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Blockchain Technology and its Applications Across Multiple Domains: A Survey

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ABSTRACT

Blockchain technology has become an active area of research and a technological option for many businesses and industrial communities. With its distributed, decentralized, and trustless nature, blockchain can provide businesses with new opportunities and benefits through increased efficiency, reduced costs, enhanced integrity and transparency, better security, and improved traceability. Although blockchain's largest applications have been in the finance and banking sector, we now see experiments and proposed applications in different fields. This paper provides an overview of blockchain technology; it brings together all the key design features, characteristics, and benefits of blockchain that make it a superior and unique technology, and it presents the popular consensus protocols and taxonomy of blockchain systems. Additionally, the paper surveys blockchain-based applications across multiple domains such as in finance, insurance, supply chain management, energy, advertising and media, real estate and healthcare. It aims at examining the industries' key issues, blockchain solutions and use cases. The paper highlights three broad limitations that blockchain technology presents: scalability, security, and regulation, and shows how these challenges could impact blockchain application and adoption.

Keywords: Blockchain, Distributed Ledger, Cryptocurrency, Smart Contracts, Decentralized Applications

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INTRODUCTION

The concept of blockchain was initially introduced in November 2008 and was implemented in January 2009. A presumed pseudonymous person or persons named Satoshi Nakamoto developed the virtual currency, bitcoin, and published the bitcoin white paper. In this paper, a decentralized, publicly available, and cryptographically secure system based on a chain of blocks was proposed, allowing peer-to-peer digital currency trading and eliminating the need for centralized financial institutions to enable currency issuance or transaction settlement (Dai & Vasarhelyi, 2017; Murray, 2018; Nakamoto, 2008). Bitcoin and blockchain are not synonymous. Blockchain provides the infrastructure for recording and storing bitcoin transactions; it has many uses besides bitcoin. Bitcoin is the first application of blockchain (M. Gupta, 2017; V. Gupta, 2017). In *Blockchain for Dummies*, M. Gupta explains,

> Bitcoin is actually built on the foundation of blockchain, which serves as bitcoin's shared ledger. Think of blockchain as an operating system, such as Microsoft Windows or MacOS, and bitcoin as only one of the many applications that can run on that operating system. (2017, para.8).

Moreover, blockchain should be considered as an overarching idea that includes various technologies and applications. The concept of blockchain can be compared to the Internet, which has many technologies and applications. It is argued that blockchain is likely to transform business in as great a manner as the Internet. Blockchain can disrupt in a positive manner central banking platforms and many business models and use cases, including trades, financial services, supply chains, business process improvement, health information sharing, and logistics management (Woodside et al., 2017).

Dissimilar to a distributed database, users in a distributed ledger do not trust each other and verify transactions independently. A distributed ledger is a replicated, decentralized, synchronized, and cryptographically secured record of data and transactions shared between contracting parties. Distributed ledgers are broadly categorized into two groups: those seeking the minimum role of trusted third parties and those who are still relying on those third parties to handle some of the systems' properties (Treleaven et al., 2017). Blockchain is usually grouped under distributed ledger technologies. These include all decentralized systems for recording transactions and sharing data across multiple servers, organizations, or countries. Blockchain is a distributed ledger, but not all distributed ledgers are blockchains; not all distributed ledgers are based on a chain of blocks (Aste & Tasca, 2017; Treleaven et al., 2017).

Blockchain is an emerging technology; its underlying technical aspects are challenging to understand, particularly for non-specialists. Complex algorithms and computer protocols underpin this technology. However, according to early adopters of technology tools, becoming a coding expert does not seem to be required to use this technology. Like any other advanced technologies, businesses and organizations do not need to master said technology's technical fundamentals to recognize its benefits (Smith, 2018a).

While many survey papers on blockchain exist, a few covered its applications across various domains. Some of these survey papers can be found in the bibliography. This paper surveys blockchain applications in several domains, focusing on fields and industries with the highest potential for blockchain application success. The objectives of this paper are as follows: first, addressing the characteristics and benefits of blockchain that make it a technological option for many individuals, businesses, and institutions; and second, discussing the recent advances of

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said technology into a number of domains; covering several blockchain applications and some developed technological tools for these applications. An in-depth discussion of the technical aspects of blockchain is beyond the scope of this survey. The paper is organized as follows. Section 2 provides an overview of blockchain technology, while Section 3 addresses blockchain applications in different domains. Section 4 discusses the limitations of blockchain technology. Section 5 concludes the paper.

BLOCKCHAIN OVERVIEW

This section discusses blockchain fundamentals, including blockchain concept, design features, characteristics and benefits, popular consensus protocols, and types of blockchain systems.

Blockchain Technology

In the white paper *Bitcoin: A Peer-to-Peer Electronic Cash System*, Nakamoto (2008) introduced two technological and innovative ideas. The first idea was that bitcoin, a digital currency that can be traded without a central financial authority. The second idea was the concept of blockchain. As its name explains, blockchain is a chain of blocks interconnected with complex computational crypto algorithms. The underlying notion of this technology is storing digital assets of any kind in blocks; blocks are linked by a digital fingerprint called hash and stored in limitless places on a distributed database (Cirstea et al., 2018; Woodside et al., 2017). Blockchain is a "distributed ledger technology for a new generation of transactional applications that establishes transparency and trust" (Linn & Koo, n.d., p. 2). Koshechkin et al. (2018) emphasized that blockchain is both a peer-to-peer network and a public database, operating without a central server.

The essential concept of blockchain is little more than the idea of a secured register or list for data records and storage of past transactions, which are validated and confirmed by blockchain parties. The core value of blockchain is the true representation of reality at any given time, thus creating trust in businesses between participants. Blockchain can be thought of as a state machine; it stores the status of things that have happened, then updates that status while a permanent record of past states remains. These past states are almost impossible to be changed (Adams et al., 2017).

One of the key strengths of blockchain is "hashing." Each block has information to be stored, and every new block added in the chain is encoded with a "hash," a code arithmetically produced and generated from the block's date. "Hashing" is not a new method; it is often used to secure passwords. Moreover, each newly added block includes the hash of the preceding block in the same block hash. In this way, falsifying new or old blocks becomes very difficult. Hashes of previous blocks determine the hashes of subsequent blocks; therefore, altering a single block would require rewriting the entire blockchain. This mechanism of linking the blocks into a chain makes tampering extremely difficult (Hughes & Morrow, 2019; White, 2017).

As shown in Figure 1, blockchain was initially introduced to trade and save the cryptocurrency bitcoin safely. This digital currency application represents Blockchain 1.0, which enabled the issuance, distribution, and transaction of digital currencies. It has then been developed further, allowing for Turing-complete programming languages. This development, which enables users to develop smart contracts that can run on the blockchain, is considered Blockchain 2.0. The most commonly used blockchain-based platform that supports smart contracts is Ethereum (Li et al., 2017; Oh & Shong, 2017). Blockchain application extension beyond currency and economics marks the Blockchain 3.0 era (Aras & Kulkarni, 2017).

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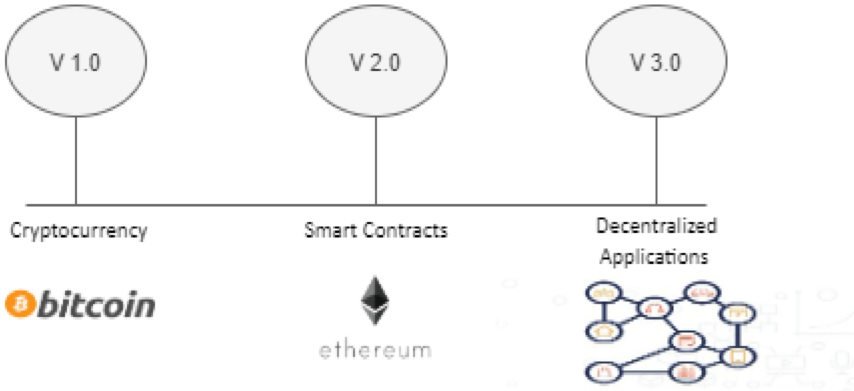

Figure 1. Development of blockchain

Engelhardt (2017) pointed out that, generally, blockchain is most suitable for businesses and institutions that meet the following conditions. First, multiple stakeholders are involved. Second, more and more trust is needed between parties. Third, the removal of an intermediary is possible to enhance trust and efficiency. Fourth, reliable tracking of activity is needed, and there is a need for data to be reliably maintained over time. Maull et al. (2017) proposed a series of steps that should be considered as part of the acquisition process of blockchain by potential blockchain adopters, as shown in figure 2. These steps demonstrate when blockchain can be used and suggest different useful types of blockchain technology for different scenarios.

Blockchain-Based Design Features

The core features of a blockchain-based design are critical to the superiority and uniqueness of this technology. Perkinson and Miller (2016) emphasized that these design features are highly appreciated, especially in environments where transaction verification, reconciliation and settlement, and dispute resolution take up an unreasonable amount of energy and resources; they summarized these features as follows.

- **Transaction confirmation:** Blockchain is underpinned by protocols that require users to confirm transactions as a precondition for posting; this ensures the validity of transactions.

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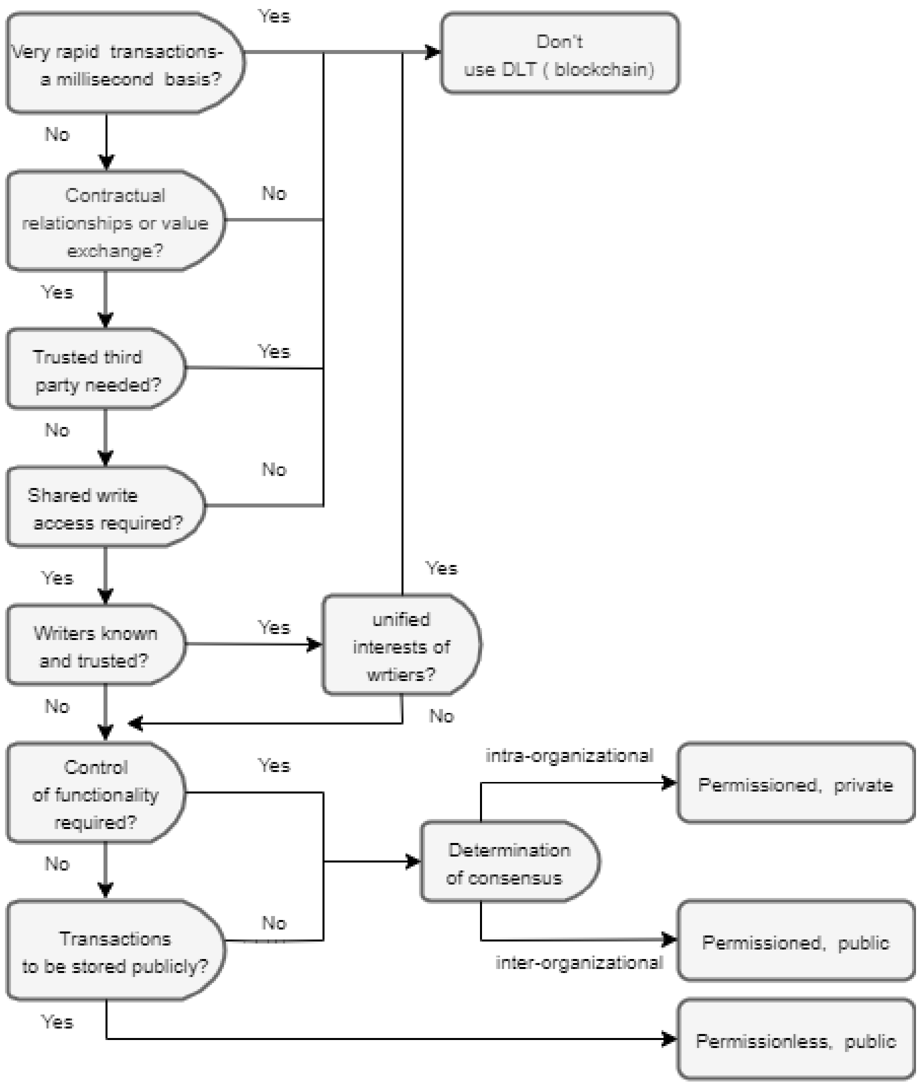

Figure 2. Flowchart of application of DLT, blockchain (Maull et al., 2017)

- **Settlement verification:** As counterparties confirm transaction details, blockchain immediately verifies the pre-transaction ownership of the underlying asset being exchanged, allowing for the settlement of the asset's transfer as the transaction is completed.
- **Permanent timestamp:** Once blocks are created, added to the chain, ordered accurately, and timestamped, an immutable record of the sequence and timing of the blocks in the chain is created.
- **Smart contract automation:** It is not an inherent feature of a blockchain design, but blockchain ledgers can support smart contracts that run automatically under specific requirements and conditions. Smart contracts are further discussed later in this section.

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Characteristics of Blockchain Technology

Characteristics of blockchain are widely discussed in the literature. Many research papers similarly framed these characteristics; however, some of the blockchain characteristics contribute to other specific characteristics, and thus the list can be shortened. Table 1 summarizes the overarching characteristics of blockchain technology.

Table 1. Characteristics of Blockchain Technology

Characteristic	**Explanation**
1. Distributed	All users of a blockchain can access the entire system, see all transactions in the distributed ledger, and verify its transaction partners' records. There is no central authority or any trusted third party for transaction verification or settlement (decentralization). The truth of data is confirmed by consensus among all blockchain's participants (consensus-based data approval). Peers communicate directly, not via a central node. Nodes, the connected computers to the network, store and spread information to each other (peer-to-peer transmission).
2. Standardized Rules	The blockchain mechanism requires following a set of same rules in every transaction processing. It is extremely difficult to falsify data in a blockchain (persistency) or delete or alter information stored in any block (immutability). This all attributes to features of the hashing function and the unique hash identifiers. However, immutability does not necessarily mean that a change of blockchain information is ever impossible. New blocks might be added to the chain to modify or clear out some old data that have been mistakenly uploaded.
3. Privacy	As an innate feature of the platform, users (nodes) cannot be publicly identified. Each party can use the blockchain with a generated address without the participant's real identity being revealed. Users interact using blockchain addresses (anonymity). Nevertheless, privacy within a blockchain cannot be preserved completely or guaranteed perfectly due to some inherent constraint.
4. Auditability	Previous records can be easily verified and traced as transactions are validated and recorded with a timestamp, making data stored in a blockchain traceable and transparent. Computational algorithms are employed to ensure the permanence and chronological order of the recording on the ledgers and the availability of this recording to all network users (irreversibility of records).

