second, how does considering the "smartification" process as happening through "digital extension services" help in answering the first question?*

To the first question, based on the above, the answer appears to be "Yes". To the second, social machines in the form of DLCs can smartify economies through digital extension services via platforms that offer value-added benefits to multiple stakeholders and categories of users. This marks a continuation of common market mechanisms, with distributed thinking community-oriented features added into the digital ecosystems approach. The rise of DLCs thus appears crucial for business and management scholars, social scientists in general, and entrepreneurs to better understand, since the growing usage of DLTs by DLCs will constitute new social and business markets, bringing along with them enterprise scale-up opportunities.

On the question of how to scale a distributed ledger system in a way to get a network effect, we can suggest that social machines both require and demonstrate digital extension. At least, it seems to make sense to speak about social machines as "extending" (rather than "evolving"), given how "extension thinking" has been invoked and applied in the past, as well as presently in several overlapping fields, including education, agriculture, technology, language, cognition, and even digital marketing. This paper thus

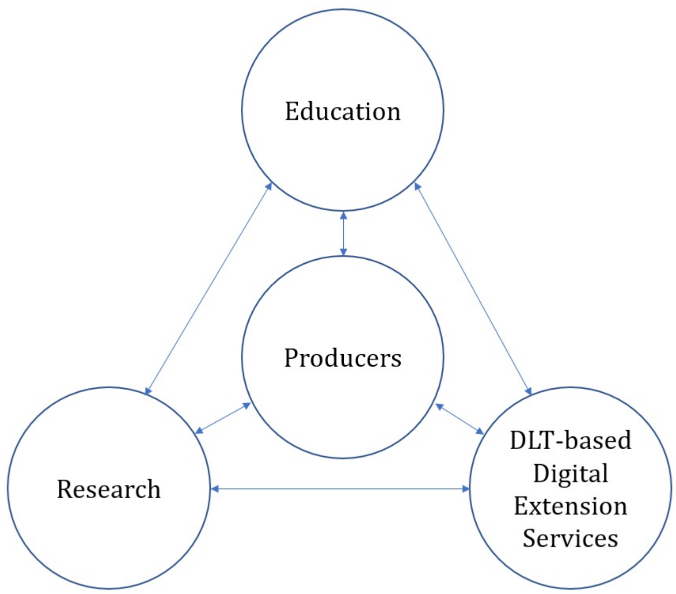

Figure 3. Agricultural Knowledge and Information Services Triangle
Source: FAO and The World Bank 2000

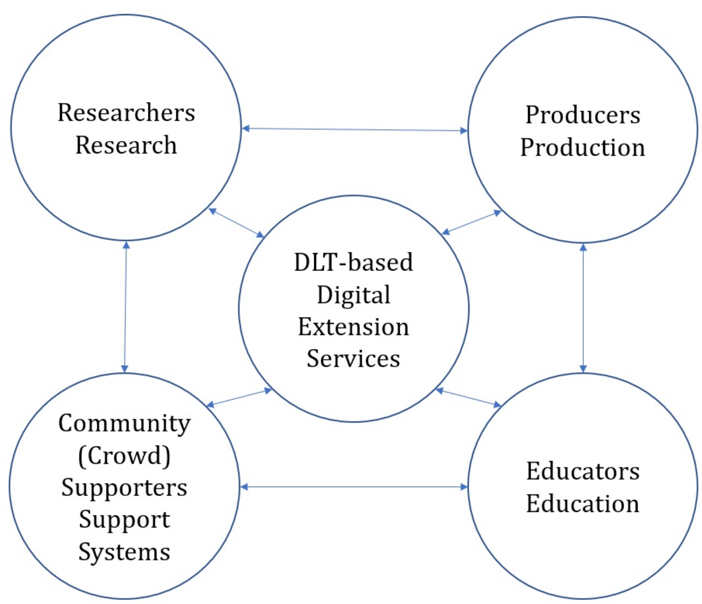

Figure 4. DLT-based digital extension services conceived as a social machine, which includes a "public ledger" (adapted and updated to add DLT backend, from Hunt et al., 2014)

