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Review

Blockchain: Current Challenges and Future Prospects/Applications

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Abstract: Blockchain is a new technology, often referred to as the Internet of Value. As with all new technologies, there is no consensus on its potential value, with some people claiming that it will bring more disruptive changes than the Internet and others contesting the extent of its importance. Despite predictions that the future is perilous, there is evidence that blockchain is a remarkable, new technology that will change the way transactions are made, based on its ability to guarantee trust among unknown actors, assure the immutability of records, while also making intermediaries obsolete. The importance of blockchain can be confirmed by the interest in digital currencies, the great number of published blockchain papers, as well as MDPI's journal Future Internet which exclusively publishes blockchain articles, including this special issue covering present and future blockchain challenges. This paper is a survey of the fast growing field of blockchain, discussing its advantages and possible drawbacks and their implications for the future of the Internet and our personal lives and societies in general. The paper consists of the following parts; the first provides a general introduction and discusses the disruptive changes initiated by blockchain, the second discusses the unique value of blockchain and its general characteristics, the third presents an overview of industries with the greatest potential for disruptive changes, the forth describes the four major blockchain applications with the highest prospective advantages, and the fifth part of the paper ends with a discussion on the most notable subset of innovative blockchain applications—Smart Contracts, DAOs (Decentralized Autonomous Organizations) and super safe networks—and their future implications. There is also a concluding section, which summarizes the paper, describes the future of blockchain, and mentions the challenges to be overcome.

Keywords: blockchain; internet of value; supply chains; Internet of Things (IoT); smart contracts; Decentralized Autonomous Organizations (DAO); trust; immutability; intermediaries; IoT; certification; supply chains

1. Introduction

Blockchain is an open, distributed ledger that records transactions between parties efficiently and in a verifiable and permanent manner. The present state of blockchain is often compared to that of the Internet in the mid-1990s, still in its infancy, when its value and potentials were not understood. For instance, in a Newsweek article published in February 1995, Clifford Stoll, a computer expert, wrote *"Baloney. Do our computer pundits lack all common sense? The truth is no online database will replace your daily newspaper, no CD-ROM can take the place of a competent teacher and no computer network will change the way government works"* [1]. Still, less than two-and-a-half decades later, people can access any newspapers or magazines from around the world electronically (including links to complete videos), use Google search 5.6 billion times a day, Facebook has more than 2.4 billion active users, while Amazon, founded just a year earlier in 1994, is now the fifth largest company on the Fortune 2019 list. The Internet has produced disruptive changes that Stoll could not have imagined back in 1995.

The two critical questions that need to be considered about blockchain are:

- What kind of changes will blockchain applications bring in the next two decades that, according to some experts, could be even more disruptive than those produced by the Internet so far?
- What new Googles, Amazons, Alibabas, and Facebooks will surface exploiting the advantages of the emerging blockchain technology?

The degree of disruption caused by the Internet can be appreciated by examining Table 1, which depicts the ten largest firms on the Fortune 500 list of 1995 and 2019. The difference between the two periods is extensive, demonstrating the changes fueled by the Internet, in a period of 24 years that chronicles the transition from an industrial to a digital era [2]. The two largest industrial companies that were number one and two in 1995 fell below the tenth position in 2019, while Apple and Amazon climbed the list to the third and fifth positions. Interestingly, Amazon, which was founded in 1994, had revenues of half a million dollars that year and a loss in 1995, and of course could not have been included on the Fortune list, while Apple was ranked 123rd. However, 24 years later both firms achieved market capitalizations approaching one trillion dollars, exploiting digital technologies and the Internet, and are global leaders in their respective fields. At the same time, it is important to note that Walmart, a traditional retailer, is at the top of the Fortune list, confirming a consumer-oriented era and proving that a traditional, brick-and-mortar firm can adapt to the digital revolution, and by doing so, be able to successfully compete with the likes of Amazon [3], the most successful digital firm, in both low prices as well as superior customer service.