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5. Security	The powerful cryptography in a blockchain gives users ownership of addresses and the associated crypt assets in an assortment of public and private keys. There is no direct association between these addresses and users' identities, eliminating identity theft. Additionally, as hashes link blocks, tampering data within any given block would change other connected blocks. Therefore, user's information and transaction data are well secured within the blockchain technology.

(Sources: Angeles, 2018; Chedrawi & Howayeck, 2018; Engelhardt, 2017; Kumar, 2019; Monrat et al., 2019; Shi et al., 2020; Smith, 2018b; Zheng et al., 2018; Zheng et al., 2017)

Benefits of Blockchain Technology

Blockchain technology is still embryonic, but it has changed many businesses and has become an appealing technology for many industries, even in this formative stage. Some of the vital benefits of blockchain application include the following (Beck, 2018; Herlihy, 2019; Kumar, 2019; Workie & Jain, 2017):

- **Transparency:** In a blockchain, a complete history of transactions is permanently maintained and simultaneously available to all network users. All users involved in a transaction are aware of any actions taken on any data or transactions executed, thus promoting increased transparency.
- **Business Continuity:** The availability and continuity of services provided is a crucial requirement for all businesses. The absence of a vulnerable single failure point in the blockchain technology means the system is never down, despite some parts' failure, thus supporting business continuity.

  Disintermediation: Blockchain infrastructure’s being truly decentralized enables a significant level of disintermediation. Technology protocols and elements can replace intermediaries, enhancing efficiency, and reducing friction-related direct and indirect costs between individuals and organizations, due to decreased trust.
- **Trust:** The blockchain mechanism's underlying concept is the establishment of a trustworthy record between untrusted parties. The good design of blockchain-embedded protocols and cryptography property enforce trust and ease its verification.
- **Smart Contracts:** Some functionality can be added to ledgers, as most blockchain applications provide some scripting languages. For instance, a rudimentary stack-based language is contained in bitcoin, whereas a language similar to JavaScript, a Turing-complete imperative language, is provided by Ethereum. These programs, so-called smart contracts, are computer codes/software designed to digitally facilitate, verify, and enforce the business logic's negotiation or performance. Smart contracts are self-executed and automate the execution of credible transactions and actions (e.g., exchange of property, money, shares, or anything that has a value), without a middleman, as the terms of agreements are fulfilled. Smart contracts can be utilized in traditional systems, but data integrity and data availability to all parties make blockchain the right technology platform to leverage smart contracts.

The discussed key design features, characteristics, and benefits of blockchain technology are summarized below in Figure 3.

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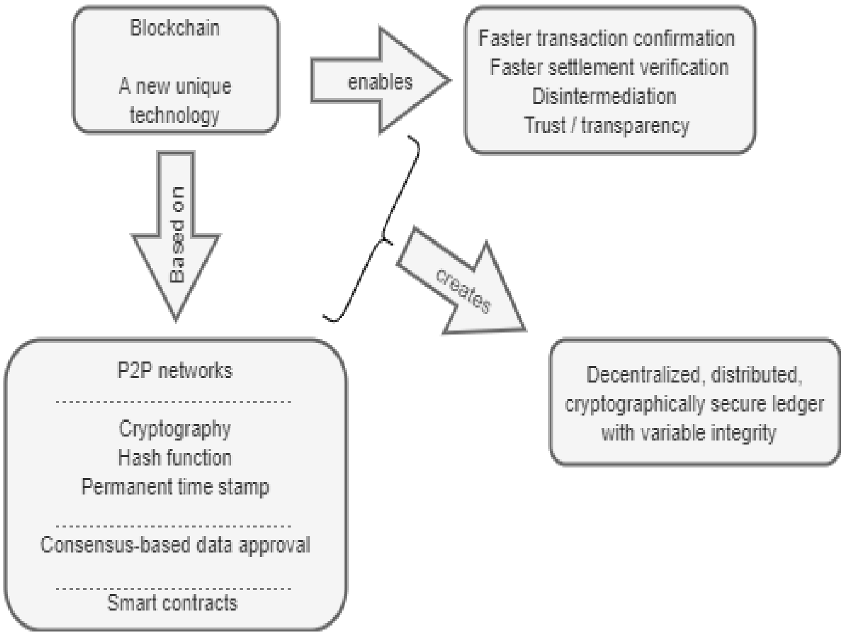

Figure 3. A combination of key design features, characteristics, and benefits of blockchain technology

Consensus Protocols

Blockchain systems are decentralized in nature, which eliminates the need for a third-party, trusted authority. To resolve and regulate disputes between nodes, protect against security violations, and ensure data and transactions are always reliable and consistent, blockchain employs the decentralized consensus protocol. There should be agreement on a common protocol for content updating amongst all nodes, and blocks should only be processed with majority consent for maintaining a constant state; this is the consensus mechanism on which the creation and addition of blocks to the ledger is based (Li et al., 2017; Puthal et al., 2018; Wu et al., 2019).

The most common consensus mechanism used in the current blockchain systems include Proof of Work (Pow), Proof of Stake (PoS), Practical Byzantine Fault Tolerance (PBFT), and Delegated Proof of Stake (DPoS) (Bach et al., 2018; Zheng et al., 2018). Some blockchain systems use other consensus mechanisms such as Proof of Authority (PoA) (Technologies, 2017), Proof of Bandwidth (PoB) (Ghosh et al., 2014), Proof of Elapsed Time (PoET) (Corso, 2019), Ripple (Schwartz et al., 2014), and Tendermint (Kwon, 2014).

Bitcoin and Ethereum, the most popular blockchain platforms, use the PoW mechanism; however, Ethereum is moving from using Ethash, a kind of PoW, to Casper, a kind of PoS (Zamfir, 2015). The most widely used consensus protocols are addressed briefly in this paper. In their research paper, Bach et al. (2018) provided a detailed comparative analysis of blockchain consensus algorithms.

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Proof of Work: PoW is a consensus approach used in the bitcoin system, requiring solving a complex cryptographic puzzle (computer calculations) to lock transactions into the ledgers. The rules state that blocks can be added to the chain when this puzzle is solved, and the consensus is achieved. The process that facilitates this is called mining, a competition in transaction validation among users (Aras & Kulkarni, 2017; Aste & Tasca, 2017; Monrat et al., 2019). Although the puzzle can be a computationally challenging problem, this problem is easily verifiable (Li et al., 2017).
Nodes called miners compete to calculate the hash value of the block header. The calculated value must be the same as or less than an absolute value. As a node arrives at the target value, the block is created and broadcasted to other nodes at particular synchronization, which must automatically confirm the truthfulness of the hash value. After the block is validated, all other nodes add this newly created block to their blockchains, rolling back any unconfirmed transactions (Aras & Kulkarni, 2017; Zheng et al., 2017). In PoW, the consensus is linked with computing power, which makes this consensus strategy expensive. The possibility of winning for any user depends on the computing power they control. Fifty-one percent of power, not of people, is required to achieve consensus. Therefore, computer power used by all nodes that did not win is wasted (Aras & Kulkarni, 2017; Aste & Tasca, 2017).

Proof of Stake: PoS is another approach to achieving consensus in a blockchain system. It saves energy compared to PoW, which increases the productivity of the whole blockchain system. In PoS, nodes do not have to do any computer calculations; instead, nodes that generate blocks have to prove they have access to a specific amount of currency to be accepted onto the system (Li et al., 2017; Vasin, 2014). The underlying idea of PoS is that acquiring a sufficiently significant amount of digital currencies might be harder for miners than acquiring sufficient powerful computing equipment. Thus, the stakes of blocks are split proportionally to miners' current wealth instead of their computing power (Aras & Kulkarni, 2017; Pilkington, 2016).
Moreover, it is argued that users with more coins are less likely to attack the system; however, the wealthiest user is bound to dominate the network. Therefore, some projects proposed solutions that are combined with the stake size (Zheng et al., 2018). For example, in Blackcoin (Vaisn, 2014), the block creator is predicted by the randomization method. A formula is used to look simultaneously for the smallest hash value and the stake size.

Practical Byzantine Fault Tolerance: The Federated Byzantine Agreement (FBA) is the approach used in dealing with the Byzantine Generals problem (Miguel & Barbara, 1999; Lamport et al., 1982, cited in Zheng et al., 2017). This approach is based on the assumption that users of the network are known to each other and can determine each other's importance. PBFT is a replication algorithm that employs the same principle (Aras & Kulkarni, 2017; Wu et al., 2019).
PBFT is a consensus mechanism used in Hyperledger Fabric by which up to one-third of malicious byzantine replicas can be handled. In PBFT, new blocks are generated in rounds, and a primary (validator) node is selected according to the same idea. The primary node is responsible for ordering transactions and multicasting requests to other replicas in its group, and each replica commits in the same way. There are three stages in this process: pre-prepared, prepared, and commit. Moving from one phase to the next requires receiving votes over two-thirds of all nodes.

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If a client does not receive replies, it will send the request to all replicas, not only to the primary, because the primary might be faulty (Aras & Kulkarni, 2017; Zheng et al., 2017). Other consensus protocols that employ a byzantine agreement protocol include the Stellar Consensus Protocol (SCP) (Mazieres, 2015) and delegated byzantine fault tolerance (DBFT) (Antshares, 2016).

Delegated Proof of Stake: DPoS is similar to PoS; however, they differ in that the former is representative democratic while the latter is direct democratic. In DPoS, delegates, which are elected by participants, generate and validate blocks. Thus, this delegation decreases the number of nodes for block validation, resulting in quick block confirmation, which leads to immediate transaction confirmation. In the meantime, delegates can tune network parameters such as block size and block intervals. Moreover, delegates proved to be dishonest can be easily voted out (Aras & Kulkarni, 2017; Monrat et al., 2019; Zheng et al., 2018). A blockchain platform that utilizes DPoS is Bitshares (Bitshares, 2015).

Comparison of Blockchain Consensus Algorithms

Consensus protocols can be compared using some key blockchain properties. Vukolic (2015) compared PoW consensus with Byzantine fault-tolerant (BFT) consensus for several blockchain properties, including node identity management, consensus finality, scalability (number of nodes and number of clients), performance (throughput, latency, and power consumption), tolerated power of an adversary, network synchrony assumptions, and correctness proofs. Wu et al. (2019) and Zheng et al. (2018) used some of these properties to compare PoW, PoS, PBFT, DPoS, Ripple, and Tendermint consensus algorithms. Additionally, Aras and Kulkarni (2017) highlighted some pros and cons of three consensus mechanisms: PoW, PoS, and PBF. Table 2 gives a comparison of the four discussed consensus approaches using some vital properties.

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Table 2. A comparison of popular consensus mechanisms

	Proof of Work (PoW)	Proof of Stake (PoS)	Practical Byzantine Fault Tolerance (PBFT)	Delegated Proof of Stake (DPoS)
Example	- Bitcoin, Ethereum (current protocol), Litecoin, Namecoin, and Dogecoin	- Peercoin,Cardano, Nxt, Mintcoin, and Ethereum (target protocol)	- Hyperledger Fabric and Stellar	- Bitshares and EOS
Node identity management	- Open and entirely decentralized: nodes can join the network freely	- Open and entirely decentralized: nodes can join the network freely	- Permissioned: nodes need to know each other's IDs	- Open and entirely decentralized: nodes can join The network freely
Power consumption (Energy-saving)	- Very poor - Wastes much energy	- Good - Saves some energy compared to PoW, as less mining work is required due to limited research space	- Excellent - No mining is needed, so great energy saving	- Good - Saves some energy compared to PoW, as less mining work is required due to limited research space
Tolerated power of an adversary	- < 25% of computing power	- < 51% of stake	- < 33 % of faulty replicas	- < 51% of validators

(Sources: Aras & Kulkarni, 2017; Bach et al., 2018; Monrat et al., 2019; Vukolic, 2015; Wu et al., 2019; Zheng et al., 2018)

Types of Blockchain Systems

Nakamoto (2008) introduced the idea of the first blockchain-based system, Bitcoin—a peer-to-peer electronic cash system, which is a decentralized public ledger; however, there are now various blockchain systems and options for individuals and businesses. These different types of blockchain systems can be classified according to two main categories: access to blockchain system (permissionless and permissioned blockchains) and access to blockchain data (public and private blockchains) (BitFury Group, 2015; Peter & Panayi, 2015).

- **Permissionless blockchains:** In these blockchains, all participants can take part in the process of transaction verification. There are no restrictions or prior authorization required for the users to create blocks.
- **Permissioned blockchains:** In these blockchains, only a number of preselected known users can create/verify blocks of transactions.
- **Public blockchains:** In these blockchains, anyone can join the network, read data, and submit transactions.

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- **Private blockchains: I**n these blockchains, data access, reading, and submitting transactions is all limited to predefined users within a single organization or some organizations.

Peters and Panayi (2015) concluded that most permissionless blockchain systems feature public access in real-world examples. In contrast, most permissioned blockchains intend to limit data access only to the organization or consortium of organizations operating the system. Aras and Kulkarni (2017) noted that the terms permissionless and public are being used interchangeably, so are the terms permissioned and private. Their research paper classified blockchains into two types: public/permissionless and permissioned/private blockchains. They also added that use cases for permissioned/private blockchain have been increasing. Buterin (2015) addressed the reasons for the preferences for non-public blockchain systems by several real-world businesses.

Sharma (2019) summarized the basic difference between these types of blockchain as follows. Public blockchains are permissionless networks; anyone can join the network (e.g., Bitcoin and Ethereum). However, permissioned blockchains are not necessarily private since some public blockchain are permissioned systems (e.g., Ripple, Sovrin, and Stellar). Private blockchains are permissioned networks; only selected known users can join the network (e.g., Hyperledger Fabric and R3's Corda).