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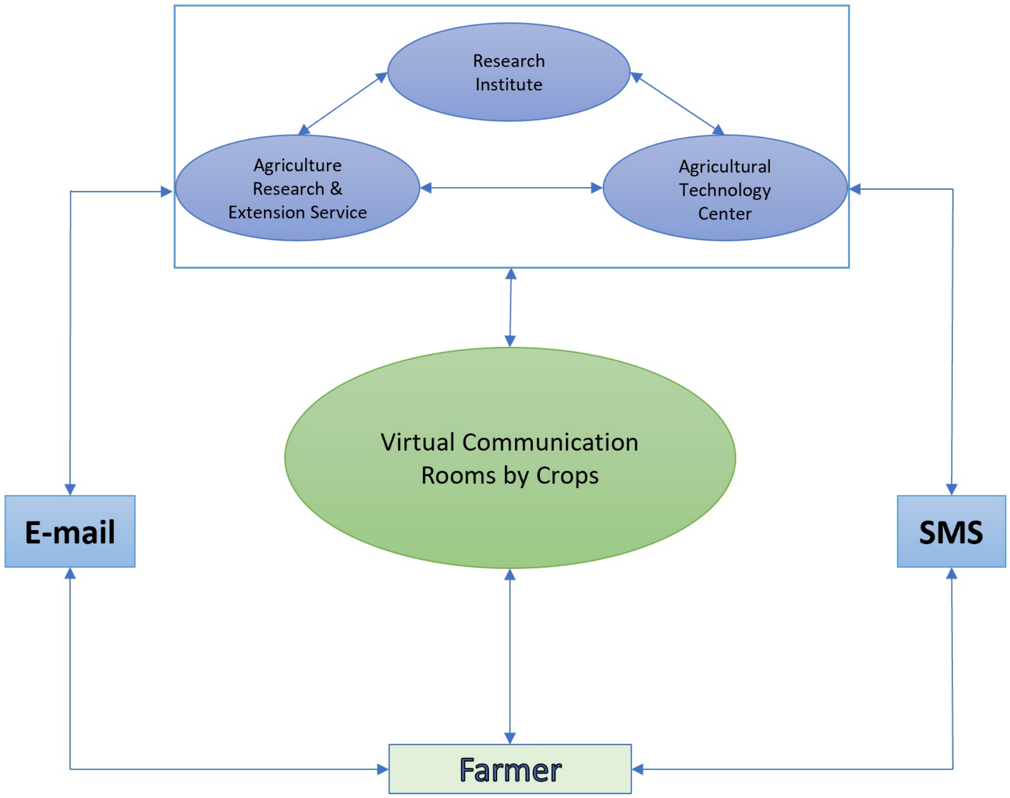

Figure 5. Extension services in a Digital Communications Ecosystem (adapted from Singh, 2006)

suggested a historical comparison to consider and explore further involving the growth of the agricultural extension movement (Roling, 1988), and university extension movements of the 19th and 20th centuries (Chapin 1894; Chapple 1896; Moulton 1897; Bittner, 1920; Lawrie, 2014), as models for the kinds of "scale change" and structural realignment that we are facing in some ways today with the digitization of economics. Today we are faced with a simple, but difficult question: How are our social machines going to be built and steered, and by whom; individuals or communities? Broader issues of DLC governance, accessibility, financial inclusion, and economic development thus continue to frame the background for this research topic.

In short, if a team builds a digital platform using DLTs, then if that platform gains attention and active user traction, they have effectively also built a "social machine". The rise of social machines should thus be more widely known in the entrepreneurial community since building them may constitute foundational innovation if a social machine works and its model is replicated by other startups. Further research can be conducted into digital (or digitizing) extension services as ways of scaling social machines based on new and established practises and strategies. A required focus on "social enterprise", not necessarily to replace, but rather to function alongside of the "corporate enterprise" or "business enterprise" of blockchains, seems to come as part of the required conversation, given the "distributed" or "decentralized" character of DLT-backed enterprises.

The paper did not address issues involving the management and governance (that is, politics and policies) of DLCs. Rather, it offered a way to think about DLCs as "social machines" constructively towards building better ones in the future, according to the categories of "smartification", with the assumption that management and governance strategies will be included in the process. It did not make a case for whether to regulate algorithms in social machines or even how this could be done in a "smart" or "smarter" way. How "smart" the "smartness" is supposed to be wasn't the

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Table 1. Similarities and differences of social machines, distributed ledger communities and digital extension services

Feature	Social Machines	Distributed Ledger Communities	Digital Extension Services
Digitalization	Yes	Yes	Yes
Scale: Mass Audience aim	Yes	Yes	Yes
Automation	Sometimes	Yes	Sometimes
Multiple Stakeholders	Yes	Yes	Yes
Combined Computational & Social Elements	Yes	Yes	Yes
Interactive Applications	Yes	Yes (DApps)	Yes
Web 3.0	Yes	Yes	Yes
Timestamping	Sometimes	Yes	Sometimes
Encryption	Sometimes	Yes	Possible Option
Smart Contracts	Possible option	Sometimes	Possible Option
Big Data	Oftentimes	Yes	Yes

main point of the article. It served instead as a conceptual paper to introduce a “frame innovation” (Dorst, 2015) for making sense of the incoming effects of social machines, through comparison with DLCs and extension services in areas relevant to entrepreneurial and economic development.

In short, the paper should appeal to entrepreneurial and business opportunities now arising via digital platforms based on DLTs, rather that getting philosophical about social machines, and what risks and rewards they (may) pose to humanity. It looked at how to make sense of economic development today when considering “distributed ledger communities” as “social machines” that can be “extended” through various digital tools, products, and services. To do this, it provided insight into the impacts these new technologies will have on how we create and store data, buy and sell electronic assets, as well as organize, manage, transact, and transfer information peer-to-peer.