The comparisons in Table 1 are history. What is thought-provoking is how the list will change over the next couple of decades and which will be the dominant firms of that time, when the extent of disruptive changes initiated by blockchain will probably be the equivalent of where the Internet is today in relation to where it was in 1995. Which firms will become the next Apple, Amazon, Alibaba, or Google? How will blockchain technology affect our societies and firms, as well as most aspects of our work and daily life? The possibilities are endless. Disruptive breakthroughs are inevitable without being able to predict the outright successes and the unavoidable failures. This introductory paper to the special issue of Future Internet, which focuses on "The Current Challenges and Future Prospects/Applications of Blockchain", consists of four parts. The first discusses blockchain's unique value and some of the inevitable changes that it is bound to bring, knowing well that there will be many surprises we will be unable to predict, as has been the case with the Internet, while some of the predicted changes will not materialize. In addition, the paper discusses the major industries and the most important applications where blockchain has started to exercise a significant impact in terms of greater security, major cost reductions, and simplification of bureaucratic procedures. The third part of the paper presents the most prominent industries with the greatest potentials for disruptive changes, the forth describes the some major blockchain categories of applications with the highest prospective advantages, while the firth part of the paper ends with a discussion on a subset of potentially the most innovative blockchain applications: Smart Contracts, DAOs (Decentralized Autonomous Organizations), super safe networks and their future implications. There is also a concluding section, which summarizes the paper, describes the future of blockchain and mentions the challenges to be overcome.

Table 1. The ten largest firms on Fortune's 500 list of 1995 and 2019.

Rank	1995	2019
1	GM (Industrial)	Walmart (Retail)
2	Ford (Industrial)	Exxon (Oil and Gas)
3	Exxon (Oil & Gas)	Apple (Hi Tech)
4	Walmart (Retail)	Berkshire (Finance)
5	AT&T (Telecom)	Amazon (Hi Tech)
6	GE (Industrial)	United Health (Health)
7	IBM (Hi Tech)	Mckesson (Pharma)
8	Mobil (Oil & Gas)	CVS Health (Health)
9	Sears (Retail)	AT&T (Telecom)
10	Altria (Industrial)	AmerisourceBergen (Pharma)

Summary:	1995	Summary:	2019
Industrial:	4	Retail:	1
Oil & Gas:	2	Oil and Gas:	1
Retail:	2	Hi Tech:	2
Telecom:	1	Finance:	1
Hi Tech:	1	Health:	2
		Pharma:	2
		Telecom:	1

Firms on the 1995 and 2019 Fortune lists.

2. The Unique Value of Blockchain

Blockchain provides a fundamental shift from the traditional Internet of information and communications to the Internet of Value, assuring the establishment of trust, achieved through the application of blockchain technology between strangers. This simple, but ground-breaking, advantage is likely to bring disruptive changes. With trust built into the systems, assets can be exchanged instantly and efficiently without the need for intermediaries. This advantage is estimated to bring more profound changes than those brought by the traditional Internet [4]. Briefly, the unique value of blockchain can be summarized as follows:

- **Trust:** New information can be added to the blockchain ledger only when the majority of network participants give their approval, after receiving satisfactory proof that the information, transmitted cryptographically, is truthful. The authentication of information is done in short intervals of time and the updated information is stored, or more precisely appended to, the blockchain ledger, and made available to all participating network peers.
- **Immutability and Transparency:** Information can only be appended to previous data and once entered, cannot be altered or lost, providing an incorruptible historical record that becomes permanent in the system. In addition, transparency is ensured while all changes are reflected on the ledger and can be audited by any party that is participating in the network.
- **Disintermediation:** The blockchain ledger (database) is not maintained by any single person, company, or government, but by all participating network computers distributed around the world. This means that two parties can interact (e.g., move funds) without the need for any central intermediary to authenticate transactions or verify that the records are truthful.
- **Substantial Improvements:** Additionally, but not always, blockchain can result in substantial cost savings and greater speed when transferring money or other assets, as transactions are possible

24/7 and do not require an intermediary working during "regular" business hours, or requiring a commission to verify the truthfulness of the records.

In addition to the aforementioned unique characteristics of the technology, blockchains offer enhanced security due to the cryptographic way that information is exchanged, making it ideal for storing highly sensitive, personal data, such as those involving financial transactions, medical health records, or other types of data that require enhanced security.

While the traditional Internet has created the likes of Google, Amazon, Alibaba, and Facebook as well as Uber and Airbnb, it has also produced huge monopolies/oligopolies that have come to dominate the market, suppressing competition and invading personal privacy. The Facebook scandal of selling personal information for profit speaks for itself [5]. Moreover, information transmitted through the traditional Internet layer is likely to be copied or altered, making it impossible to guarantee its trustworthiness without depending on the approval of an intermediary, such as a financial institution to verify account balances prior to transferring money, or an expert to attest that a video has not been modified. Blockchain overcomes these drawbacks of the traditional Internet while providing unique additional advantages. Inevitably, these advantages will be exploited in ways not obvious at present, to disrupt current business practices and create the new giants that are likely to dominate the world. The challenge for firms is to exploit the emerging blockchain technologies by following the successful example of Walmart (see Table 1) and avoiding that of Sears [6].