Many research papers categorize the current blockchains into three groups: public, private, and consortium (Buterin, 2015; Chedrawi & Howayeck, 2018; Puthal et al., 2018; Shi et al., 2020; Wu et al., 2019; Zheng et al., 2018). These three types of blockchain systems can be compared according to some properties, as shown in Table 3. Buterin (2015) demonstrated that investment capacity and privacy needed could play key roles in choosing private or consortium blockchains.
Furthermore, consortium blockchains are suitable for companies with similar goals and have no problem sharing the cost and sharing their data. Moreover, Xu et al. (2017a) provided a taxonomy of blockchain and blockchain-based systems that can help design and evaluate the software's architectures using blockchain. The taxonomy is based on architectural design characteristics for a blockchain-based system such as degree of decentralization, client storage and computation support, and blockchain infrastructural configuration. Xu et al. also considered other criteria in their taxonomy, such as cost efficiency and performance.

Table 3. A comparison of blockchain types

Property	**Public**	**Private**	**Consortium**
Consensus determination	- All users	- One centralized organization	- Predefined list of users
Consensus process	- Permissionless, everyone can join the consensus process	Permissioned, pre-certification is required	
Identity anonymity	- Users are (pseudo) anonymous	- Users are known	
Read permission	- Public data are visible	- Restricted but can be public	
Immutability	- Tampering is almost impossible because transactions are stored in	- Tampering is possible if dominant nodes want to	

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	different nodes in the distributed network		
Infrastructure	Decentralized	Centralized as it is controlled by one entity	Semi-centralized
Efficiency	- Low; a large number of users, making transaction processing quite long	- High - Restricted, with few nodes, so fast transaction processing, and high latency	

(Sources: Casino et al., 2019; Chedrawi & Howayeck, 2018; Monrat et al., 2019; Zheng et al., 2018)

APPLICATIONS OF BLOCKCHAIN

Blockchain technology has the potential to disrupt and revolutionize many businesses and professions. Blockchain-based cryptocurrency applications have been widely recognized and used, but blockchain applications have expanded to other fields. Many businesses appreciate it and started to study its potentials. We can now see some blockchain use cases in different areas beyond finance and banking applications such as in supply chain management, advertising verification, energy-saving, and healthcare. In future, it is expected we will see more useful applications with the development of intuitive interfaces and more use cases. (Anjum et al., 2017; Appelbaum & Smith, 2018). Access to information, data integrity, and operation resilience, among many other drivers, motivates businesses and industries to experiment and develop blockchain-based applications (Klimos, 2018).

This survey paper discusses blockchain-based applications in the following sectors: finance, accounting, insurance, supply chain management, energy, advertising and media, legal, real estate, healthcare, and IOT. It focuses on key issues, blockchain solutions, and blockchain use cases. The main benefits of using blockchain in these different fields are summarized at the end of this section in Table 4.

Financial Applications

Many potential applications in different financial areas follow the success of blockchain-based cryptocurrency platforms. Generally, trusted intermediaries carry out financial activities between individuals and institutions. Through its enabled design features and characteristics, blockchain can replace the services provided by these trusted middlemen, particularly, avoidance of the duplications of financial transactions and registration and validation of financial activities (Al-Jaroodi & Mohamed, 2019). Some blockchain-enabled financial applications that disintermediate primary services provided by banks and financial institutions include the following examples.

Payments

When Nakamoto introduced the bitcoin, blockchain started as a peer-to-peer electronic cash system. The bitcoin payment system succeeded and gained increasing interest as an effective method of making cross-border transfers and paying remittances at a lower transaction cost than that of the traditional financial system, with a much faster settlement speed.

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Thus, blockchain has been experimenting as an alternative payment solution (Collomb & Sok, 2016). Nowadays, hundreds of trillions of dollars flow worldwide through an old financial system of increased cost and slow payments. Public blockchain-based cryptocurrency systems, such as Bitcoin and Ethereum, allow anyone around the globe to transfer, pay, and receive money, eliminating the traditional role of trusted intermediaries for verifying and settling transactions. Almost all of the European Payments Council believed that blockchain technology would transform the industry by 2025 (How Blockchain Could Disrupt Banking, 2018).

It is not expected that cryptocurrencies can completely replace fiat currencies in the near future. Still, regarding payments, over the last few years, there has been a rising increase in cryptocurrencies' transaction volume, mainly Bitcoins and Ethereum (How Blockchain Could Disrupt Banking, 2018). Moreover, banks and financial organizations have started to embrace and experiment with blockchain.

On October 16, 2017, JPMorgan Chase & Co, an American multinational investment bank and financial services holding company, announced it was launching the Interbank Information Network (IIN) in corporation with two international partners: Royal Bank of Canada and Australia and New Zealand Banking Group Limited. On September 25, 2018, the IIN expanded, with the involvement of more than 75 banks. This network is the first of its kind globally, where many banks participate in a live application of blockchain technology (Financial Times, 2018; JPMorgan, 2017). They declared that "the new initiative will use blockchain technology to minimize friction in the global payments process. IIN will allow payments to reach beneficiaries faster with fewer steps and better security" (JPMorgan, 2017, para.2).

There are several companies now that use blockchain technology to revolutionize B2B payments. For example, Bitpay[1] is a bitcoin-payment service provider that helps merchants accept and store bitcoin payments and is currently the world's biggest bitcoin-payment processor. The company has more than 40 integrations and has a partnership with e-commerce platforms like Shopify and LemonStand for facilitating bitcoin payments.

Furthermore, the first bitcoin tax payments that were accepted in the state of Ohio were transacted via BitPay's platform. BitPesa[2] is another company focusing on improving B2B payments in developing countries, including Kenya, Nigeria, and Uganda. It has processed over five hundred million dollars since its establishment in 2013 (How Blockchain Could Disrupt Banking, 2018).

Financial Clearance and Settlements

Companies and institutions can use blockchain to record, validate, and process financial settlements without the need for a clearinghouse. Blockchain can facilitate clearing procedures that include adjusting financial obligations to authorize payments (Al-Jaroodi & Mohamed, 2019). Blockchain can enable the direct settlement of transactions and maintain track of those transactions more effectively than current systems such as SWIFT (How Blockchain Could Disrupt Banking, 2018).

The Royal Bank of Canada, one of the first adopters of this application, started to use blockchain-based Hyperledger for its US–Canada interbank settlements (Suberg, 2017).

Examples of companies that are working with traditional banks to improve transactions using blockchain include Ripple and R3. Ripple[3] is a company and a digital-payment processing

[1] https://www.cbinsights.com/company/bitpay
[2] https://www.cbinsights.com/company/bitpesa
[3] https://www.cbinsights.com/company/ripple-labs

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system, and it has a cryptocurrency known as XRP, released in 2012. The company is developing blockchain-based solutions that banks can use for improved clearance and settlement. More than 100 clients already agreed to try its blockchain system. R3[4] is another company working on blockchain for banks and is planning to be the new operating system for financial markets. In May 2017, the company collected $107M from a group of banks, including Bank of America Merrill Lynch and HSBC (How Blockchain Could Disrupt Banking, 2018).

Stock Trading

Stock trading is traditionally managed by a centralized authority like an exchange market. This centralized management keeps track of all trading transactions and settlements. This kind of system is associated with increased fees and delayed settlements (Al-Jaroodi & Mohamed, 2019). Some blockchain-based solutions have been developed in this regard (Monrat et al., 2019). For instance, Polymath[5], a blockchain technology company, is developing a marketplace and platform to facilitate digital security trading. The company is partnering with Blocktrade, Corl, and Ethereum Capital in launching security tokens on its platform (How Blockchain Could Disrupt Banking, 2018). Another example is the tZERO[6] trading platform owned by Overstock. tZero raised $134M in a private digital token offering in October 2018. These tokens became available for trading on tZero in January 2019 (Elliott, 2018). Moreover, Chain company, after its incorporation into a new company named Interstellar, launched the integration of live blockchain transactions between NASDAQ's stock exchange and Citi's banking systems (How Blockchain Could Disrupt Banking, 2018).

Trade Finance

Traditional trade finance is associated with many issues such as loaded paper, increased errors, and slow method of processing transactions between counterparties. Blockchain has a lot to offer to the world of trade finance, ranging from removing papers, automating processes and payments, reducing fraud, and cutting costs to tracking and tracing shipments and allowing all participants to access the same information (The Banker, 2018; Monrat et al., 2019). Many companies and banks formed consortia with a commitment to finding solutions for improved trade finance. For example, IBM and the bank-led consortium R3 developed a blockchain project. This project involved 12 international banks, including BBVA, Mizuho, and U.S. Bank, and aimed at digitizing paper letters of credit (Macknight, 2018).

Standrad Chartered and HSBC banks are working together, committed to utilizing blockchain technology to improve trade finance. Israel-based Wave, a Fintech company, has developed a blockchain solution that finance people can use to give letter of credit transactions. EuroFinance in Barcelona used this platform and succeeded in providing a blockchain solution to Ornua and the Seychelles Trading Company. Wave's platform streamlined the company's supply chain, reduced transaction costs and documentation errors, and sped up the documents transfer to clients worldwide. Furthermore, blockchain was used to improve and facilitate trade processes between Australia and Japan, from issuing credit letters to delivering trade documents. This was conducted by "IBM's Hyperledger Fabric—built on the Linux Foundation's open-source version—and secured by IBM" (How Blockchain Could Disrupt Banking, 2018, para.14).

Accounting Applications

[4] https://www.cbinsights.com/company/r3-cev
[5] https://polymath.network/
[6] https://www.tzero.com/

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Blockchain is a promising technology for the accounting profession. A self-auditing and immutable record can mean massive changes for not just how much time and effort is required to verify the financials of a company, but significant reductions in the difficulty and complexity of audits (Right networks, 2017). Blockchain offers a compelling new method of recording, processing, verifying, and storing financial transactions and information and can radically change the landscape of the accounting profession and reshape the business ecosystem (Liu et al., 2019).

Blockchain might be the next technology innovation in accounting. Instead of keeping separate records based on transaction receipts, companies can enter their transactions directly into a shared ledger, which creates an interlocking system of enduring accounting records. As these entries are distributed and cryptographically sealed, it becomes almost impossible to be falsified or destroyed to conceal an activity; this is like verifying transactions by a notary but in an electronic manner (Delloite, 2016). Besides, entries between two trading partners become easily comparable, while data privacy is maintained (Fanning & Centers, 2016).

Dai and Vasarhelyi (2017) described how blockchain could enable a real-time, verifiable, and transparent accounting ecosystem. They outlined the implications of blockchain on audit If electronic records of inventory items and information in electronic invoices, bills of lading, letters of credit, receipts, etc., are documented in the blockchain, providing a complete audit trail. They discussed how blockchain technology, along with smart contracts, could be utilized to initiate the performance-based compensation based on predefined criteria automatically. They also analyzed how the use of blockchain could automate revenue recognition based on algorithms and data from shipping activities recorded in the blockchain ledger.

Yu et al. (2019) concluded that as blockchain technology is in the experimental phase, its application to financial accounting would be progressive. In the short term, it can be used by firms as a platform for voluntary information disclosure, which could enable companies to address the trust problem with stakeholders, particularly investors. In the long term, its application can have a massive impact on financial accounting; it can lead to an effective reduction in disclosure and earnings management errors and a substantial increase in the quality of accounting information, in addition to mitigating information asymmetry issues. Deloitte (2016) mentioned in their discussion of the first steps towards blockchain-based accounting that starting with a joint register for all accounting-entries is unnecessary. Blockchain technology, as a source of trust, can be beneficial in the current accounting structures. Its integration with the typical accounting procedures can be achieved gradually, starting from securing records' integrity to completely traceable audit trails. Eventually, fully automated audits might become real.

The big four accounting firms (Deloitte, PricewaterhouseCoopers (PwC), Ernst & Young (EY), and KPMG) and many financial institutions have already recognized the importance of blockchain and thus have launched several projects. Their cooperation has produced various initiatives to examine the utilization of this technology in accounting and auditing (Bonson & Bednarova, 2019; Liu et al., 2019; Del Castillo, 2016). For example, Deloitte announced forming a blockchain team of 800 professionals in 20 countries (Alarcon & Ng 2018). With its blockchain lab in Dublin, Deloitte developed its first blockchain-based software platform, called Rubix, which allows clients to build customized blockchain and smart contracts (Minichiello, 2015).

EY is also involved in another blockchain-based project, Libra, which is a start-up focused on distributed ledgers (Allison, 2015). EY has launched EY Ops Chain that focuses on pricing, digital contract integration, shared inventory information, invoicing, and payments (Prisco, 2017). Similarly, PwC developed a platform called De Novo, through which it offers proprietary blockchain content covering the latest developments in the FinTech Industry (Bonson & ‘Bednarova, 2019; Kokina et al., 2017). Besides, it has a global blockchain team

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and has set up a Blockchain Experience Lab, which works cooperatively with industry experts (Brender et al., 2019). Moreover, accounting standard sitters, particularly the FASB, are putting significant interest in researching blockchain, assessing the impact of blockchain technology on financial reporting, and discussing potential business applications (Kinory et al., 2020).

Insurance-Related Applications

The insurance industry is showing an ever-growing interest in blockchain technology and its implementation in many areas, including sales, underwriting, customer onboarding, claims processing, payments, asset transfers, and reinsurance (Cognizant, 2017). The use of blockchain can support the insurance marketplace transactions between different clients, policyholders, and insurance companies. Blockchain can be leveraged across many activities such as negotiating, buying and registering insurance policies, submitting and processing claims, and supporting insurance companies' reinsurance activities (Al-Jaroodi & Mohamed, 2019; Cohn et al., 2017). Moreover, blockchain can enhance the insurance value chain because it has the ability to offer long-term strategic benefits, including lower operational costs due to reduced duplication of processes, reduced counterparty risks, increased automation of processes, and secure and decentralized transactions (Cognizant, 2017; Hewa & Liyanage, 2020).

Many different insurance industry contracts can be reduced to simple "if-then" statements and digitized as blockchain-based smart contracts. Digital management of existing policies would significantly reduce administration costs. Smart contracts can avoid the problems of disagreements or misinterpretations of policies' terms through the ability to easily administer "if-then" transactional relationships; this allows for the automatic execution of the terms through digital mechanisms that implement the agreed-upon insurance policies (Al-Jaroodi & Mohamed, 2019; Cohn et al., 2017; Hewa & Liyanage, 2020). According to Aras and Kulkarni (2017), blockchain can transform different insurance sectors such as travel insurance, crop insurance, property and casualty insurance, and, most importantly, health. It is possible to create a multiparty share network where insurers, hospitals, funeral homes, a department of health, and the beneficiary can be the blockchain's nodes. This setup can provide the necessary disintermediation and speed required to streamline insurance and claim processes and remove fraud.