The paper offered a sociological perspective on smart(er) digital economies to open a new conversation that brings together several over-lapping languages and socio-technical contexts. Social machines and DLTs appear set to be among the most disruptive innovations for societies around the world since the computer and internet. They provide digital tools, processes, procedures, and governance options via local and regional, along with global “extension” agents to reach masses as well as targeted niches of online participants. Innovative DLCs must there involve administrative and informational foresight about how to use the current and new technological tools to engage knowledges that come from centres, peripheries, and everywhere in between. The arrival of DLTs fundamentally changes the research landscape for social and applied scientists and innovators by enabling new “testing” grounds with volunteer users who can now finally be protected in more secure ways from institutional exploitation with “self-sovereign” digital identities.

The topics highlighted in this paper raise significant ethical issues. The use of real-time updated, dynamic public/private hybrid databases based on voluntary data sharing in using “mechanisms” available in today’s newly forming DLCs is significant. The data collected from members can be used to create a real-life experimental (educational, marketing, or other) laboratory involving actual decisions that people make at micro-, mesa-, and potentially larger society-wide macro- levels. We have a lot of work still in front of us to figure out how to do this the right way, which requires “smarter” distributed thinking that has not yet been cached out or discussed.

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Appendix

Two Types of Progress, Growth, Innovation

0 to 1	1 to n
Technology	Globalization
Invention	Scaling
Vertical progress	Horizontal progress
Creating new things	Copying existing things

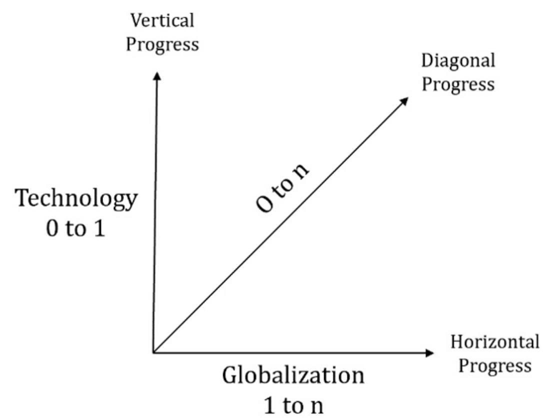

Figure 6. Intensive (“0 to 1”) and Extensive (“1 to n”) thinking about progress, growth, development & innovation.
Source: Image modified from Thiel & Masters, 2014. This diagram adds to Thiel & Masters with “0 to n” diagonal progress.

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“*Cross Pollinators can create something new and better through the unexpected juxtaposition of seemingly unrelated ideas or concepts.*”

Tom Kelley
Author of Creative Confidence, The Art of Innovation and The Ten Faces of Innovation and partner at the renowned design and innovation consultancy IDEO

Blockchain Technology Symposium 2021 (BTS’ 21) is a forum where academic researchers, industry professionals, and decision makers came together to present recent advancements, discuss adoption barriers, tackle common challenges, and explore future roadmaps surrounding blockchain and its related technologies such as consensus algorithms, smart contracts, cryptocurrencies, and distributed ledger technologies generally. As a follow-up to BTS’18 & BTS ‘20, which were hosted by Ryerson University and The Fields Institute, and by popular demand, BTS 2021 gathered a diverse audience from academia, industry, and policy makers to engage in a dialogue around crucial topics in the adoption of blockchain technology, with the aim of cross-fertilizing ideas from these communities to address the challenges and seize the opportunities brought forward by this promising technology. BTS’21 featured multidisciplinary and multi-sectoral talks and presentations on four major themes: (1) decentralized finance (DeFi), (2) decentralized identity, (3) decentralized health and (4) decentralized supply chain management. This article provides reflections on some of the key insights found in the BTS’21 presentations.

Introduction

In his 2004 book, *The Medici Effect*, Francis Johansson describes how creativity and innovation emerge when new ideas are begotten of existing ideas (Johansson, 2004). As ideas bounce off one another, they sometimes stick and form new combinations, and these recombinant ideas generate better ideas. When a person steps into the intersection of disciplines or cultures, the combination of ideas that results can lead to an extraordinary amount of creative new thinking. Thus, from the intersection between two or more fields or sectors, and their underlying ideas, arises technological innovation.

An example of this can be found in the Nobel Laureate, Michael Smith, of the University of British Columbia, who established a then-new interdisciplinary institute, the UBC Biotechnology Laboratory in 1986. This lab brought together established scientists working in the various sub-disciplines of biochemistry to solve important problems in protein structure-function analysis. It is in the spirit of generating this “Medici Effect” through inviting a variety of contributions in a “laboratory” environment that the authors of this article developed Blockchain Technology Symposium ’21 and its forerunners.