2.1. Technical Characteristics of Blockchain-Based Systems

The architecture of a distributed ledger system consists of many different technological components. In more detail, such systems utilize different types of data structures (e.g., a reversed linked list, direct acyclic graphs), distributed computing mechanisms (e.g., consensus protocols), cryptographic techniques (e.g., hashing functions, asymmetric-key cryptography, and digital signatures) blended with game theoretical concepts (e.g., concepts that are based on financial *incentivization structures*; used mostly in public, permission-less and open-participation protocols e.g., the Bitcoin Blockchain). Clients transact over a distributed peer-to-peer network by exchanging messages using message-passing techniques. In such a system, the identity of each client is recorded with a pair of public/private keys that are mathematically linked with each other (based on asymmetric-key cryptography). In reality, only the public key (referred to as the *address*) of a client is revealed to other clients of the network.

The exchange of information between nodes falls under the concept of a *transaction*. For a blockchain-based system, the concept of a *transaction* can be abstract and can encapsulate any type of data. For example, some blockchain protocols record the transfer of assets as a transaction (e.g., a digital currency). Each client who wishes to interact with the network uses his/her private key to sign the transaction. The mechanism of signing transactions enforces authentication and integrity of transactions over the entire network. These signed transactions are then propagated to the network and need to be validated before being added to the underlying append-only structure (also known as the *ledger*).

Usually, all transactions are queued and their validity is verified according to the rules of the protocol before being appended to the *ledger*. Considering the Bitcoin blockchain [7] all transactions are queued in the *transaction* pool, and miners propose blocks (sets of transactions) to be added to the chain. Miners are required to check: (i) the validity of each transaction, and (ii) that the current block will refer to the correct hash of the previous block (each block is linked with the hash of the previous block thus forming a chain i.e., the blockchain. An alternation to any of the previous blocks will result in a different hash value, thus it is easy to detect whether data from a block has been tampered). If that is the case then the proposed block is added to the chain and all nodes update the state of the world. The system is required to maintain a global view of the world, among a set of untrusted parties that are competing with each other and attempt to reach consensus, under certain rules and conditions that are defined by each protocol. For instance, the Bitcoin protocol proposes a computationally intensive consensus algorithm (also known as proof-of-work) for maintaining a level of robustness

(i.e., preventing double spending), at the same time incentivizing actors (with a reward model) to participate in a computational race for validating blocks, by finding the solution to a hash puzzle [8].

2.2. Consensus

Many characteristics of distributed systems are utilized as part of the fundamental architecture for distributed ledger or blockchain systems. Many build on traditional distributed protocols for ensuring multiparty collaboration in a peer-to-peer participation environment using cryptography and services replication [9]. Since the peers that participate in such distributed environments are likely to be untrusted, highly unpredictable protocols for blockchain-based systems are built with techniques for detecting and tolerating failure of services, i.e., *Byzantine* failures. Thus, a fundamental challenge of such systems relates to the ability of the system to guarantee persistency of data that are stored on the data structure, e.g., a *blockchain*. Many different processes need to coordinate their actions and define the total order of the information that is stored on each block (a block refers to a set of validated transactions where each transaction contains data. The validity of each transaction is verified cryptographically by signing each transaction). To put this into the context of a blockchain-based system, the challenge is for such processes to reach *consensus* on the block to be appended to the chain at each particular index. Blocks are timestamped and thus are ordered chronologically. Therefore, each blockchain system embeds a consensus protocol that aims towards ensuring the following properties for each correct process: (i) all processes that are correct *agree* on the same block; (ii) the chosen block is considered *valid* and proposed by one process; and (iii) forward process is guaranteed since processes will eventually agree upon the state of the world. Today, and according to the protocol many consensus algorithms, alternative to the power intensive proof-of-work consensus implementation, have been proposed, e.g., consensus algorithms that are built with Byzantine Fault Tolerance (BFT), e.g., pBFT [10], or proof-of-stake [11].

2.3. Algorithmic Executions

Another characteristic of distributed ledgers or blockchain systems is the support of different kinds of scripting languages that have been introduced, with different levels of expression. Such scripting capabilities are coined with the term *smart contracts* that refer to executable code that is deployed and executed on such systems. Briefly, they are scripting languages that are Turing-complete (e.g., Solidity for Ethereum) that support looping constructs. Other systems offer more primitive scripting capabilities without, at least in principle, constructs that permit repetition. For instance, the Bitcoin script is considered as a Turing-incomplete scripting language. Ethereum provides a more high-level programming language that builds on a virtual machine that compiles the code to bytecode that is executed at the low-level. On the other hand, the Bitcoin script is a simple stack-based programming language that is embedded directly at the low-level in transaction inputs and outputs. Other systems, such as Hyperledger Fabric, use isolated environments to execute computation within Docker containers [12].