Many insurance companies are leading the pack in using blockchain. Daley (2019a) gave details about nine companies that are using blockchain to develop insurance practice. For example, in October 2016, the top five European insurance giants, Aegon (Netherlands), Allianz (Germany), Munich Re (Germany), and Swiss Re and Zurich Insurance Group (Switzerland), launched the Blockchain Insurance Industry Initiative (B3I) to examine if the application of blockchain is feasible in the insurance industry and develop blockchain-based proofs of concept for insurance (Daley, 2019a; Huawei's Blockchain Whitepaper, 2018). B3I could develop a blockchain prototype for property reinsurance contracts. With 38 insurers' and brokers' involvement, the company could implement the full reinsurance contract process on a secure blockchain (Daley, 2019a).

In 2017, InsureX Technologies[7] developed the first blockchain-based alternative insurance marketplace for trading and managing insurance products. It aims to improve efficiencies in the insurance industry. In 2018, an Insurance Protocol on a blockchain called Aigang[8] was proposed to allow the community, companies, and developers to develop insurance prediction markets and insurance products themselves. They can build a self-insurance platform with a smart contract and a risk-based tokenization system.

[7] https://www.crunchbase.com/organization/insurex-technologies
[8] https://www.crunchbase.com/organization/aigang#section-overview

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Supply Chain Management Applications

Blockchain technology can enhance transparency and accountability in supply chain systems (Ahram et al., 2017; Hewa & Liyanage, 2020). Blockchain enables better quality, outcomes, and performance of effective supply chain management (SCM) processes. Once tracking data are entered onto a blockchain ledger, they become immutable. Blockchain increases trust between suppliers in the chain as all are enabled to track shipments, deliveries, and progress. Blockchain eliminates middleman auditors; thus, it increases efficiency and lowers cost, and suppliers can carry out their own checks and balances at any time (Koetsier, 2017; Kshetri, 2018; Pournader et al., 2020). Blockchain can enhance the measurement of product quality while it is transported. For example, just by analyzing information on a product's shipping path and duration, supply chain stakeholders can determine if a product was not in the right place or was stored for too long.

These issues are critical when it comes to refrigerated goods, which require more special and careful handling. In this manner, blockchain-based solutions can be used to ensure the genuineness and quality of products (Kshetri, 2018).

Blockchain can be used in logistics. Logistics management is associated with some complexity. For example, several companies are involved in the activities and synchronized sub-activities that various institutions carry out, including plants, storage firms, shipping companies, and regulatory entities. Thus, it is crucial to have logistics management applications with advanced embedded functions that facilitate planning, scheduling, coordinating, monitoring, and validating these activities. Blockchain technology can effectively and securely support these functions. The application of blockchain in managing logistics transactions will result in reductions in processing times, management costs, and human errors. Additionally, using smart contracts will enhance agreements and contracts among involved parties faster and at a lower cost (Al-Jaroodi & Mohamed, 2019; Hackius & Petersen, 2017; Maesa & Mori, 2020).

Many blockchain-based supply chain and logistics management platforms and applications have been developed and used to recognize these benefits of blockchain and its considerable impact on the SCM and logistics industry. IBM has developed a blockchain-based food-traceability platform. The pilot phase in 2018 has already seen millions of food products tracked by retailers and suppliers, including Walmart, The Kroger Co., Driscoll's, Dole, Golden State Foods, McCormick and Co., McLane Co., Nestle, Tyson Foods, and Unilever (Stanley, 2018). Maersk, a Danish shipping company, is using blockchain to track all its shipments across the world, with attributes such as condition, temperature, and location (Jackson, 2017). Another example is Provenance, which piloted a traceability project in Indonesia's fishing industry through mobile phones, blockchain, and smart tagging. The company could successfully track fish for the first half of 2016 (Kshetri, 2018).

Energy-Related Applications

The energy industry is working on new models and mechanisms to improve its service delivery to customers. Similarly, consumers favor having new methods to buy energy and understanding the origins of their energy purchased. Blockchain-based smart contracts can substantially accelerate a significant development in the energy industry, microgrids (Cohn et al., 2017). A microgrid is defined as "the cluster of multiple distributed generators (DGs) that supply electrical energy to consumers without any shortage" (Sivachandran & Muthukumar, 2014, p. 1). Instead of the exclusive reliance on a power factory that supplies electricity for a district, a microgrid enables all electric power consumers to manage their usage and possibly produce and sell energy using solar panels or any other energy alternative methods. Residents can sell

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extraneous energy to other residents or back to the larger grid. Blockchain can facilitate microgrid-related transactions (Cohn et al., 2017; Monrat et al., 2019).
Blockchain-based smart contracts enable the application of power-exchange restrictions and regulations, payments management, and direct interaction between users, without a centralized microgrid authority (Hewa & Liyanage, 2020; Munsing et al., 2017). Blockchain is being tried in the United States to facilitate microgrids. One example is the cooperation between Siemens, an automation company, and a New York-based startup called LO3 Energy. They are developing blockchain-based microgrids to allow for local energy trading. LO3 Energy has already piloted a microgrid and a peer-to-peer trading platform called TransActive Grid in Brooklyn in New York. Over 130 buildings participated, aiming to allow buildings to sell their extra generated energy to other microgrid participants (Brooklyn Microgrid, 2017; Cohn et al., 2017).
Moreover, in their paper, Aitzhan and Svetinovic (2018) addressed whether transaction security can be achieved in decentralized smart grid energy trading without the need for a trusted third party. They concluded that blockchain technology combined with multi-signatures and anonymous encrypted-message propagation streams could ensure higher security and privacy in decentralized smart grids energy trading. Furthermore, some digital currencies have been developed in the energy world, like Solarcoin[9], to encourage renewable energy use and production
Bao et al. (2020) and Silvestre et al. (2020) discussed blockchain applications in the energy sector, including peer-to-peer energy trading in the smart grid, which would provide consumers and prosumers with more energy-purchasing-scheme choices in a truly low-cost energy trading environment. They also presented some proposed peer-to-peer energy trading markets based on blockchain in which blockchain is mainly used to realize the market auction mechanism. Some examples include a decentralized market platform for consumers and prosumers in local energy markets based on the private blockchain (Mengelkamp et al., 2018), a decentralized energy auction system based on blockchain (Hahn et al., 2017), and a blockchain-assisted distributed double auction to facilitate peer-to-peer energy trade (Thakur et al., 2018)

Advertising and Media Applications

Online advertising has become an essential part of activities in the business world. Despite the benefits of online advertising, including measurability, interactivity, increased revenue, trust, and cost-effectiveness, several issues are associated with it. For example, users are concerned about the confidentiality of information and the viewer's advertising data, while publishers and advertisers are concerned about fraud, inefficiency, and measurement and cost in advertising (Chen et al., 2018; Tran, 2018). Tran (2018) addressed three major issues in online advertising. First, there are many intermediaries in the advertising industry that add costs for both advertisers and publishers. The process of online advertising is becoming ineffective and expensive for advertisers and publishers. Publishers sometimes do not sell all of their inventory, and the price of most of their inventory sold is too low. Likewise, advertisers incur an additional cost paid to mediators.
The second issue concerning users (customers) is the privacy of the users' data. Users research queries are quite often tracked and stored, then used to target users with relevant ads. Although some users allow this, it is still an issue that many Internet users are not in favor of it and consider it a violation of personal privacy. The third issue is related to ad fraud. One example is using bots for seeing or clicking on ads, leading to the unrealistic measurement of campaigns. Blockchain provides solutions to all of these problems. Blockchain enables a direct connection between stakeholders in online advertising without intermediaries' help; it can provide accurate

[9] https://solarcoin.org/

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information to all stakeholders, including the actual number of users' clicks and frequency and time of ads' display (Krishnan, 2018).

Many companies have been working on developing blockchain-based advertising platforms. The Interactive Advertising Bureau (IAP), the largest and most respected advertising industry association, is exploring the future of blockchain for video advertising. On February 8, 2018, it released "Blockchain for Video Advertising: A Market Snapshot of Publisher & Buyer Use Cases"(IAB, 2018, para.1); it is a detailed whitepaper addressing strong implementations of blockchain in digital video advertising.

The paper illustrated the natural fit of blockchain for the digital advertising supply chain (IAB, 2018). Papyrus[10] has been developed to handle fraud and violations in the digital advertising industry. According to its website, the universal blockchain platform "connects advertisers, publishers, agencies, advertising platforms, and verifiers within the Papyrus blockchain network to create trust, fairness, and efficiency within the digital advertising market." Its platform will use smart contracts based on data points, reduce transaction costs, and share information about third parties' reputations for honesty. This will build transparency, control spending, and reduce fraud.

AdBank[11] is another organization that developed a blockchain platform using smart contracts to build transparency between the advertisers and the publishers in the advertisement payment system. Also trying to clean up issues of fraud and transparency in the digital advertising space is Adshares[12]. It states it is "the answer to negative trends in digital marketing. Lack of transparency allows intermediaries to charge high fees. Increasing centralization gives big players the ability to censor unwanted content" (Newsbtc, 2020, para.1). It uses blockchain to connect the advertisers and publishers, and it lets them make direct deals using cryptocurrency.

As the Internet has drastically developed, many media-sharing services have become available. However, many problems exist with media distribution, such as the easy copy creation and modification of media and the possibility of plagiarism and unauthorized distribution. The traditional digital rights management of network media has several problems. For instance, ensuring the quality of media works or protecting copyrights is becoming hard to achieve. Many studies have addressed these problems, but these problems could not be solved with a centralized management system (Cho & Jeong, 2019; Xu et al., 2017b). Moreover, existing online social networks (OSNs) are built on centralized systems that store all users' information. This centralization raises several shortcomings because users do not actively control their data; thus, their data can be managed, sold, or stolen (Guidi, 2020).

Blockchain technology can provide solutions to these problems. Neither a central server nor the reliability of the network's use is needed with this technology. Many studies addressed media blockchain, focusing on content security and content rights information using blockchain (Cho & Jeong, 2019). For example, Bhowmik and Feng (2017) proposed a distributed and tamper-proof media-transaction framework based on blockchain. Their multimedia blockchain framework addresses the issue of the current unavailability of any trusted mechanism that can readily retrieve the transaction trails or alteration histories. Their proposed framework comprises a Compressed Sensing–based self-embedding watermarking algorithm, a blockchain distributed ledger, and authentication to detect any tampering and retrieve the original content.

To solve the Chinese network media industry's problems like low qualities of network media, plagiarism, and uncontrolled copyrights, Xu et al. (2017b) proposed a network media's digital rights management scheme based on the blockchain. Their scheme used a consensus protocol to complete copyright confirmation in real-time, smart contracts to execute real-time transactions, and digital signature and hash chains to ensure transactions' reliability.

[10] https://papyrus.network/
[11] https://adbank.network/us/
[12] https://adshares.net/

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IBM and Unilever are working on a blockchain solution with essential financial reconciliation solutions for digital media buying. They are hoping it will build a foundation to solve problems and create transparency throughout the industry. The first part of their project uses smart contracts to validate agreed-upon figures and to clear up discrepancies in the system (Weed & Rangaiah, 2018). Furthermore, some blockchain-based online social media platforms have been proposed. For example, Chakravorty and Rong (2017) presented Ushare, a conceptual solution based on blockchain for creating a user-centric social network that actively allows users to control and securely share content. Ushare comprises four key elements: a blockchain that would keep a record of ownership of data items and the number of shares made; a relationship system that would enable programmable code to be executed on the blockchain and control the number of allowed shares for a data item; a hash table that stores encrypted data that a user shares; and finally a local personal certificate authority that manages a user's circles and encryption keys and controls access to content.

Legal-Related Applications

The power the legal industry holds comes with a very specialized set of legal practice requirements, including standards of behavior, trust accounting, and confidentiality. Trust is the mainstay of these requirements. Preceding technologies could not accommodate the security and transparency necessary to create that trust (Legaler, 2018). Therefore, the practice of law has been bypassed for the most part by the technological revolution, remaining analog, whereas other services like banking and accounting continued to race into digital. Blockchain technology solves this issue. It adds the missing trust component to online services. This will allow anybody with a cell phone to engage in legal advice online confidently. It will enable contracts to run online, and it will allow users to perform legal identity verification. It will also allow fractional ownership of assets and many more (Legaler, 2018).

The legal industry is well suited for applying blockchain. Key factors that drive its adoption include the high number of players; the high volume of documents, information, and transactions involved; a low level of trust; and significant friction related to legal fees. The two broad blockchain uses in legal services are maintaining records and conducting transactions. These two uses can be further divided to cover information registry, identity management, smart contracts, transaction registry, and payments. Other areas for blockchain use within the legal industry will be explored as the technology expands and becomes more robust (Sanger, 2019). Legal innovators assume that blockchain and smart contracts will transform legal practice. It is likely that blockchain and smart contracts to be implemented in many areas within the legal sector, such as intellectual property, property, public records, land registry, and contracts. For instance, the state of Illinois conducted a pilot study to test using blockchain for recording and retaining its land records (Ambrogi, 2017a; Evans, 2018).

Many law firms devoted resources to explore and create their own blockchain, believing they would gain a technological advantage over their competitors. For example, Baker Hostetler, an American 1,000-attorney law firm, declared the creation of the Global Legal Blockchain Consortium in August 2017. A group of companies with joined resources will work together to "drive the adoption and standardization of blockchain in the legal industry, with the larger goal of improving the security and interoperability of the global legal technology ecosystem" (Ambrogi, 2017a, para.2). Founders include Baker Hostetler, Orrick, IBM Watson Legal, and a newly established company, Integra Ledger.

The latter company aims to become the legal industry's ledger for blockchain digital identities (Ambrogi, 2017b; Evans, 2018). This is not the only consortium of its kind; there is the Enterprise Ethereum Alliance (EEA), "a cross-industry collaborative blockchain consortium,"

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which aims to leverage open-source Ethereum technology for enterprise solutions (Ambrogi, 2017b, para.9).