The Blockchain Technology Symposium is Canada’s

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premier blockchain conference. Previous symposia were held in 2018 (BTS '18) and 2020 (BTS '20) at the Fields Institute in Toronto, organized by Ryerson University. The BTS intends to be a forum where academic researchers, industry professionals, and decision makers can come together to present recent advancements, discuss adoption barriers, tackle common challenges, and explore future roadmaps surrounding blockchain and related distributed ledger technologies (DLTs), such as consensus algorithms and smart contracts [1].

BTS '21 was hosted by Blockchain@UBC at the University of British Columbia. The event coincided with Blockchain@UBC's fifth anniversary commemoration, and once again brought academic researchers, industry professionals, and decision-makers together, this year around the four "meta-themes" of: decentralized finance (DeFi), decentralized identity, decentralized health, and decentralized supply chains. Our goal was to explore and chart recent advancements, adoption barriers, common challenges, and successful strategies for overcoming those challenges across these four areas of blockchain and distributed ledger application. What resulted was a cornucopia of ideas concerning blockchain and distributed ledger innovation.

The objective of this article is to summarize some of the key ideas articulated in BTS '21 presentations in four sections corresponding to each of the four meta-themes.

Decentralized Finance

BTS '21 opened with a "tour de force" presentation on the topic of central bank digital currencies (CBDCs) presented by Rainer Boehme, a professor for Security and Privacy, Department of Computer Science, University of Innsbruck, Austria. Noteably, Dr. Boehme holds a master's degree in communication science and economics (2003) and a doctorate in computer science (2008), embodying the interdisciplinary knowledge so generative of foundational and new ideas associated with digital and cryptocurrencies that characterize discourse on decentralized finance and CBDCs. Boehme argued that CBDCs should allow central banks to provide a universal means of payment for the digital era, while at the same time upholding consumer privacy and the private sector's primary role in both the retail payment system and financial intermediation. He set out the economic and operational requirements for a "minimally invasive" design of CBDCs and discussed implications for the underlying technology. Developments inspired by popular cryptocurrency systems do not meet these requirements, he argued. Instead, cash serves as the parallel non-digital model. Digital banknotes that run on "intermediated" or "hybrid" CBDC architectures, supported with technology to facilitate record-keeping that involves direct claims on the central bank by private sector entities, were said to be showing promise. The economic design should emphasize the use of a CBDC as medium of exchange and could limit its use as a store of value. Underlying this novel trade-off for central banks, he argued that they can either operate complex technical infrastructures or complex supervisory regimes. Many ways to proceed are possible, while all require central banks around the world to develop substantial technological expertise. Will they be up to the challenge?

This question was provided an answer in the following keynote presentation from Dinesh Shah, Director of Fintech Research at the Bank of Canada. Shah outlined the Bank of Canada's research agenda encompassing the analysis of emerging and potentially disruptive distributed ledger technologies with wide applications to financial system and market infrastructure. BTS '21 participants were given an overview of 5 years of innovative research led by the Bank of Canada considering the implications of blockchain and distributed ledger technologies for financial payments and stability, with the latest research concentrating on the design of a Canadian digital Loonie. Andreas Veneris, Connaught Scholar and Professor at the Department of Electrical and Computer Engineering, cross-appointed with Computer Science at the University of Toronto, provided further detail concerning the rapidly unfolding vision for the future of a decentralized digital currency in Canada. Veneris noted that technological developments in other sectors contrast to those in the financial sector, which, he noted, still operate on legacy infrastructure(s). The net effect is that current payment systems lack the flexibility to adapt to economic digitization. They remain slow, clunky, and expensive; with consumers often

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receiving their digital service, or even physical goods, faster than the merchant receives the payment. Further, the emergence of decentralized finance (DeFi), through blockchain technology, has already demonstrated a capacity to disrupt the financial sector, impact national sovereignty, and affect established monetary transmission channels. Hence, it is no surprise that both national governments and tech firms are now building new digital infrastructures for finance, banking, and payments that circumvent those legacy practices. Veneris outlined research that he and his colleagues have been conducting with the Bank of Canada that advances the field in applying decentralized technologies to create the financial infrastructure of the future.