2.4. Permissioned vs. Permissionless

According to the requirements of each deployment of a distributed ledger system, different levels of access permission can be defined. Thus, in general, distributed ledgers can be classified according to the permissions of participation and access control. Mainly these are of two types: (i) *permissionless*; there are no requirements for who joins the network, and there is an open participation policy in place which means anyone can join—in other words, anyone can be a node and participate in the validation process (public networks such as Bitcoin)—and, (ii) *permissioned*; such systems usually operate under the authority of an entity or a consortium. In addition, there is a strict policy on who joins the network and control over the nodes that are participating in the consensus (private or consortium networks built with Hyperledger Fabric). It is often the case that the identity of such nodes is known.

Overall, there is great interest in the technologies behind distributed ledger systems that has triggered a significant body of research work on the various consensus protocols according to the requirements and access policies. Furthermore, the unique characteristics of such systems have inspired the development of many interesting applications across the spectrum of many industries.

3. Practically all Industries will be Affected by Blockchain with Three Facing the Highest Disruptive Potential

Given its advantages, blockchain technology can disrupt practically all industries [13]. At present, startups from a wide spectrum of industries are emerging by developing and monetizing blockchain-based technologies with the aim of disrupting existing business practices or processes [14]. The funds invested in blockchain friendly startups are vast, with total venture capital investments reaching $822 million, from 279 separate VC deals, during the first half of 2019. Interestingly, 159 of the 279 deals were seed stage ones (indicating that the entrepreneurial zeal has not declined), while the remaining ones were no longer building proofs of concepts for the industry, but rather providing workable applications [15] to customers. Today, there are more than 50 leading blockchain startups whose sole purpose is the disruption of traditional industries through the application of blockchain innovations [14]. These startups are in addition to the giant tech firms (Microsoft, IBM, and Alibaba) that are heavily investing in blockchain applications. A recent IDC study [16] estimates worldwide spending on blockchain solutions to reach $15.9 billion by 2023.

Global blockchain spending will be led by the banking industry, which will account for roughly 30% of the worldwide total, followed by healthcare, insurance, finance/fintech, and food. In addition, governments can benefit greatly by using blockchain technologies in most of the functions and services they provide to their citizens, reducing costs substantially and improving their efficiency [17]. A notable example is Estonia, where the early adoption of the technology has shown significant prospects. Approximately 99% of public services are available on-line 24/7, and more than 1400 years' worth of time resources have been saved by shifting to digital technologies. For instance, Guardtime https://guardtime.com/ uses blockchain technology and includes, among other applications, the health records of all its citizens, allowing them to use any health service they need anywhere in the country. Most importantly, by simply using their ID card they can receive access to their health records in real-time in order to be consulted by the medical personnel examining them, while the system automatically updates its records with the additional information obtained from new examinations.

At present, many blockchain projects are being developed as the technology has passed the proof-of-concept phase and has moved into application, substantially improving operational efficiency and reducing costs. As things stand now, the question is no longer whether blockchain is here to stay, but rather how quickly the technology will reach mass adoption. Simplifying outdated processes, reducing bureaucracy, allowing transparency, and increasing trust levels for business processes; these visible benefits are the motivation for driving applications to further grow blockchain's penetration into the business world and among governments. Only then will the benefits from adopting the technology show how fast and successful the transition will be, from the current mode of operations of the various industries to one dominated by blockchain. There is little doubt that there will be many challenges to overcome, but the benefits of trust, immutability/ transparency and disintermediation provided by blockchain, if properly exploited, can compensate for all of these challenges. Finally, current efforts to integrate blockchain with Artificial Intelligence (AI) will open a new spectrum of opportunities for additional applications by exploiting the combined advantages of both technologies [18].

As discussed above, there are a number of major industries that are being affected by blockchain technologies in ways that have been published elsewhere. In the remainder of this section we will concentrate on the set of less-known industries (i.e., health care, music, and HR), that are highly likely to feel the impact of blockchain technology [19] and its disruptive changes.

3.1. Health Care

Accurate and detailed medical records are essential for the wellbeing of patients, as they contain valuable information about their medical history, which is needed for diagnostic purposes and to improve the examining doctor's decision about suggested treatment(s). At the same time, privacy concerns, including the secure storage of medical data, must be addressed. This means that medical information must be made readily available to qualified medical personnel, especially for emergency cases. However, it must be safeguarded from unauthorized parties (medical insurance companies would be extremely interested in the medical records of potential clients when deciding whether to accept/reject them and what premiums to charge). Blockchain technology provides an ideal solution for doing so as safety is assured, while the person involved can decide who, when, and what parts of her/his medical records can be disclosed. Given the importance of having truthful and continuously updated medical records for all their citizens, countries are encouraging the development of such a system that would convert all medical information available at present into digital form, using the same system not only across a single country, but even at a regional or global level so that information could be shared even when travelling away from home.