Some blockchain use cases in the legal sector include, for example, OpenLaw (a smart contract creation tool), Agreements Network (Smart Contract Layer and Protocol), and Integra Ledger (a blockchain). OpenLaw[13] is "a blockchain-based language for the creation and execution of legal agreements" (Legaler, 2018, p.29). The OpenLaw markup language is used for wrapping executable logic around traditional legal prose. The developed contracts can be uploaded to a public repository, creating a knowledge common in smart legal agreements, or kept secure in a private instance. Agreements Network[14] is a blockchain layer. It provides the infrastructure for the distribution and execution of smart contracts or active agreements. Its contract management platform can use smart contract technique to create, prove, and operate legal agreements. Integra Ledger[15] is a private, permissioned blockchain based on the Hyperledger Fabric blockchain and hosted on the IBM Blockchain Platform. It is used to confirm legal data's authenticity and enhance data-exchange security between legal departments (Legaler, 2018).

Real Estate Applications

Real estate transactions are complex, opaque, and expensive because many parties are involved in the process, including brokers, government property databases, title companies, escrow companies, inspectors, appraisers, and notaries public (Puthal et al., 2018; Wouda, 2019). Morrison (2018) mentioned that scammers are increasingly targeting real estate transactions, according to the FBI. For example, 9,645 victims of real estate fraud were reported in 2017. According to Openledger[16], blockchain in real estate delivers efficient and reliable workflows, enhancing transparency and visibility at all stages, and ultimately offering safer investments to everyone. However, these scams are just a small part of the transactions that blockchain can touch upon and strengthen. Beyond addressing fraud, distributed ledger smart contracts simplify transaction processes, cut out unnecessary intermediaries, reduce costs for main parties, and accelerate the closing of deals.

Blockchain can process the registration and transfer of property ownership more efficiently, particularly in less-developed countries with legal systems in which public authorities dealing with real estate registers lack the principle of trust and transparency or in which land registry systems are unreliable (Morena et al., 2020). With blockchain's help, it becomes possible to gather all information about properties and give access to parties who need this information.

Furthermore, every property can have a corresponding digital address containing occupancy, finance, legal, building performance, and physical attributes, which conveys perpetually and maintains all historical transactions (Hewa & Liyanage, 2020; Puthal et al., 2018; Veuger, 2018).

The real estate industry is primed to incorporate blockchain to solve current problems within the industry and change the way transactions are completed. These changes are already underway in the real estate space. For example, in the Netherlands, the Municipality of Rotterdam is working with Deloitte to build the first Blockchain application in real estate for the purpose of documenting rental contracts (Morena et al., 2020; Veuger, 2018).

Their projects consist of: (1) "digitalizing building data; digitalizing the ownership situation; (3) transferring ownership; (4) closing of rental contracts; and (5) unlocking contract information for third parties" (Morena et al., 2020, p.275). Yang and Wang (2019) proposed a real estate transaction platform based on blockchain technology. This platform uses the

[13] https://www.openlaw.io/
[14] https://agreements.network/
[15] https://integraledger.com/
[16] https://openledger.info/solutions/blockchain-real-estate/

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Hyperledger Fabric platform to effectively connect purchasers, sellers, financial institutions, and government departments and aims to realize the real estate transaction information release and transaction. It can also query historical transactions.

Daley (2019b) gave useful information about 17 blockchain companies revolutionizing the real estate industry. For instance, Propy[17] is a universal real estate marketplace that uses smart contracts to conduct international real estate transactions. Propy enables buyers, sellers, brokers, agents, and notaries to come together through using a set of blockchain-based smart contracts that facilitate the real estate process. Another example is ShelterZoom[18]; it is a secure online platform that manages all the offer-and-acceptance processes in real estate transactions. Using blockchain technology and its mobile tools and dashboards, brokers, agents, buyers, and sellers can transact in a transparent and more efficient environment. Another blockchain use case in real estate is Ubitquity.[19] Ubitquity uses a SaaS platform with blockchain technology to offer a simple solution for storing and searching for real estate titles. The platform inputs property information through a distributed ledger, making it transparent, incorruptible, and encrypted.

Healthcare Applications

Patients' data are among the most significant and sensitive elements in healthcare. Healthcare providers are going digital, where patient data and records are now digitized and stored in what is so-called the electronic medical record (EMR) (Al-Jaroodi & Mohamed, 2019; Maesa & Mori, 2020). This digitization allows for easy retrieval and sharing for better care and more effective decision making but exposes medical data to a high risk of patient-privacy violations (Aras & Kulkarni, 2017). Moreover, managing patient health records effectively is problematic in the healthcare industry. Different healthcare providers need various pieces of information to give the best care to patients. EMRs are scattered over several systems that are unconnected to each other. Additionally, these records might not be up to date, with some remaining in paper forms on shelves (Demarinis, 2018).

While health records are being increasingly digitized, the sharing of EMRs between various healthcare providers and healthcare organizations has lagged behind EMRs application, due to many reasons, but mainly due to security and privacy (Al-Jaroodi & Mohamed, 2019; Gordon & Catalini, 2018).

However, there can be a healthcare system where EMRs are up to date and sharing EMRs and other healthcare information among several providers is secure: one that uses blockchain (Al-Jaroodi & Mohamed, 2019; Demarinis, 2018). The value of blockchain in healthcare goes beyond security and privacy. Blockchain can be a common database of health data and information that doctors, hospitals, patients, and all other stakeholders could access regardless of their electronic medical systems. With its use, doctors can spend less time completing administrative tasks, allowing for more patient care, and more research results can be shared for new treatments. It can enhance drug development as results become more accessible and minimize claim and billing fraud (Hughes & Morrow, 2019; Marr, 2017).

Blockchain is changing the way the healthcare industry functions. Mediators may become obsolete. Companies that are slow to change may lose out to those that use the technology to cut costs and increase efficiencies. PwC, a London-based financial services company, released a report in 2018 entitled "A Prescription for Blockchain and Healthcare: Reinvent or be Reinvented." The report said that in a survey of 74 global healthcare companies, 49% of them are developing, piloting, or implementing blockchain projects (PwC, 2018).

[17] https://propy.com/browse/
[18] https://www.shelterzoom.com/
[19] https://www.ubitquity.io/

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Use cases and the benefits of adopting blockchain technology in healthcare are numerous. Zhang et al. (2018) identified seven potential blockchain use cases in healthcare:

> prescription tracking to detect opioid overdose and over-prescription, data sharing to incorporate telemedicine with traditional care, sharing cancer data with providers using patient-authorized access, cancer registry sharing to aggregate observations in cancer cases, patient digital identity management for better patient record matching, personal health records for accessing and controlling complete health history and health insurance claim adjudication automation to surface error and fraud. (p. 5)

Angeles (2018) discussed in detail three promising healthcare use cases: healthcare data exchange and interoperability, drug supply chain integrity and remote auditing, and clinical trials and population health research, which have had successful proof-of-concept pilots by MEDRec, Patientory, and AmerisourceBergen and Merck Co.

Patientory[20], a software and service company, offers a blockchain-based application that securely stores and manages health information in real time, giving patients control of their own health data. Patients, doctors, and health organizations can access, store, and share information safely, resulting in improved healthcare coordination among different providers (Angeles, 2018; McFarlane et al., 2017). In their white paper, Ekblaw et al. (2016) proposed the MedRec, a decentralized record management system to handle electronic medical records using blockchain technology. This system does not store patients' health records; it stores signatures of the records on a blockchain and reports to patients who control and manage these records' flow on the blockchain (Halamka et al., 2017). Two leading healthcare organizations, AmerisourceBergen, a drug wholesaler, and Merck & Co, a drug developer, are working together to use blockchain technology for improved drug supply chain integrity and remote auditing. Additionally, they aim through blockchain use to comply with healthcare industry regulations that address the detection and removal of fake, stolen, or contaminated drugs in the supply chain (Angeles 2018; Antonovici, 2018).

Futhermore, Yue et al. (2016) proposed the Healthcare Data Gateway (HGD), a blockchain-based app architecture that empowers patients to own, control, and easily and securely share their data without fearing a privacy violation. However, these medical data cannot be altered or deleted by anyone, including patients themselves. As health data are diverse, Yue et al. proposed using simple, unified Indicator Centric Schema (ICS) to organize all different kinds of patient data. They also addressed that MPC (Secure Multi-Party Computing) can be a solution that makes it possible for an untrusted third party to conduct computations with patient data without privacy violations. Xia et al. (2017) also proposed MeDShare, a blockchain-based system that highlights the issue of medical data sharing in cloud repositories among big service providers. Data transitioned and shared between entities and actions taken on the MeDShare system are all recorded immutably. Their proposal also uses smart contracts and an access control mechanism to track data behavior, revoking malicious users' access.

Internet of Things

Internet of things (IoT) is one of the most evolutionary information and communication technologies (ICT). IoT is "a network of networks of uniquely identifiable endpoints (or "things") that communicate without human interaction using IP connectivity — whether locally or globally" (Lund et al., 2014, p. 2). IoT based services have been exponentially growing

[20] https://patientory.com/

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worldwide, particularly in telehealth, manufacturing, and in urban areas to form smart cities. IoT technologies solve many problems without the need for human-human workforce intervention. (Kumar & Mallick, 2018; Makhdoom et al., 2019). It was forecasted that IOT would connect 30 billion devices by 2020 (Lund et al., 2014).

IoT is not one technology; it is a group of various technologies that work together for smartness achievement (Kumar & Mallick, 2018). Lee and K. Lee (2015) highlighted the different intricate technologies involved in successfully implementing IOT's idea and development of IoT-based products and services. These include radio frequency identification (RFID), wireless sensor networks (WSN), middleware, cloud computing, and IoT application software. The applications of IoT are diverse. The typical applications include smart parking, smart homes and offices, smart grids and logistics management, and telehealth, with RFID and near field communication (NFC) (Miorandi et al., 2012; Shah & Yaqoob, 2016).

The widespread adoption of IoT technologies and applications involves many issues. The most relevant and critical issues are related to security and privacy. The adoption of IoT solutions on a large scale is unexpected when system-level confidentiality, authenticity, and privacy are not guaranteed (Miorandi et al., 2012; Shah & Yaqoob, 2016). IoT continues to suffer from privacy and security vulnerabilities due to two reasons. First and foremost, in IoT, information is exchanged, and data are authenticated solely through a central server, creating chances for increased device spoofing, false authentication, and less reliability in data sharing. Second, there are resource constraints with most of its devices (Dorri et al., 2016; Kumar & Mallick, 2018).

Blockchain technology can enhance security and privacy in IoT (Abou Jaoude & Saade, 2019; Patwary et al., 2020). Blockchain removes IoT's centralization concept and enables the smooth flow of data for every transaction with proper authentication (Kumar & Mallick, 2018; Lee & K. Lee, 2015). There exist some works that discussed the role of blockchain in IoT and proposed some blockchain solutions for improving security and privacy in IoT (Kumar & Mallick, 2018; Makhdoom et al., 2019; Patwary et al., 2020). For instance, Huh et al. (2017) proposed blockchain to develop an IoT system.

They said IoT devices could be controlled and configured using Ethereum, the blockchain computing platform. As Ethereum supports smart contracts, they could write their own Turing-complete code to run on top of Ethereum so they can readily manage the configuration of IoT devices and build a key management system.

Dorri et al. (2017) addressed IoT security and privacy challenges by leveraging blockchain, taking smart homes as a representative case study. They proposed the application of blockchain in IoT considering different components of the smart home tier and the associated transactions and procedures. They analyzed the security feature of their proposed blockchain-based smart home framework. Hardjono and Smith (2016) proposed a privacy-preserving method for commissioning an IoT device into a cloud ecosystem. They introduced the ChainAnchor architecture to allow the device to prove its manufacturing provenance without reliance on a trusted third party and to register anonymously through a blockchain system. Other proposed applications of blockchain in the IoT sector include what Zhang and Wen (2015) introduced, a new IoT E-business model, and realize the transaction of smart property and paid data on the IoT with the help of peer-to-peer trade based on the blockchain and smart contract. In this model, distributed autonomous corporations (DAC) are adopted as a decentralized transaction entity. People trade with DACs to obtain coins and exchange sensor data without any third party.

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Table 4. Benefits of using blockchain in different industrial domains

Field of applications	Benefits of blockchain application
Finance	• Facilitates fast, secure, low-cost payment processing services without intermediaries. • Enables near-real-time transfers and settlement. • Minimizes friction in the global payments process. • Facilitates financial clearance and settlements without the need for a clearinghouse. • Enables digital stock trading without involving a third party. • Improved trade finance (i.e., automated processes, payments and settlements, reduced fraud, faster and cheaper track of shipments, and faster documents transfer).
Accounting	• Enables a new method of recording, processing, verifying, and storing financial transactions and information. • Enables a real-time, verifiable, and transparent accounting ecosystem. • Reduces cost, errors and fraud, eliminates reconciliations, and provides a complete audit trail.
Insurance	• Eliminates fraud and establishes a transparent insurance marketplace. • Automated insurance claims. • Enhances insurance policies and related activities, including sales, underwriting, customer onboarding, claims processing, payments, asset transfers, and reinsurance.
Supply chain management	• Enhances visibility, transparency, and accountability in supply chain systems. • Ensures supply chain traceability and compliance. • Increases trust among stakeholders in the chain. • Helps track the status of products and ensures the genuineness and quality of products. • Improved logistics management.
Energy	• Facilitates energy trade in microgrids. • Facilitates microgrid-related transactions without the need for a centralized microgrid authority. • Enhances security and privacy in smart grids energy trading. • Enables the use of digital currencies in power exchanges.
Advertising and media	• Enables cost-effective online advertising. • Enables a direct connection between stakeholders in digital advertising and media without the help of intermediaries. • Reduces fraud and violations in the digital advertising and media industries. • Enhances transparency in the media industry. • Helps ensure content security and content rights information. • Helps ensure the quality of media works and protect copyrights.
Legal	• Creates trust in online legal services. • Facilitates the creation and execution of legal agreements through the use of smart contracts. • Increases data integrity and transparency in the legal sector.
Real estate	• Eliminates processing fees and commissions. • Improved secure transaction process. • Reduces fraud in the real estate industry. • Helps potential investors trace the history of real estate when all registry and transfer records of different real estate properties are stored on a blockchain.

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	• Helps establish trusted and transparent real estate network that effectively connects all different stakeholders.
Healthcare	• Enables secure sharing of medical information. • Enables patients to manage their medical information. • Enhances healthcare data exchange and interoperability. • Ensures drug supply chain integrity. • Helps establish common health data and information databases that stakeholders can access and use. • Facilitates clinical research and analysis because blockchain enables sharing, tracking, and caring for data.
IoT	• Enhances security and privacy in interconnected devices. • Smart contracts for enhancing IoT security. • Helps establish an identity and access management system that strengthens IoT security.