These keynote presentations were followed up by a series of short talks that further delineated DeFi innovations. Dr. Shin’Ichiro Matsuo from George Washington University’s CyberSMART research centre discussed how to establish harmonization among regulatory requirements and technology development, specifically with respect to “anti-money laundering” (AML) and “know-your-customer” (KYD) privacy enhancement of key management. Matsuo reported that in late 2020, FinCEN published a draft of revised regulation on “virtual asset service providers” (VASP) and unhosted wallets. This year, the Financial Action Task Force (FATF) proposed a revised guidance, which may affect VASP and broader blockchain applications like DeFi and “non-fungible tokens” (NFTs). Though it is essential to integrate privacy-enhancing features to blockchain technology as a way to protect citizens' rights, we need to find a good balance of privacy protection and AML to achieve individual goals and social goals, Matsuo argued. At the Blockchain Governance Initiative Network (BGIN), multi-stakeholders, including engineers, businesses, regulators, and academia, drafted a common document to understand the problems and potential solutions. Matsuo reviewed the discussion at BGIN, including how multi-stakeholder discussions help to create a common understanding and provided a summary of discussions at the FATF’s Virtual Assets Contact Group (VACG) and the Private Sector Consultative Forum event. Artemij Voskobojnikov continued the theme of key management and cryptocurrency wallets by presenting some of his UBC doctoral research on UX issues, security, and privacy risks affecting crypto-asset users, and which prevent non-users from perceiving DLTs as suitable for adoption. Mahsa Moosavi presented work with Jeremy Clark discussing regulatory issues associated with trading on blockchains and distributed ledgers. Moosavi’s talk outlined an evaluation framework comparing four major trade execution systems for blockchain-based assets: (1) central exchanges (CEX) (Binance, Bitfinex), (2) on-chain dealers (Uniswap), (3) hybrid designs (EtherDelta, 0x, IDEX), and (4) on-chain order books. Using the evaluation framework, he argued that fully on-chain exchanges have a better threat model, yet rarely exist in practice because they tend to be slow and difficult to regulate. He then pointed to how infeasible it is to drop a continuous-time order book onto a blockchain when designing a fully on-chain order-driven exchange, highlighting such limitations as slow and non-continuous block intervals, lack of support for accurate time-stamping, dropped or re-ordered transactions, and the potential for front-running. To overcome these limitations, Moosavi presented a novel proof-of-concept system, Lissy, and its primary operations based on a priority queue (PQ) as the core data structure for the call market and illustrating results of the improved design with results from a variety of tests and optimizations, including testing the full call market on an Ethereum Layer-2 scaling solution, Arbitrum.

Following the talks, a group of diverse experts in decentralized finance– Greg Hagen from the University of Calgary’s Faculty of Law and author of a submission to the Bank of Canada’s recent Call for ideas relating to the establishment a Canadian CBDC; Andy Leung, CEO of the decentralized finance company, Acquanow; Alfred Lehare, Associate Professor, Haskayne School of Business, University of Calgary; and Andreas Park, Associate Professor of Management, Rotman School of Business, University of Toronto– presented their perspectives on DeFi development challenges and opportunities, expertly guided through a series of questions and answers by Zach Masum, who leads the British Columbia Securities Commission’s Fintech and Innovation Team (FIT), which handles a broad spectrum of fintech-related matters including DeFi, AI/machine learning, DLTs, robo-advising, crowdfinancing, online

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trading, and other technology-focused business models.

Decentralized Identity

The following day opened in an equally spectacular keynote from Jan Camenisch, VP of Research & Crypto at DFINITY and Director of the DFINITY Zurich Research Lab. He also serves on the decentralized identity blockchain Sovrin’s Technical Governance Board. Before joining DFINITY, Jan was a Principal Research Staff Member at IBM Research —Zurich, where he led the Privacy & Cryptography research team and was a member of the IBM Academy of Technology. Those familiar with research in cryptography will be aware of Camenisch’s enormous impact in the field of cryptography (see, for example, Camenisch and Standler, 1997; Camenisch and Lysyanskaya, 2001; and Brickell, Camenisch and Chen, 2004, to name just a few of his contributions). Camenisch’s presentation showed his latest research on the history of cryptography and use of distributed ledgers as the basis for an “internet computer”. Camenish recounted how, for centuries, cryptography had been the art of encrypting messages, while now it has become an immensely powerful tool to extend the internet’s functionality from connecting billions of people to also providing millions of developers and entrepreneurs with a public compute platform. This is creating a revolutionary new way to build websites, enterprise systems, DeFi, and open internet services, about which Camenisch gave a masterclass in cryptography past, present, and future.

Camenish’s more theoretical talk was followed by Joni Brennan, President of the Digital ID & Authentication Council of Canada (DIACC), who presented a recently completed survey of Canadians’ attitudes toward the adoption of decentralized ID. The study found that the COVID-19 pandemic has rapidly accelerated Canadians’ openness to Digital ID adoption, noting that three-quarters of Canadians feel that it’s important to have a secure, trusted, and privacy-enhancing digital ID to make transactions online safely and securely. As governments across the country focus on post-pandemic recovery, investing in digital ID makes strong economic sense, especially for small and medium-sized businesses (SMEs). For SMEs, the impact of digital identity could be used to improve processes that are difficult today. This is especially true in situations where businesses need to provide proof of identity to another business. Considering that SMEs account for approximately 30 percent of Canada’s overall GDP ($450 billion CAD), if we assume that the average SME could be just one percent more efficient with access to trusted digital identity, adopting digital IDs could result in a potential $4.5 billion CAD of added value to SMEs and reinvestments in the Canadian economy.