There are several countries putting their resources into leveraging blockchain technology to improve the quality of their citizens' lives. In addition to Estonia already mentioned, UAE, Singapore, and other countries are implementing blockchain to store medical records. The problem is the cost of doing so and the need to standardize and digitize all information. The USA, for instance, has provided $28 billion in federal stimulus money to implement Electronic Health Records (EHRs) while MedRec, an MIT-backed initiative, is going a step further by developing a digital family history of medical records, that can be passed down from generation to generation [19]. Moreover, Daley (2019) illustrates the importance of health care by pointing out that in the USA 20% of its GNP is spent on health care and that even small improvements can save vast amounts of money while improving the quality of health services [20]. Most importantly, Daley [20] describes 15 examples showing how blockchain can revive the health industry by improving the level of service while saving money. Finally, Agbo et al. (2019), list the following benefits of blockchain for healthcare applications: Decentralization, improved data security and privacy, health data ownership, availability and robustness, transparency and trust, and data verifiability [21].

3.2. Music/Movies

Starting in the early 1990s, as computers' memory increased manifold and the Internet became faster and widely used, users were able to download any song they wanted without paying or, alternatively, exchange music among themselves. The effect of free downloading/exchanging of music had serious repercussions for the music industry that suffered great financial losses, leaving artists, record labels, and everyone else concerned in an extremely difficult situation, with many firms going bankrupt. Interestingly, the same situation repeated itself with movies 20 years later when high Internet speeds and larger computer storage made downloading movies in short time spans practical. Blockchain is a way to solve the problem of illegal downloading with several innovative ideas being introduced to pay artists and studios for legal downloads. For instance, Mycelia's mission is to "empower a fair, sustainable and vibrant music industry ecosystem involving all online music interaction services." Its blockchain-based platform allows musicians to introduce smart contracts for the sharing of music by ensuring that profits go to the artists and not to the middlemen. Another blockchain-based company, SingularDTV, is setting the foundation for a decentralized entertainment industry by building an Ethereum application empowering artists and allowing them to receive loyalties for their work directly, avoiding the big companies that would receive the lion's share of revenues. The major objective of firms like Mycelia and SingularDTV is to avoid the middlemen, but also bureaucratic obstacles, while reducing the costs when a payment for downloading music or a movie is made.

Another direction for the music and movie industry is to provide unlimited usage of music or movies with small monthly fees. This is done by firms such as Spotify and Netflix that pay artists a loyalty, often tiny, each time a song is played or a movie is watched. The low monthly fee and the ease of listening/viewing copyrighted content are the disincentives to illegal downloads, creating a win/win situation. At the same time, intermediaries like Spotify and Netflix build great monopolistic power imposing their terms and keeping the largest part of the received revenues, putting the creators of music/movies at a disadvantage. The ultimate purpose of blockchain is to abolish, or at least reduce the power of monopolies, and according to its proponents this will eventually happen using decentralized structures allowing creators to interact directly with users, making intermediaries obsolete. Will this ever become possible? Even if the answer is no, blockchain can substantially reduce the power of monopolies, as interest groups can be created whose members can obtain services directly from artists or other providers. As blockchain technology improves and transaction costs are further reduced, the decrease in the power of monopolies may accelerate, creating the democratization of power between consumers and firms.

3.3. Human Relations (HR)

Human resource departments are responsible for activities spanning a wide variety of critical functions ranging from identifying and hiring the right employees for the right jobs, to training/educating them to advance in their careers and better achieve organizational objectives and maintaining a safe and pleasant work environment where they can work productively and creatively. In this part, we will concentrate on identifying, hiring, and retaining employees, activities where blockchain can offer its greatest benefits, greatly affecting the way these tasks are performed and their effectiveness. At the hiring level "attracting sufficient numbers of the right talent that have the most relevant credentials in a timely manner, and then hiring the right person(s) from that pool is one of the most crucial HR tasks. This is the essence of recruitment" [22]. Furthermore, the larger the candidate pool, the easier it will be to find the right candidates to fill the required positions. This is where blockchain can contribute the most, by identifying talented individuals from around the world using social media and assuring the correctness of the information in the curriculum vitaes of prospective candidates. In addition, AI can be used to screen such information in order to schedule initial interviews, using video conferencing to avoid unnecessary travelling and related expenses, before the short-listed candidates can be invited for their final interviews.