LIMITATIONS OF BLOCKCHAIN

As blockchain is an emerging technology, there are some challenges associated with its implementation and use. One hurdle that needs to be addressed is that people simply do not know enough about this technology or how it works. The total lack of blockchain expertise in many organizations represents a severe stumbling block for blockchain growth and adoption (Bizarro et al., 2018). There are still further blockchain issues that need to be addressed. One involves the scalability of blockchain. Other areas to overcome are the concerns over security and regulations.

Scalability

The entire blockchain has to be present for the consensus purpose and block validation; thus, all previous validated transactions have to be stored for validating new transactions, which require a large amount of storage. The significant factors contributing to the scalability issue are the original block-size restriction and the delayed consensus process. With each transaction comes data, and with a maximum size of 1MB per block, there are only so many payments that can be processed at once. The Bitcoin blockchain can only handle six to seven transactions per second, maximum (Monrat et al., 2019; Puthal et al., 2018; Zheng et al., 2018).
If crypto was to replace traditional currency, processing hundreds of thousands of transactions per second is required to ensure the economy could continue moving without considerable delays for consumers and businesses (Blenkinsop, 2018). By comparison, the networks that Visa and Mastercard use process: "more than 5,000 transactions per second with the capacity to process volumes multiple times that number. Bitcoin, in contrast, takes 10 minutes to clear and settle a single transaction vs. Ethereum that takes 15 seconds" (Vlastelica, 2017, para.5). Moreover, miners may delay small transactions because of the small blocks' size, as they prefer those transactions with a high transaction fee. Nevertheless, if the blocks' size was increased, that would decelerate block-propagation speed (Puthal et al., 2018; Zheng et al., 2018).
Several proposed solutions address the blockchain's scalability problem, which are related to optimizing blockchain storage or redesigning blockchain (Zheng et al., 2018). For instance, Bruce (2014) proposed a novel cryptocurrency scheme. In this scheme, old transactions can be forgotten by the network, and the proposed database, called the account tree, is used to hold every unique, non-empty address and the balance of all those addresses. As a result, not all transactions need to be stored to validate a transaction, reducing the need for long-term data storage. Eyal et al. (2016) presented Bitcoin-NG (Next Generation), a new blockchain protocol

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designed to scale. This new protocol's underlying idea is to divide traditional blocks into two parts to reduce the propagating size. This new version of blockchain addresses the tradeoff between block size and network security. Moreover, the Lighting Network[21] is a promising blockchain implementation capable of handling millions of transactions per second across the network.

Security

Although blockchain is characterized by a set of security features that make it resistant to attack, it is not completely infallible, and so some blockchain security risks do exist (Nawari, 2019; Zamani et al., 2018). Li et al. (2017) conducted an end-to-end study on the blockchain's security threats. We summarize three typical risks: 51% attacks, privacy leakage, and private key security.

- **The Majority Attack (51% Attacks):** The blockchain employs a distributed consensus mechanism to create mutual trust. This consensus mechanism is susceptible to 51% vulnerability. Attackers might exploit this issue to control the entire blockchain (Li et al., 2017; Monrat et al., 2019). In the simplest terms, if a user controls over 51% of the network, they can then manipulate and modify the blockchain. As they control most of the network, they can dictate the consensus (McBee & Wilcox, 2020; Nawari, 2019).

  Moreover, these dominant user(s) can choose which transactions get approved; thereby, they can refuse other transactions and let their own coins be spent multiple times, known as the double-spend issue. Cryptocurrencies with small communities of miners are more susceptible to this type of attack since a single user can obtain a great deal of control in the early stages of blockchain. Thus, cryptocurrencies with big communities of miners like Bitcoin are relatively resistant to such attacks (Al-Jaroodi & Mohamed, 2019; Nawari 2019)

- **Privacy leakage:** Blockchain is considered a very safe system because users connect with pseudonymity, only making transactions with generated addresses, not with their real identities, and can generate many addresses to protect against information leakage (Zheng et al., 2018). It is possible to trace the users' behaviors in the blockchain; thus, blockchain takes precautions to protect users' transaction privacy. For example, in Bitcoin and Zcash, one-time accounts are used to store the received cryptocurrency. Also, users assign a private key to each transaction to become impossible for attackers to infer, if cryptocurrencies in different transactions are received by the same user (Li et al., 2017). However, regardless of all of the privacy protection measures in blockchain and proposed methods to improve blockchain anonymity, complete privacy cannot be achieved (Li et al., 2017; Nawari, 2019).

Kosba et al. (2016) emphasized that transactional privacy is not guaranteed in the blockchain, because although participants can create new pseudonymous public keys to enhance their anonymity, the values of all transactions and balances for each (pseudonymous) public key are publicly visible. Biryukov et al. (2014) proposed an effective method to deanonymize Bitcoin users, allowing for linking user pseudonyms to IP addresses. They argued that their system is reliable even when users are behind network address translation (NAT) or firewalls. The underlying idea is that each client can be uniquely identified by a set of nodes he/she connects to "entry nodes." This set can be learned at the time of connection and then used to determine the origin of a transaction.

[21] https://lightning.network/

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Moreover, Miller et al. (2017) empirically evaluated two linkability weaknesses in Monero's mixin sampling strategy. Monero[22] is "a privacy-centric cryptocurrency that allows users to obscure their transaction graph by including chaff coins, called 'mixins,' along with the actual coins they spend" (Miller et al., p.1). First, the majority of Monero transaction inputs do not include any mixins. Transactions with zero mixins do not ensure privacy to the users that send them. Second, the mixins are not selected randomly, leading them to being distinguished from real coins by their age distribution easily; the real input is usually the "newest" input.
They concluded that these weaknesses could be exploited to infer the real transaction inputs with 80% accuracy overall, for transactions with one or more mixins.

Private key security: It is argued that blockchain is only as secure as private keys (Yeoman, 2018). Users' private keys are considered the identity and security credentials in blockchain systems. These keys are generated and maintained by users and used to prove ownership of a crypto asset (i.e., bitcoin). However, it is impossible to recover private keys if lost (McBee & Wilcox, 2020). If criminals obtain private keys, they can manipulate users' blockchain accounts. Moreover, blockchain does not rely on any centralized trusted third party, so if private keys are stolen, tracking the criminal's behaviors and recovering the modified blockchain information becomes difficult (Li et al., 2017).
According to Mayer (2016), Bitcoin and Ethereum use the Elliptic Curve Digital Signature Algorithm (ECDSA) for payment authorization. However, the ECDSA scheme has a vulnerability that there is insufficient randomness in the signing process, enabling attackers to recover the users' private keys.

- **Regulation** One of the primary issues with implementing blockchain for many businesses is the lack of regulations and standards. According to a survey of blockchain-savvy executives conducted by Deloitte, regulatory issues were cited to be among major barriers to increased investment in blockchain technology. This technology supports many features, such as cryptographic signatures and smart contracts, but current regulations do not address them (Deloitte, 2018). Besides, a poll of senior professionals who attended the Ernst & Young Global Blockchain Summit in New York found out that regulatory complexity is significantly impacting widespread blockchain adoption (Ernst & Young, 2018).

Lin and Liao (2017) mentioned that, using Bitcoin as an example, the characteristics of this decentralized system will weaken the central bank's ability to control economic policy and the amount of money, making the government cautious of blockchain technologies. Therefore, authorities have to address this new issue and speed up the formulation of new policies to stop its likely impact on the market. As blockchain is still in its infancy, governments are continuously modifying regulations as it develops. For instance, in 2018, over 17 U.S. state legislatures considered and approved many bills relating to blockchain technology implementation. These bills address various areas, including "the recognition of cryptographic signatures, the definition and use of smart contracts, and the use of blockchains for maintaining business records" (Deloitte, 2018, para.2).

[22] https://www.getmonero.org/

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CONCLUSION

Blockchain is a promising technology and highly appreciated and accepted for its decentralized infrastructure and peer-to-peer nature. Blockchain has demonstrated its potential for facilitating complex processes such as transaction verification, reconciliation and settlement, and dispute resolution through its design features. Besides, blockchain can transform traditional business with its vital characteristics, including distribution, anonymity, immutability, and audibility. As blockchain was designed to eliminate intermediaries' role, particularly in the financial transaction space, it employs a decentralized consensus protocol for transaction processing and validation. PoW, PoS, PBFT, and DPoS are the most commonly used consensus mechanisms by the existing blockchain systems. Blockchain was introduced as a decentralized public ledger, but there are now various types of blockchain systems. A blockchain network can be public, private, or consortium. Blockchain systems' choice is guided by critical factors such as investment capacity, privacy needed, and goals. For instance, financial organizations value the privacy element, so they are more interested in private blockchains. In contrast, companies with similar activities and goals are willing to share costs and data and may opt for consortium blockchains.

Blockchain showed its worthiness through cryptocurrency applications, but now its applications go beyond the digital currency field. With the same features, blockchain can be leveraged across various domains, as this paper demonstrated: advertising and media, energy, real estate, healthcare, and many others. These different industries are becoming interested in blockchain and have started to study its potentials and applicability, as they could no longer resist the key benefits of blockchain: transparency, business continuity, disintermediation, and trust.

As blockchain enables smart contract functionality, we see many proposed smart contract applications in different areas. We all know that blockchain has a lot of potential to solve problems. However, we are also starting to see some of the issues facing blockchain, specifically with regard to scalability, security, and regulation. It is crucial to address the current limitations of blockchain so that it becomes efficient and more durable.

REFERENCES

- Abou Jaoude, J. & Saade, G.R. (2019). *Blockchain Applications - Usage in Different Domains*. IEEE Access 7.

- Adams, R., Glenn Parry, G., Godsiff, P. and Ward, P. (2017). *The Future of Money and Further Applications of The Blockchain.* Strategic Change, 26(5), 417- 422.

- Ahram et al. (2017). *Blockchain Technology Innovations*. IEEE Technology & Engineering Management Conference (TEMSCON).

- Aitzhan, N. and Svetinovic, D. (2018). *Security and Privacy in Decentralized Energy Trading Through Multi-Signatures, Blockchain and Anonymous Messaging Streams.* IEEE Transactions on Dependable and Secure Computing, 15 (5), 840-852.

- Alarcon, J. and Ng, C. (2018) *Blockchain and The Future of Accounting*. Pennsylvania CPA Journal.

.

- Al-Jaroodi, J. and Mohamed, N. (2019). *Blockchain in Industries: A Survey*. IEEE Access, 7, 36500-36515.

- Allison, I. (2015). *Deloitte, Libra, Accenture: The Work of Auditors in The Age of Bitcoin 2.0 Technology*. International Business Times. Retrieved from https://www.ibtimes.co.uk/deloitte-libra-accenture-work-auditors-age-bitcoin-2-0-technology-1515932.

- Ambrogi, R. (2017a). *Consortium Formed to Drive Blockchain Adoption in Legal Industry.* Retrieved from https://www.lawsitesblog.com/2017/08/consortium-formed-drive-blockchain-adoption-legal-industry.html

- Ambrogi, R. (2017b). *In Legal, Blockchain Is the New Black, Why All the Buzz About Blockchain*? Retrieved from https://abovethelaw.com/2017/08/in-legal-blockchain-is-the-new-black/

- Anjum, A., Sporny, M. and Sill, A. (2017). *Blockchain Standards for Compliance and Trust.* IEEE Cloud Computing, Published by The IEEE Computer Society, 84-90.

- Angeles, R. (2018). *Blockchain-Based Healthcare: Three Successful Proof-of-Concept Pilots Worth Considering.* Journal of International Technology and Information Management, 27 (3), 47-83.

- Antonovici, A. (2018). *AmerisourceBergen, Merck to Expand Blockchain Test Project for Tracking Drugs*. Crypto Vest website. Retrieved from https://cryptovest.com/news/amerisourcebergen-merck-to-expand-blockchain-test-project-for-tracking-drugs/

- Antshares (2016). *Antshares Digital Assets for Everyone*. Retrieved from https://www.antshares.org

- Appelbaum, D. and Smith, S. (2018). *Blockchain Basics and Hands-on Guidance: Taking the Next Step toward Implementation and Adoption*. The CPA Journal, 28-37.

- Aste, T. and Tasca, P. (2017). *Blockchain Technologies: The Foreseeable Impact on Society and Industry*. Computer Published by The IEEE Computer Society, 18-28.

- Aras, T.S. and Kulkarni, V. (2017). *Blockchain and Its Applications – A Detailed Survey*. International Journal of Computer Applications,180 (3), 29-35.

- Bach, M.L., Mihaljevic, B. and Zagar, M. (2018). *Comparative Analysis of Blockchain Consensus Algorithms*. In Proceedings of the 2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), Opatija, Croatia, 1545-1550.

- Bao, J., He, D., Luo, M. & and Choo, K. K. (2020). *A Survey of Blockchain Applications in the Energy Sector.* IEEE Systems Journal.

- Beck, R. (2018). *Beyond Bitcoin: The Rise of Blockchain World*. Published by The IEEE Computer Society, pp.54-58.

.

- Bhowmik.D, and Feng,T. (2017). *The Multimedia Blockchain: A Distributed and Tamper-Proof Media Transaction Framework*. Digital Signal Processing (DSP), 22nd International Conference on. IEEE.

- BitFury Group (2015). *Public Versus Private Blockchains Part 1: Permissioned Blockchains, White Paper*. Retrieved from https://bitfury.com/content/downloads/public-vs-private-pt1-1.pdf

- Bitshares (2015). *Bitshares - Your Share in The Decentralized Exchange*. Retrieved from https://bitshares.org/

- Biryukov, A., Khovratovich, D. and Pustogarov, I. (2014). *Deanonymisation of Clients in Bitcoin P2P Network.* Proceedings of the ACMSIGSAC Conference on Computer and Communications Security, New York, NY, USA, 15–29.

- Bizarro, A.P., Mankowski, F. and Mankowski, H. (2018). *Blockchain Technology: Benefits, Risks and the Future*. Internal Auditing, 12-16.

- Blenkinsop, C. (2018). *Blockchain's Scaling Problem, Explained*. Retrieved from https://cointelegraph.com/explained/blockchains-scaling-problem-explained

- Bonson, E. and Bednarova, M. (2019). *Blockchain and Its Implications for Accounting and Auditing.* Meditari Accountancy Research, Vol. 27, No. 5, pp. 725-740.