The short talks that followed highlighted various dimensions of digital ID research and adoption, with Michael Cholod’s rousing presentation on the need to protect personally identifiable information and online privacy, Mike Brown of ATB Financial recounting four years of experimentation in the journey towards adopting digital identity in Alberta led by ATB, and Gregory Sandstrom presenting a more theoretical talk connecting decentralized IDs and technologies with the notion of “social machines” first articulated by Tim Berners-Lee and Mark Fischetti (1999), calling attention to a constructive framework for thinking about how to build better ecosystems. This presentation made a basic appeal about incoming opportunities in DeFi and digital identity currently arising via business ecosystems enabled by DLTs, in particular by means of “digital extension services” that allow for mass global scaling of decentralized solutions.

Marc Kneppers, Chief Security Architect at TELUS, then led participants through a panel session with experts in the area of digital ID: Mathieu Claude, CEO of Northern Block; Doug Heintzman, VP of Global Strategy at Soveren and Insolar, Chetan Phull, Associate Lawyer in Cybersecurity, Technology and Data Management Law | Deloitte Legal Canada LLP, and Darrell O’Donnell, a well-known strategy and technology advisor on digital identity. Panellists pointed to many digital ID projects illustrating the fact that decentralized digital identity solutions are not only becoming a reality, but also we can now see that they are set to add real social and economic value.

The day wrapped up with an enlightening presentation by Tatsuya Kurosaka, President and Chief Executive Officer, Kuwadate Incorporated, and Tatsui Narita,

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Councillor for Competition Policy in Digital Economy, Cabinet Secretariat, Japan, presenting on digital ID developments in Japan and calling for global collaboration on research and implementation. Additional global perspectives offering feedback were provided by Volker Skwarek, Professor for Embedded Systems and Head of the Research and Transfer Centre for Digital Business Processes at Hamburg University, and Victoria Lemieux, Associate Professor of Archival Science and Co-Lead of Blockchain@UBC at UBC.

Decentralized Health

It is no surprise, given how the global pandemic has concentrated peoples’ attention on the need to innovate in healthcare, that the third BTS ’21 day focused on decentralized health, which presented evidence of remarkable advancements in this sector over the past year. Dr. Chandana Unnithan, Associate Professor, Torrens University Australia, and CISO/CTO Lifeguard Digital Health, opened the session by sharing insights from her involvement in Australian, Canadian, and World Health Organization initiatives focused on the use of blockchain and distributed ledger technologies in global disease surveillance. Dr. Unnithan noted how, globally, blockchain technology is being used to encourage consumer-centred health care and facilitate remote healthcare management. She argued that some inimitable features that render this technology an excellent catalyst in healthcare include its ability to validate transaction processes, prevent system failure from any single point of transaction, and approve data sharing with optimal security. In many countries, she noted, hospitals are already using blockchain in electronic medical record systems, while health professionals leverage the approval of data sharing as a best method for peer consultations with patient engagement. In the current context, Dr. Unnithan argued that blockchain has the potential to strengthen disease surveillance systems during outbreaks such as the SARS-CoV-2 outbreak, which result in health emergencies. The blockchain system enables classifying health security concerns, analysing preclusion methods, and facilitating rapid and impactful decision making. The potential for distributed health solutions to strengthen health care systems and reduce the global burden of disease, mortality, and morbidity is being researched around the world, and stands to make an enormous contribution to the betterment of global health.

Dr. Wendy Charles, Chief Scientific Officer at BurstIQ, next presented the concept of “Ethics by Design”, drawing upon work discussed in Charles et al. (2019). She argued that as commercial blockchain organizations develop blockchain platforms for healthcare, these organizations should be mindful of patient-centered designs and need for data protection. These principles then influence decision points for maximizing data access, control, analytics, and engagement. She went on to discuss the ethical principles, challenges, and opportunities for responsible design and implementations of decentralized health technologies based on real-life experiences with the implementation and operation of blockchain solutions in a wide variety of global contexts. Dr. Charles’ generosity in sharing a wide variety of strategies and solutions from her own experience was particularly appreciated by participants, picking up issues involving the assurance of data accuracy and fair representation of individuals in relation to health data records stored “on chain”.

Following the keynotes, three short talks exemplified some of the developments and issues discussed by the keynote presenters. Noelannah Neuberger presented innovative work being led by Dr. Lili Liu at the University of Waterloo on applying self-sovereign identity solutions to address challenges faced by those suffering from dementia. This ongoing project has aimed to: (1) develop a lay definition of self-sovereign identity (SSI) that is understandable to persons with dementia and their caregivers, and (2) obtain feedback from the dementia community pertaining to the use of guardianship within the context of SSI, including how it can be applied specifically for those living with dementia. Dr. Neuberger outlined the research team’s two-phase study, with the first phase consisting of concept development that involved a search of the grey and scholarly literature, conducting interviews, and focus groups including persons with dementia and their caregivers. Key elements of SSI highlighted by participants and in the literature included digital identity, decentralized authority, ownership and control, privacy and security. This was captured in a short video for knowledge translation [2]. To meet the second objective, the team then conducted semi-structured

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interviews with persons living with dementia, caregivers, members of industry, and community organizations from Canada, the United States, the United Kingdom, the Netherlands and Australia. Results were divided into three categories: (1) current guardianship practices, (2) potential benefits and limitations of SSI on guardianship, and (3) considerations regarding guardianship and SSI. The findings from this project will be used to determine the feasibility of integrating SSI to assist in collecting valuable data from missing persons with dementia.