The decentralized nature of blockchain technology can revolutionize the way HR practices are performed, first by verifying the submitted information of the academic achievements and employment history of candidates, thus eliminating costly mistakes. Such a process will expand in the future as employment history will be placed on public or private blockchain networks and will include a person's successes and failures, promotions, salary raises, as well as all other related information, raising HR management to a different level of importance. The main difference between how HR recruitments were performed in the past and how they are now, has been the speed and accuracy coupled with an emphasis on identifying and hiring talent and consequently providing the right environment to keep these talented hires motivated and productive. In the future, the greatest challenge for HR teams will be to enlarge their global reach of identifying talented employees and convincing them to accept the job offer.

4. Blockchain Applications

Blockchain applications cut across industries, providing great opportunities and considerable benefits by exploiting blockchain's advantages. This section specifically focuses on a prominent subset of categories of applications that are expected to hold potential and are likely to be adopted in the near future. Most importantly there is a great number of additional applications that are beyond the scope of this paper as they have been described elsewhere [13,23].

4.1. Supply Chain

Supply chain applications are moving in two broad directions. First, in improving efficiency by reducing bureaucratic and other obstacles, and improving operations in order to be more cost-effective. Second, they aim to guarantee the authenticity, provenance, and freshness of materials/products bought by consumers [24]. Supply chain operations are dominated by paper-based methods based on letters of credit (costing 1%–3%) and factoring (costing 5%–10%). These requirements and methods are increasing costs by an estimated trillion dollars a year, while at the same time slowing down transactions considerably [25]. By utilizing the fundamental characteristics of the technology and more specifically disintermediation, the role of intermediaries along the chain is eliminated thus further reducing associated costs. Furthermore, a new trust model is established directly between buyers and sellers based on transparency in the various processes, from tracking delivery of goods to payment processing, with the use of smart contracts. Skuchain https://www.skuchain.com/ is a blockchain startup that aims to empower enterprise supply chains utilizing its blockchain technology at the intersection of payments (letter of credit and wire transfer) and finance (operating and short-term trade loans). On another note, Provenance https://www.provenance.org/ is focusing on building trust between consumers and retailers by tracking the provenance of goods from the source all the way to the final consumer. In addition to these startups, existing retailers such as Walmart are looking into exploiting the advantages of blockchain technology to improve efficiency and reduce supply chain costs [26], Nestle [24] is targeting the freshness of its milk products, while other blockchain applications are concerned with verifying the authenticity of a product (e.g., it is not a counterfeit) as well as its origin (e.g., when buying a fish, to be able to trace where and when it was caught). Moreover, IBM has developed a blockchain system to support data integration processes between manufacturers, retailers and suppliers to provide greater reliability, transparency and security [27]. The aforementioned projects are indicative examples of how the characteristics of blockchains are opening up new opportunities for traceability applications [28].

4.2. Certification

One of the greatest potentials of blockchain technology is that it can serve as a decentralized, permanently unalterable storage layer for any type of information, or asset, and not just used for the settlement of financial transactions. This makes the technology suitable for storing and certifying all kinds of information, transactions, employment qualifications, and sensitive records/documents. What has attracted the greatest interest, however, is the certification of data (e.g., Stampery https://stampery.com/) and verification of identities (e.g., ShoCard https://shocard.com/, using mobile verifications). There are many, additional areas where certification using blockchain technology can be applied, including the issuing of land registry title deeds and eventually even using it to vote, which could be done at any specified time, anywhere in the world, at the convenience of the voter. The benefits of being able to issue IDs/passports and driver's licenses on the blockchain layer can save billions by maximizing value and convenience, while at the same time minimizing fraud. A major area of such an application is with respect to academic certificates that can enable the verification of academic credentials (e.g., block.co https://block.co/), the authenticity of academic degrees worldwide, and eliminate fraudulent claims while facilitating selecting qualified persons from across the globe.