- Brender, N Gauthier, M JH Morin, JH. And Salihi, A. (2019). *The Potential Impact of Blockchain Technology on Audit Practice*. Journal of Strategic Innovation and Sustainability, Vol. 14, No.2, pp. 35-59.

- Brooklyn Microgrid (2017). Power technology Website. Retrieved from https://www.power-technology.com/features/featurethe-brooklyn-microgrid-blockchain-enabled-community-power-5783564/

- Bruce, J. (2014). *The Mini-Blockchain Scheme. Available at:* http://cryptonite.info/files/mbc-scheme-rev3.pdf

- Buterin, V. (2015). *On Public and Private Blockchains*. Retrieved from https://blog.ethereum.org/2015/08/07/on-public-andprivate-blockchains/

- Casinoa, F., Dasaklisb, K. and Patsakisa, C. (2019). *A Systematic Literature Review of Blockchain-Based Applications: Current Status, Classification and Open Issues*. Telematics and Informatics 36, 55–81.

- Chakravorty, A., Rong, C. (2017). *Ushare: User Controlled Social Media Based on Blockchain*. In: Proceedings of the 11th International Conference on Ubiquitous Information Management and Communication, IMCOM 2017.

- Chedrawi, C. and Howayeck, P. (2018). *Audit in the Blockchain Era Within A Principal-Agent Approach.* In: Information and Communication Technologies in Organizations and Society (ICTO 2018): Information and Communications Technologies for an inclusive world. At: University Paris Nanterre - Pole Léonard de Vinci, Paris-France.

.

- Chen, W., Xu, Z., Shi, S., Zhao, Y. and Zhao, J. (2018). *A Survey of Blockchain Applications in Different Domains*. ACM Int. Conf. Proceeding Ser, 17–21.

- Cho, S. and Jeong, C. (2019). *A Blockchain For Media- Survey: The Aspect of Content Security and Content Right Management*. International Conference on Electronics, Information, and Communication (ICEIC).

- Cirstea, A., Enescu, M.F., Bizon, N., Stirbu, C. and Ionescu, M.V. (2018). *Blockchain Technology Applied in Health: The Study of Blockchain Application in the Health System (II).* ECAI - International Conference,10th Edition Electronics, Computers and Artificial Intelligence, Iasi, Romania.

- Cognizant (2017). *Blockchain: A Potential Game-Changer for Life Insurance. Digital* Systems & Technologies. Retrieved from https://www.cognizant.com/whitepapers/blockchain-a-potential-game-changer-for-life-insurance-codex2484.pdf

- Cohn, A. West, T and Parker, C. (2017) *Smart After All: Blockchain, Smart Contracts, Parametric Insurance, and Smart Energy Grids.* Georgetown Law Technol. Rev, 1 (2), 273–304.

- Collomb, A. and Sok, K. (2016). *Blockchain / Distributed Ledger Technology (DLT): What Impact on the Financial Sector?* Digiworld Economic Journal, 103, 93-111.

- Dai, j. and Vasarhelyi, A. M. (2017*). Toward Blockchain-Based Accounting and Assurance.* Journal of Information Systems, 31 (3), 5-21

- Daley, S. (2019a). *Nine Companies Using Blockchain To Revolutionize Insurance*. Retrieved from https://builtin.com/blockchain/blockchain-insurance-companies

- Daley, S. (2019b). *17 Blockchain Companies Boosting the Real Estate Industry.* Retrieved from https://builtin.com/blockchain/blockchain-real-estate-companies

- Deloitte (2016). *Blockchain Technology A Game-Changer in Accounting?* Retrieved from https://www2.deloitte.com/content/dam/Deloitte/de/Documents/Innovation/Blockchain_A%20game-changer%20in%20accounting.pdf.

- Deloitte (2018). *Blockchain And the Five Vectors of Progress*. Retrieved from https://www2.deloitte.com/us/en/insights/focus/signals-for-strategists/value-of-blockchain-applications-interoperability.html

- Del Castillo, M. (2016). *Big Four' Accounting Firms Meet to Consider Blockchain Consortium. CoinDesk*. Retrieved from https://www.coindesk.com/big-four-accounting-firms-meet-to-weigh-benefits-of-blockchain-consortium.

- Demarinis, S. (2018). *US Health Care Companies Exploring Blockchain Technologies*. Explore 14 (6).

- Dorri, A. Kanhere, S. and Jurdak, R. (2016). *Blockchain in Internet of Things: Challenges and Solutions.* Retrieved from https://arxiv.org/abs/1608.05187

.

- Dorri, A. Kanhere, S., Jurdak, R and Gauravaram, P. (2017). *Blockchain for IoT Security and Privacy: The Case Study of a Smart Home*. In: IEEE Percom Workshop on Security Privacy and Trust in the Internet of Thing.

- Ekblaw, A., Azaria, A., Halamka, J.D. and Lippman, A. (2016). *A Case Study for Blockchain in Healthcare: "MedRec" Prototype for Electronic Health Records and Medical Research Data*. Whitepaper. Retrieved from https://www.healthit.gov/sites/default/files/5-56-onc_blockchainchallenge_mitwhitepaper.pdf

- Elliott, A.R. (2018). *The Blockchain Technology Revolution Is About to Remake the Stock Market.* Investors Business Daily.

- Engelhardt, A.M. (2017). *Hitching Healthcare to the Chain: An Introduction to Blockchain Technology in the Healthcare Sector*. Technology Innovation Management Review, 7(10), 22-34.

- EY (2018). *Regulatory complexity is the greatest barrier to widespread blockchain adoption, while regulatory changes are the primary driver of broader*. Retrieved from https://www.ey.com/en_gl/news/2018/06/regulatory-complexity-is-the-greatest-barrier-to-widespread

- Eyal, I., Gencer, A.E., Sirer, E.G. and Van Renesse, R. (2016). *Bitcoin-NG: A Scalable Blockchain Protocol*. Proceedings of 13th USENIX Symposium on Networked Systems Design and Implementation (NSDI 16), Santa Clara, CA, USA, 45–59.

- Evans, J. (2018). *Curb Your Enthusiasm: The Real Implications of Blockchain in the Legal Industry*. Journal of Business, Entrepreneurship and the Law, 11 (2), 273-300.

- Fanning, K. and Centers, D.P. (2016). *Blockchain and Its Coming Impact on Financial Services.* Journal of Corporate Accounting and Finance, Vol. 27, No. 5, pp. 53-57.

- Financial Times (2018). *J.P. Morgan Widens Blockchain Payments to More Than 75 Banks*. Retrieved from https://www.ft.com/content/41bb140e-bc53-11e8-94b2-17176fbf93f5

- Ghosh, M., Richardson, M., Ford, B. and Jansen,R. (2014). *A Torpath to Torcoin, Proof-of-Bandwidth Altcoins for Compensating Relays*. Retrieved from https://www.smithandcrown.com/open-research/a-torpath-to-torcoin-proof-of-bandwidth-altcoins-for-compensating-relays/.

- Gordon, W. and Catalini, C. (2018). *Blockchain Technology for Healthcare: Facilitating the Transition to Patient-Driven Interoperability*. Computational and Structural Biotechnology Journal 16, 224–230.

- Guidi, B. (2020). *When Blockchain Meets Online Social Networks*. Pervasive and Mobile Computing 62.

- Gupta, V. (2017). *A Brief History of Blockchain*. Harvard Business Review Digital Articles, 2-4.

.

- Gupta, M. (2017). *Blockchain for Dummies*. Retrieved from https://www.officetoday.ca/2019/04/22/what-is-blockchain-bitcoin-cryptocurrency-the-ibm-blockchain-for-dummies-book-excerpt/

- Hackius, N, and Petersen, M (2017). *Blockchain in logistics and supply chain: Trick or Treat?* In: Kersten, Wolfgang Blecker, Thorsten Ringle, Christian M. (Ed.): Digitalization in Supply Chain Management and Logistics: Smart and Digital Solutions for an Industry 4.0 Environment. Proceedings of the Hamburg International Conference of Logistics (HICL), 23, 3-18.

- Hahn, A., Singh, R., C.-C. Liu, C.-C. and Chen, S. (2017). *Smart Contract-based Campus Demonstration of Decentralized Transactive Energy Auctions*. in Proc. IEEE Power Energy Soc. Innovative Smart Grid Technol. Conf.

- Halamka, J.D., Lippman, A., & Ekblaw, A. (2017). *The Potential for Blockchain to Transform Electronic Health Records*. Harvard Business Review Digital Articles, 3, pp. 2-5.

- Hardjono, T. and Smith, N. (2016). *Cloud-Based Commissioning of Constrained Devices Using Permissioned Blockchains.* Proceedings of the 2nd ACM International Workshop on IoT Privacy, Trust, and Security, ACM, 29–36.

- Herlihy, M. (2019). *The Roots of Blockchain Technologies Are Deeply Interwoven in Distributed Computing: Blockchains From A Distributed Computing Perspective*. Communications OF The ACM, 62 (2), 78-85.

- Hewa, T. & Liyanage, M. (2020). *Survey on Blockchain based Smart Contracts: Applications, Opportunities and Challenges.* Journal of Network and Computer Applications.

- How blockchain could disrupt banking (2018). CBInsights Website. Retrieved from https://www.cbinsights.com/research/blockchain-disrupting-banking/

- Huawei's Blockchain Whitepaper (2018). Retrieved from https://www.huaweicloud.com/content/dam/cloudbu-site/archive/hk/en-us/about/analyst-reports/images/4-201804-Huawei%20Blockchain%20Whitepaper-en.pdf

- Huh, S., Cho, S, and Kim, S. (2017). *Managing IoT Devices using Blockchain Platform*. In: International Conference on Advanced Communication Technology. ICACT, 464-467.

- Hughes, f. and Morrow, J.M. (2019). *Blockchain and Health Care.* Policy, Politics, & Nursing Practice, 20 (1), 1-4.

- IAB (2018). *IAB Explores the Future of Blockchain For Video Advertising in New Comprehensive Whitepaper*. Retrieved from https://www.iab.com/news/iab-explores-future-blockchain-video-advertising-new-whitepaper/

- Jackson, B. (2017). *Canada's First Commercial Blockchain Service Could Become The 'Interac' For Digital Transactions*. Canada: IT World. Retrieved from https://www.itworldcanada.com/article/canadas-first-commercial-blockchain-service-could-become-the-interac-for-digital-transactions/391673

.

- JPMorgan (2017). *J.P. Morgan Deploys Blockchain With New Correspondent Banking Network*. J.P. Morgan Website. Retrieved from https://www.jpmorgan.com/country/US/en/detail/1320562088910

- Kinory, E., Smith, S. & Church, K. (2020). *Exploring the Playground: Blockchain Prototype Use Cases with Hyperledger Composer*. Journal of Emerging Technologies in Accounting,Vol. 17, No. 1, pp. 77–88.

- Klimos, P. (2018). *The Distributed Ledger Technology: A Potential Revamp for Financial Markets?* Capital Markets Law Journal, 13 (2), 194-222.

- Koetsier, J. (2017). *Blockchain Beyond Bitcoin: How Blockchain Will Transform Business in 3–5 Years*. Retrieved from https://www.inc.com/john-koetsier/how-blockchain-will-transform-business-in-3-to-5-years.html

- Kokina, J., Mancha, R. and Pachamanova, D. (2017) *Blockchain: Emergent Industry Adoption and Implications for Accounting*. Journal of Emerging Technologies in Accounting, Vol. 14, No. 2, pp. 91-100.

- Kosba, A., Miller, A., Shi, E., Wen, Z. and Papamanthou, C. (2016). *Hawk: the Blockchain Model of Cryptography and Privacy-Preserving Smart Contracts*. Proceedings of IEEE Symposium on Security and Privacy (SP), San Jose, CA, USA, 839–858.

- Koshechkin K.A., Klimenko G.S., Ryabkov I.V. and Kozhin P.B (2018). *Scope for the Application of Blockchain in the Public Healthcare of the Russian Federation*. Procedia Computer Science 126, 1323–1328.

- Kshetri, N. (2018). *Blockchain's Roles in Meeting Key Supply Chain Management Objectives*. International Journal of Information Management 39, pp. 80–89.

- Krishnan, K. (2018). *Blockchain's Disruption of Marketing*. Ideas2it Website. Retrieved from https://www.ideas2it.com/blogs/blockchains-disruption-marketing/

- Kumar, N. and Mallick, P. (2018). *Blockchain Technology for Security Issues and Challenges in IoT*. International Conference on Computational Intelligence and Data Science (ICCIDS). Procedia Computer Science 132, 1815-1823.

- Kumar, V.N. (2019). *Recent Advances in Blockchain Technology*. IDRBT, Staff Paper Series, 5 (1) ,31-54.

- Kwon, J. (2014). *Tendermint: Consensus Without Mining*. Retrieved from https://cdn.relayto.com/media/files/LPgoWO18TCeMIggJVakt_tendermint.pdf

- Lee, I. and Lee, K. (2015). The IoT (IoT): *Applications, Investments, and Challenges for Enterprises*. Business Horizons, 58, 431- 440.

- Legaler (2018). *Blockchain For Lawyers*. E-book.

.

- Li, X., Jiang, P., Chen, T., Luo, X. and Wen, Q. (2017). *A Survey on The Security Of Blockchain Systems. Future Generation Computer Systems*. Retrieved from http://dx.doi.org/10.1016/j.future.2017.08.020

- Lin, C. I. and Tzu-Chun Liao, C. T. (2017). *A Survey of Blockchain Security Issues and Challenges*. International Journal of Network Security, 19(5), 653-659.

- Linn, L. A., & Koo, M. B. (n.d.). *Blockchain for health data and its potential use in health it and health care related research*. Retrieved from https://www.healthit.gov/sites/default/files/11-74-ablockchainforhealthcare.pdf

- Lund, D., MacGillivray, C., Turner, V., Morales, M. (2014). *Worldwide and Regional Internet of Things (IOT) 2014–2020 Forecast: A Virtuous Circle of Proven Value and Demand*. International Data Corporation (IDC). Tech. Rep. Retrieved from http://branden.biz/wp-content/uploads/2017/06/IoT-worldwide_regional_2014-2020-forecast.pdf

- Macknight, J. (2018). *Faster, Cheaper, Smarter: Blockchain in Trade Finance Distributed Ledger*. Banker, 169 (1110).