A second short talk was presented by Dr. Rob Fraser, CEO of Molecular You, an AI-driven personalized healthcare company. Dr. Fraser noted that one of blockchain's key applications has been to decentralize the management of privacy. Blockchain protocols such as Hyperledger's Indy and Aries, the platform used to develop Molecular You's novel blockchain solution, MyPDx, which is being developed in collaboration with the University of British Columbia and StonePaper, with funding support from Canada's Digital Technology Supercluster, have been specifically designed to give users control over their health data to achieve decentralized privacy management and secure data sharing. The solution design gives users custody and control over their personal health data credentials in a manner that fundamentally respects users' privacy. Nevertheless, it still allows for and incentivizes the sharing of verifiable credentials that contain personal health data to advance knowledge in an ecosystem of mutually beneficial healthcare partnerships.

Finally, Dr. Mark Martz, Director of the Arizona Center for Tobacco Cessation and Assistant Professor of Practice in the Mel and Enid Zuckerman College of Public Health at the University of Arizona, presented on the suitability and application of blockchain technology in a use case aimed at encouraging smoking cessation. Picking up on earlier themes discussed by Dr. Unnithan, Dr. Martz noted the global phenomenon of people facing an inability to access preventive, population-based health care services efficiently and effectively. Additional challenges were identified in areas with limited access to technology and scarce financial resources. Information technology has enabled health care providers to improve patient access to preventive services. However, when providers rely on external care providers to provide such services, gaps potentially arise when delivering services in a timely manner that can influence adherence in the patient program. Dr. Matz highlighted these challenges in the context of the Arizona Smokers' Helpline (ASHLine), a tobacco cessation service provider located in Arizona that delivers education, behavior change, and pharmacotherapy interventions to support successful quit attempts. He explored the viability of implementing a DLT-based architecture to fill this gap in patient enrollment for improving patient program adherence and quit outcomes for ASHLine clients.

During the last panel session, Evgueni Loukipoudis, Chief Technology Officer, Canada's Digital Technology Supercluster; Chang Lu, Postdoctoral Research Fellow, University of British Columbia; Lucy Yang, Community Director, Covid-19 Credentials Initiative; and R. Mohan Tanniru, Professor, University of Arizona, all shared their impressions and insights on the state of current technical, adoption, and regulatory challenges, along with existing opportunities in the area of decentralized health. The panellists updated participants on the global decentralized health landscape, discussed new uses, prime movers, industry leaders, early adopters and the unique challenges of rolling out a novel emerging technology in a sector that is not known for adopting information technology innovations.

The day's final session offered information about The University of British Columbia's new micro-certificate in "Blockchain Innovation and Implementation" [3], a part-time program designed for professionals who need to identify, assess, and lead blockchain initiatives. This program represents one of a growing number of new blockchain programs and educational offerings now available across Canada and globally [4].

Decentralized Supply Chain

The final keynote was delivered by another international luminary in the field, Dr. Aggelos Kiayias, Chair in Cyber Security and Privacy and Director of the Blockchain Technology Laboratory at the University of Edinburgh. Dr. Kiayas focused his presentation on "Rethinking Information Technology Services as Incentive Driven Collaborative Systems", picking up on themes from

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Sandstrom's talk on "social machines". With the introduction of Bitcoin and blockchain technology, Dr. Kiayas noted, we are witnessing the first example of an information technology service deployed via open and incentive-driven participation. Viewed in this light, the IT service emerges out of self-interest from computer node operators who enroll themselves to support the system's operation, which they do in exchange for rewards provided by the system's digital (or crypto) currency. In his talk, Kiayias fleshed out this approach as a novel paradigm for deploying general purpose IT services, discussing design challenges and use cases beyond financial transactions, such as anonymous communications and supply chain management.

Sergei Belieav, EVP and Chief Strategy Officer for DLT Labs, is an emerging leader in applying blockchain to enterprise data management, for which his talk provided an overview. He made the point that nowadays companies don't compete; supply chains do. Business leaders need to realize the value of agility in a modern economy, especially as we prepare for recovery from a global pandemic. Digitization, automation, and blockchain are key considerations as companies attempt to shave costs and improve efficiency, according to Beliaev, while "hyper-automation" is grabbing headlines around the world as companies become more networked. A key challenge with multiple parties that need to work together is how to ensure that information is reliable, trusted, auditable, secure, and can be shared among parties. Beliaev views blockchain-based networks as having turbo boost power for hyper-automation, in that they establish tamper-proof real-time data-sharing networks. Coupled with fully automated execution that uses smart contracts, distributed ledgers offer the most effective foundation today for bringing independent market participants together, while minimizing the overhead burden of administration, and simplifying business processes.