4.3. IoT

The Internet of Things (IoT) is becoming essential for many daily activities and a major technological component for smart cities, smart homes, and vehicles. In addition, wearable devices have opened up many opportunities in medicine, e.g., programs which monitor our health, tracking our daily exercise, and even enabling remote care. The number of interconnected devices is expected to reach 20 billion by 2020 [29]. The combination of blockchain with the IoT can foster many interesting applications and systems, especially with the use of smart contracts for autonomous decision-making. Broadly speaking,

there are three crucial challenges for the effective application of IoT technologies in the billions of devices currently in use, or soon to be interconnected: absolute security, effective interoperability, and rich connectivity. Exploiting the information generated by such IoT devices can effectively transform our homes and cities and have a profound effect on the quality of our lives, while saving energy and providing us with useful, personalized information. According to [30] "Because blockchain is built for decentralized control, a security scheme based on it should be more scalable than traditional centralized ones. Moreover, blockchain's strong protections against data tampering would help prevent a rogue device from disrupting a home, factory or transportation system by hacking or relaying misleading information". Additionally, the smooth interoperability of sensors, scanners and cameras connected to various IoT devices, can transfer information between the various devices automatically and be used to control operational and stability objectives, creating smart homes and other smart entities serving unnoticed users. Currently, a large number of firms https://99firms.com/internet-of-things-companies/ are working on the potential prospects of IoT applications in a market that is expected to exceed the half trillion dollar mark by 2021, with some of these firms specializing exclusively in blockchain IoT applications.

4.4. Gambling Industry

Trust has continued to be one of the major challenges for the gambling industry in general. Especially for online gambling service providers, there are concerns with regards to the fairness of the random processes utilized (i.e., in the calculation of odds) and of course the protection of the funds that are involved in gambling transactions. According to Christodoulou et al. (2019) the unique characteristics of blockchain technology can be leveraged to inform verifiable and transparent pseudorandom generation processes [31]. Such processes will be auditable by anyone without the need of any external trustee service or an oracle, and that only by observing public data that have been recorded on the ledger. In addition, with the existence of smart contracts in many blockchain-based protocols gamblers and online gambling operators can engage in transparent contractual agreements that are algorithmically governed, as well as, supporting the principles of instant pay-outs with the use of digital currencies.

5. Disruptive Blockchain Applications

Blockchain is a new technology with a little more than a decade of history since it was first introduced by Satoshi Nakamoto in 2008 (refer to [32]). As mentioned in subsequent sections in terms of its development, blockchain stands today where the Internet was in the middle of the 1990s, with huge disruptive potentials. In this section, we concentrate on a most notable subset of blockchain applications expected to mushroom over the next decade, i.e., Smart contracts, Decentralized Autonomous Organizations (DOA), and Super Secured Networks, along with their integration that promises to fundamentally change transactions among people and businesses and the way organizations are structured and operate.

5.1. Smart Contracts

Smart contracts are probably the blockchain technology with the highest potential to affect, or even revolutionize, all sorts of transactions from the execution of legal agreements to the IoT. Smart contracts encapsulate algorithmic code that is served by a peer-to-peer network. For example, a smart contract can be instantiated to algorithmically enforce the terms of an agreement without the need for a traditional legal document. In such cases, smart contracts allow the performance of transactions without lawyers or notaries. The transactions are trackable and irreversible and do not require courts and judges to be enforced. Consider for example, the executor of a will who approves the directives of the deceased on how the money will be spent/allocated and his/her assets distributed. Instead of an executor, a programmable, legally binding smart contract can achieve the same purpose, using blockchain technology and avoiding any intermediary. Doing so would certainly reduce costs

and improve efficiency. The Chainlink https://chain.link/ network enables smart contracts in various networks for existing applications and external data, sending payments postulated in the smart contract to designated bank accounts, and creating secure cross-chain connectivity between the smart contract and other public or private parties. An additional application of smart contracts is where the IoT facilitates the sharing of services and resources, leading to the creation of a decentralized marketplace of services between devices and people that would allow us to automate, in a cryptographically verifiable manner, time-consuming work flows, and interactions (see [33]).

The following is a non-exhaustive list of major platforms with smart-contract capabilities:

Ethereum https://www.ethereum.org/use/**:** Ethereum is a blockchain based open software platform and cryptocurrency that enables developers to build and deploy a decentralized application (dApp). The network permits the execution of Turing-complete algorithms written in the programming language Solidity, on a virtual machine known as the Ethereum Virtual Machine (EVM), based on available resources from peers. A wide range of applications previously unimagined are now fueled by the network, ranging from electronic voting, compliance, trading, etc.

NEM: NEM is an alternative blockchain-based, decentralized peer-to-peer network that enables third parties to build smart asset applications such as, but not limited to, crowdfunding tokens and cryptocurrencies. NEM uses proof-of-importance consensus rather than proof-of-stake or proof-of-work and this distinguishes it from other blockchains. NEM's benefits include multi-signature accounts, mosaics, privacy, messaging, scaling, and the fact that practically every member of the NEM community can suggest updates and developments.

NEO https://nem.io/enterprise/**:** NEO's protocol offers the opportunity to execute trustless smart contracts that can be used for financial dealings, but also as a platform for more complicated transactions. It competes with Ethereum for its ease of use. It is employed mainly in Asia where it is considered a market leader.