- Maesa, D. & Mori, P. (2020). *Blockchain 3.0 Applications Survey*. Journal of Parallel and Distributed Computing 138, 99-114.

- Makhdoom, I., Abolhasan, M., Abbas, H. and Ni, W. (2019). *Blockchain's Adoption in IoT: The Challenges, and A Way Forward*. Journal of Network and Computer Applications, 125, 251–279.

- Marr, B. (2017). *This Is Why Blockchain Will Transform Healthcare.* Forbes Website. Retrieved from https://www.forbes.com/sites/bernardmarr/2017/11/29/this-is-why-blockchains-will-transform-healthcare/#15f707d1ebe3

- Maull, R., Godsiff, P., Mulligan, C., Brown, A. & Kewell, B. (2017). *Distributed ledger technology: Applications and* implications. Strategic Change, 26(5),481–489.
- Mayer, H. (2016). *Ecdsa Security In Bitcoin And Ethereum: A Research Survey*. Retrieved from https://blog.coinfabrik.com/wp-content/uploads/2016/06/ECDSA-Security-in-Bitcoin-and-Ethereum-a-Research-Survey.pdf

- Mazieres, D. (2015). *The Stellar Consensus Protocol: A Federated Model for Internet-Level Consensus*. Stellar Development Foundation.

- McBee. P.M. & Wilcox, C. (2020). *Blockchain Technology: Principles and Applications* in Medical Imaging. Journal of Digital Imaging 33,726–734.

- McFarlane, C., Beer, M., Brown, J. and Prendergast, N. (2017). *Patientory: A Healthcare Peer-to-Peer EMR Storage Network v1.1*, *Whitepaper*. Retrieved from http://www.patientory.com/wp-content/uploads/2017/04/Patientory_Whitepaper-1.pdf

- Mengelkamp, E., Notheisen, B., Beer, C., Dauer, D. & Weinhardt, C. (2020). *A Blockchain-based Smart Grid: Towards Sustainable Local Energy Markets.* Comput. Comput Sci Res Dev, 33 ,207–214.

.

- Miller, A., Möser, M., Lee, K. and Narayanan, A. (2017). *An Empirical Analysis of Linkability In the Monero Blockchain*. ArXiv preprint: arXiv:1704.04299.

- Minichiello, N. (2015). Deloitte launches Rubix, a One Stop Blockchain Software Platform. Retrieved from https://bravenewcoin.com/insights/deloitte-launches-rubix-a-one-stop-blockchain-software-platform.

- Miorandi, D., Sicari, S., Pellegrini, F. and Chlamtac, I. (2012). *Internet of things: Vision, applications and research challenges: Survey Paper*. Ad Hoc Networks 10, 1497-1516.

- Monrat, A., Olov Schelen, O. & Andersson, K. (2019). *A Survey of Blockchain From the Perspectives of Applications, Challenges, and Opportunities. IEEE Acc*ess 7, 117 134–117 151.

- Morena, M., Truppi, T., Pavesi, S. A., Cia, G., Giannelli, J. and Tavoni, M. (2020). *Blockchain and Real Estate: Dopo di Noi Project*. Property Management, 38 (2), 273-295.

- Morrison, J. (2018). *Scammers Are Increasingly Targeting Real Estate Transactions*. Retrieved from https://www.forbes.com/sites/jimmorrison/2018/09/17/scammers-are-increasingly-targeting-real-estate-transactions/#176d7e703815

- Munsing, E. Mather, J and Moura, S. (2017). *Blockchains for Decentralized Optimization of Energy Resources in Microgrid Networks.* In Proc. IEEE Conf, Control Technol, Appl. (CCTA), pp. 2164_2171.

- Murray, J. (2018). *The Coming World of Blockchain: A primer For Accountants and Auditors.* The CPA Journal, pp.20-27.

- Nakamoto, S. (2008*). Bitcoin: A Peer-To-Peer Electronic Cash System.* Retrieved from https://bitcoin.org/bitcoin.pdf

- Nawari, o.n. and Ravindran, S. (2019). *Blockchain And the Built Environment: Potentials and Limitations.* Journal of Building Engineering, 1-16.

- Newsbtc (2020). *Adshares Price, Charts, Marketcap and Other Stats*. Retrieved from https://www.newsbtc.com/cryptocurrencies/adshares/

- Oh, J. and Shong, I. (2017). *A Case Study on Business Model Innovations Using Blockchain: Focusing on Financial Institutions*. Asia Pacific Journal of Innovation and Entrepreneurship, 11(3), 335-344.

- Patwary, A.A., Fu, A., Battula, K.S., Naha, K.R., Garg, S. & Mahanti, A. (2020) *FogAuthChain: A Secure Location-Based Authentication Scheme in Fog Computing Environments Using Blockchain.* Computer Communications, 162, 212-224.

- Peters, G. and Panayi, E. (2015). *Understanding Modern Banking Ledgers through Blockchain Technologies: Future of Transaction Processing and Smart Contracts on the Internet of Money*. Social Science Research Network.

.

- Perkinson, J. and Miller, R. (2016). *Unimpeachable Blockchains: Could Blockchain Revolutionize the Accounting Profession*. Chartered Accountants Australia & New Zealand.

- Pilkington, M. (2016). *Blockchain Technology: Principles and Applications*. In Handbook of Research on Digital Transformations. London, U.K.: Edward Elgar Publishing.

- Pournader, M., Shi, Y., Seuring, S. & Koh, S.C. (2020). *Blockchain applications in supply chains, transport and logistics: a systematic review of the literature*. International Journal of Production Research, (58) 7.

- Prisco, G. (2017) *Big Four Accounting Firm EY Launches "Ops Chain" Platform, Opens Blockchain Lab in NYC*. Retrieved from https://cryptoinsider.media/big-four-accounting-firm-ey-launches-ops-chain-platform-opens-blockchain-lab-nyc/.

- PWC (2018). *A Prescription for Blockchain and Healthcare: Reinvent or Be Reinvented* Retrieved from https://www.pwc.com/us/en/health-industries/health-research-institute/assets/pdf/pwc-hri-a-prescription-for-blockchain-in-ealthcare_27sept2018.pdf

- Puthal, D., Malik, N., Mohanty, S., Kougianos,E. and Das, G. (2018). *Everything You Wanted to Know About the Blockchain: Its Promise, Components, Processes, and Problems*. IEEE Consumer Electronics Magazine, 6-14.

- Sanger, N. (2019). *Blockchain For Legal Services: Revolution or Evolution. Legal Business World Publications.* Retrieved from https://www.legalbusinessworld.com/single-post/2019/08/27/Blockchain-for-Legal-Services-Revolution-or-Evolution

- Sharma, R. (2019) *Public vs. Private Permissioned Ledgers and Blockchain Standards*. Forbes Technology Council. Retrieved from https://www.forbes.com/sites/forbestechcouncil/2019/06/11/public-vs-private-permissioned-ledgers-and-blockchain-standards/?sh=630c18ca550b

- Schwartz, D. Youngs, N. and Britto, A. (2014). *The Ripple Protocol Consensus Algorithm*. Ripple Labs Inc White Paper 5.

- Shah, S. and Yaqoob, I. (2016). *A Survey: Internet of Things (IOT) Technologies, Applications and Challenges*. In Proc. Int. Conf. Smart Energy Grid Eng. (SEGE), Oshawa, ON, Canada, pp. 381–385.

- Shi, S., He, D., Li, L., Kumar, N., Muhammad Khurram Khan, K.M. & Choo, K-k. (2020). *Applications of blockchain in ensuring the security and privacy of electronic health record systems: A survey*. Computers & Security 97.

- Silvestre et al. (2020). *Blockchain for power systems: Current trends and future applications*. Renewable and Sustainable Energy Reviews 119.

- Sivachandran, P. and Muthukumar, R. (2014). *An Overview of Microgrid System*. International Journal of Applied Engineering Research, 9 (22), 12353-12376.

- Smith, S. S. (2018a). *Blockchain Augmented Audit - Benefits and Challenges for Accounting Professionals*. The Journal of Theoretical Accounting Research, 14 (1), 117-137.

.

- Smith, S. S. (2018b). *Implications of Next Step Blockchain Applications for Accounting and Legal Practitioners: A Case Study*. Australasian Accounting Business & Finance Journal, 12 (4) ,76-89.

- Stanley, A. (2018). *Ready to Rumble: IBM Launches Food Trust Blockchain For Commercial Use*. Retrieved from https://www.forbes.com/sites/astanley/2018/10/08/ready-to-rumble-ibm-launches-food-trust-blockchain-for-commercial-use/#2a2b49107439

- Suberg, W. (2017*). Hyperledger Blockchain 'Shadows' Canadian Bank's International Payments.* Cointelegraph Website. Retrieved from https://cointelegraph.com/news/hyperledger-blockchain-shadows-canadian-banks-international-payments

- Technologies, P. (2017). *Proof of Authority Chains*. Retrieved from https://github.com/paritytech/parity/wiki/Proof-of-Authority-Chains.

- Thakur, S., Hayes BP. & Breslin, JG. (2018). *Distributed double Auction for Peer-to-Peer Energy Trade Using Blockchains*. 5th Int. Symp. Environ. Energies Appl, 1–8.

- The banker (2018). *Why Blockchain Can Revolutionize Trade Finance*. Banker, 169, *(1110).*

- Tran, T. (2018). *Blockchain Technology and Potential Applications in Online Advertising.* International Conference on Marketing in the Connected Age (MICA-2018), Danang City, Vietnam.

- Treleaven, P., Brown, G.R. and Yang, D. (2017). *Blockchain Technology in Finance.* Computer Published by The IEEE Computer Society, 14-17.

- Right Networks (2017). *Emerging Tech Trends in Accounting*. Retrieved from https://www.rightnetworks.com/assets/Emerging-Trends-In-Accounting.pdf

- Vasin, P. (2014). *Blackcoins proof-of-stake protocol v2.* Retrieved from https://blackcoin.co/blackcoin-pos-protocol-v2-whitepaper.pdf

- Veuger, J. (2018). *Trust in A Viable Real Estate Economy with Disruption and Blockchain*. Facilities, 36, 103-120.

- Vlastelica, R. (2017*). Why Bitcoin Won't Displace Visa or Mastercard Soon*. Retrieved from https://www.marketwatch.com/story/why-bitcoin-wont-displace-visa-or-mastercard-soon-2017-12-15

- Vukolic, M. (2015). *The Quest for Scalable Blockchain Fabric: Proof-of-Work vs. BFT Replication.* in International Workshop on Open Problems in Network Security, Zurich, Switzerland, 112–125.

- Weed, K. and Rangaiah, B. (2018). *How Blockchain Is Bringing Trust To Digital Ad Buys*. IMB website. Retrieved from https://www.ibm.com/blogs/blockchain/2018/03/how-blockchain-is-bringing-trust-to-digital-ad-buys/

.

- White, G. (2017). *Future Applications of Blockchain in Business and Management: A Delphi Study*. Strategic Change, Vol. 26, No. 5, PP. 439- 451.

- Woodside, M. J., Augustine Jr, K. F., and Giberson, W. (2017). *Blockchain Technology Adoption Status And Strategies*. Journal of International Technology and Information Management, 26(2), 65-93.

- Workie, H. and Jain, K. (2017). *Distributed Ledger Technology: Implications of Blockchain For the Securities Industry*. Journal of Securities Operations & Custody, 9 (4), 347-355

- Wouda.P.H. and Opdenakker, R. (2019). *Blockchain Technology in Commercial Real Estate Transactions*. Journal of Property Investment & Finance, 37 (6), 570-579.

- Wu et al. (2019). *A Comprehensive Survey of Blockchain: From Theory to IoT Applications and Beyond.* IEEE Internet of Tgings Journal (6) 5.

- Xia et al. (2017). *MeDShare: Trust-less Medical Data Sharing Among Cloud Service Providers Via Blockchain.* IEEE Access, 5, 14757 - 14767.

- Xu et al. (2017a). *A Taxonomy of Blockchain-Based Systems for Architecture Design*. IEEE International Conference on Software Architecture (ICSA), Gothenburg, Sweden, 3-7.

- Xu, R., Zhao, H., Zhang, L. and Peng, Y. (2017b). *Design of Network Media's Digital Rights Management Scheme Based on Blockchain Technology.* IEEE 13th International Symposium on Autonomous Decentralized Systems, 128-133.

- Yang, l. and Wang, j. (2019). *Research on Real Estate Transaction Platform Based on Blockchain Technology*. Journal of Physics: Conference Series. 1486 072074.

- Yeoman, M. (2018). *Blockchain Is Only as Secure as Your Private Keys*. Retrieved from https://www.venafi.com/blog/blockchain-only-secure-your-private-keys

- Yu, T., Lin, Z. and Tang, Q. (2019). *Blockchain: The Introduction and Its Application in Financial Accounting*. The Journal of Corporate Accounting & Finance, Vol. 29, No. 4, pp. 37–47.

- Yue, X., Wang, H., Jin, D., Li, M. and Jiang, W. (2016). *Healthcare Data Gateways: Found Healthcare Intelligence on Blockchain with Novel Privacy Risk Control.* Journal of Medical Systems, 40.

- Zamfir, V. (2015). *Introducing Casper the Friendly Ghost, Ethereum Blog*. Retrieved from https://blog.ethereum.org/2015/08/01/introducing-casper-friendly-ghost/

- Zamani,E., He. Y. and Phillips, M. (2018). *On the Security Risks of the Blockchain*. Journal of Computer Information Systems, DOI: 10.1080/08874417.2018.1538709.
- Zhang, P., Schmidt, D., White, J., & Lenz, G. (2018). *Chapter One-Blockchain Technology Use Cases in Healthcare*. Advances in Computers, 111, pp.1–41.

- Zhang, Y. and Wen, J. (2015). *An IoT Electric Business Model Based on The Protocol of Bitcoin*. Proceedings of 18th International Conference on Intelligence in Next Generation Networks (ICIN), Paris, France, pp.184–191.

.

- Zheng, Z., Xie, S. and Dai, H. (2018). *Blockchain Challenges and Opportunities: A Survey*. Int. J. Web and Grid Services, 14(4), 352-375.

- Zheng, Z., Xie, S. and Dai, H., Chen, X. and Huaimin Wang, H. (2017). *An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends*. IEEE 6th International Congress on Big Data, 557-564.

.