The short talks that followed picked up on the keynote themes. Michel Legault's talk discussed the challenges of decentralized information management, when managing content as part of network transactions. Transactions on a DLT may require supporting documents, for example, photos, reference documents, or actual contracts. This type of electronic content has typically been stored and managed on content management systems that include enhanced features, such as document version control, metadata tagging, and the retention and disposition of records. Legault highlighted several issues of importance as DLTs become an increasingly popular method to complete transactions and share information, such as whether electronic documents should be stored directly on a blockchain, or in a supporting content management system (either with a traditional system or a distributed storage system), the need to consider whether updates to supporting documents will be done within an existing, completed, or new transaction, and the retention and disposition of records governed by legal and regulatory requirements. Mohamed Sadegh Sangari, a postdoctoral researcher in the Cybersecurity Research Lab (CRL) at Ted Rogers School of Management at Ryerson University, presented work with Atefeh Mashatan on building resilience through decentralization and a data-driven analysis of blockchain implications for supply chain resilience. Dr. John Steen, Associate Professor & Director of the Bradshaw Research Initiative in Minerals and Mining (BRIMM) at The University of British Columbia discussed applying DLTs in the context of sustainable mining, observing that the mining sector is on the cusp of the biggest production surge in history driven by the need for metals as the global economy shifts to electric power. According to the World Bank we will need as much copper in the next 30 years as we have produced in the entire history of humanity. In facing this challenge, the mining sector has become an innovative adopter of blockchain technology in three main areas. First, making transactions between producers and customers more efficient. This is happening now and being used for bulk materials like iron ore. Second, coordinating inputs and information in mining operations. This also improves business productivity, while having the potential to make mining into a business of networks and consortia, much like the aerospace industry. Lastly, blockchain has great potential both to allow customers to see the product history of what they are buying as well how it was produced. This has potential for branding some metal products as "green" or "fair trade".

A closing panel session led by Dr. Atefeh Mashatan and featuring Dr. Henry Kim, Associate Professor of

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Operations Management and Information Systems, Co-Director, BlockchainLab; Patrick Mandic, CEO, Mavennet; Erik Valiquette, Canadian Blockchain Supply Chain Association; and Paul Horbal, Partner at Bereskin & Parr LLP, covered the current state of the supply chain industry, from procurement and logistics to transportation. Each panelist drew upon their expertise and experience to articulate some supply chain management shortcomings that could be addressed by the decentralizing processes afforded by blockchain technology. Cross-sectional challenges such as patenting intellectual property that touches multiple jurisdictions, lack of interoperability among supply chain platforms, governance issues, and standardization gaps were among topics that were extensively discussed during the session in the specific context of supply chain management. Finally, the panelists shared their future vision for decentralized supply chains, discussing both technical and non-technical challenges that need to be addressed before supply chains can more fully leverage the potential of decentralization.

Conclusion

BTS ’21 demonstrated how the past four to five years’ research and development has given rise to many new ventures and initiatives that are bringing what were at one time only theoretical ideas into practical realities. Those who missed taking part in the BTS ’21 event may wish to review recordings of the sessions that are available online [5]. BTS ’18 was notably marked by the generation and proliferation of a wide variety of use case ideas for applying blockchain and distributed ledger technologies. BTS ’20 saw much more talk about adoption, but from a primarily theoretical “looking ahead” standpoint. BTS ’21 went further to demonstrate the growing maturity of decentralized solutions, including discussions of real projects, real challenges, and real opportunities for coming applications.

The multidisciplinarity of the challenges and the requirement for cross-pollination of ideas to tackle these challenges are also evident. Technical innovation must go hand in hand with local and national policy development, as well as social innovation if advancements such as CBDCs, global internet computers, personalized healthcare powered by blockchains, and distributed ledger-based global supply chain ecosystems are to succeed on a mass scale.

With the excitement of BTS ’21 now at a close, we await with eager anticipation BTS ’22, to be hosted by the University of Calgary. With the pace of innovation in the space of decentralized and distributed technologies, we are confident that the research and developments featured at the next BTS event will demonstrate considerable further advancements, especially if BTS ’21 has been successful as a “cross-pollinator” stimulating a “Medici Effect” that creates new connections and networks of innovation among participants.

Links

[1] BTS ’18 presentations can be found at: http://www.fields.utoronto.ca/activities/18-19/blockchain_technology

BTS ’20 presentations are available at: http://www.fields.utoronto.ca/activities/19-20/BTS_2020

[2] What is self-sovereign identity? Technology and Aging Research Group, 2020. https://youtu.be/0WicIm8x_GY

[3] For more information: https://extendedlearning.ubc.ca/programs/ubc-microcertificate-blockchain-innovation-implementation

[4] See, for example, https://www.accounting-degree.org/college-cryptocurrency-blockchain-courses/

[5] See the BTS’21 schedule, where videos are in the process of being finished editing, then links will be added: https://blockchain.ubc.ca/blockchain-technology-symposium-21-schedule

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