Cardano https://cardanodocs.com/: Cardano is quite similar to Ethereum, allowing the deployment and execution of smart contracts. The major feature that differentiates it from Ethereum and other smart contracts is "ouroboros", its proof-of-stake extracting algorithm that consumes less energy than Ethereum's. Another unique feature of Cardano is its issuing of debit cards that can be funded from the user's online wallet and used as a traditional debit card.

Hyperledge https://www.hyperledger.org/**:** Hyperledger is an open-source framework and tool for abstracting the complexity of developing blockchains (including permissioned blockchains), a project administered by the Linux foundation. It offers modular design, and a variety of tools for executing smart contracts on distributing ledgers. For Hyperledger Fabric, multiple smart contracts can be defined within the same chaincode and then the chaincode can be deployed to a blockchain network. This means that the smart contracts manage the transaction or business logic, while the chaincode manages the smart contracts defined within it.

In addition to smart contracts, there is also a large push to develop smart cities that would incorporate technology as an infrastructure to alleviate many of the current problems in cities, while using green energy, integrated forms of transportation, water and pollution management, universal identification (ID), wireless Internet systems, and promotion of local commerce. Finally, there are those claiming that smart cities could become the greatest future challenge and the pathway for the widespread adoption of blockchain technology, given the complexity of designing and implementing smart cities [34].

5.2. Decentralized Autonomous Organizations (DAOs)

Unlike traditional organizations that are regulated by laws and legal contracts that are enforced by a country's legal system, DAOs can be governed by a set of agreed upon rules postulated in an open-source protocol, or a smart contract, that can only be changed by the majority rule, agreed upon by its founding members. The stakeholders of a DAO are motivated by incentives spelled out in the network charter, and fully transparent rules written into the protocol/smart contract governing it.

There are no bilateral agreements, the only governing laws regulating the behavior of all participants are the directives written in the DAO's smart contract. The cost of establishing and operating a DAO can be substantially lower than that of traditional organizations as they do not need a CEO, managers, employees, or office buildings. A DAO can be created and operate by the computer code included in the smart contract, offering all the advantages of a conventional organization. For example, stock market funds that invest solely in market indices would have no need to pay executives, employ personnel, or occupy offices, when they can be run 24/7 as a DAO. The characteristics or complexity of a DAO depend on several factors that include the number of stakeholders, as well as the difficulty of processes that need to be governed in the smart contract. The more centralized the rules, the more the DAO will resemble a traditional company, while the less centralized the more it will look like a flat, non-traditional organization better fitting the model of an open-source, distributed organism that exists autonomously on the Internet.

The potential benefits of DAOs in comparison to traditional organizations can go well beyond cost reductions and more efficient operations. Such benefits will be the equivalent of the machine automation that revolutionized the production of goods, except that it will be applied to the management of organizations. The possibilities are innumerable, including the emergence of brand new organizational forms that will use machine-to-machine (M2M) interactions. A DAO managing autonomous vehicles (AV) could, for instance, collect payment from the customers it transports, pay road tolls and parking fees, disburse the cost of charging its batteries or that of its repairs, while at the end of a predefined period reimburse DAO's stakeholders with the period's profits. At the same time, there are potential challenges with malicious actors that could attempt to attack the system and gain access to its funds and tasks that cannot be done using programmed decision rules. Equally important, DAOs must adapt to changes in the business and external environment, as well as identify emerging trends and attract and exploit talent to innovate.

DAOs are still in their very early stage of development and there is still a great deal to learn to improve their creation, avoid the inevitable early stage problems and smooth their operations. DAOs can be compared with the huge and inefficient steam engines used to extract water from mines, versus today's robotic automation that can produce goods with minimal human interventions. The ultimate objective of DAOs is to build a "collective intelligence" for the management of organizations, to improve the hierarchical structure of today's large organizations, thus encouraging innovation and deterring bureaucracy. There are several start-ups such as Aragon https://aragon.org/, DAOStack https://daostack.io/ and Colony https://colony.io/ whose purpose is to avoid or minimize the disadvantages of hierarchical organizations while exploiting the value of the wisdom of the crowds. Their goal is not to replace managers with smart contracts that will automate decision-making, but rather to free managers from repetitive decisions to be able to concentrate their efforts on innovation and high-level strategic decisions affecting the long-term future of the organization.

5.3. The Significance of Super Secured Networks

"The DAO", launched on 30th April 2016 on the Ethereum protocol, that was meant to operate similar to a venture capital fund for the crypto eco-system providing more control to its founders and participating members, was the first attempt of such a decentralized autonomous organization. The project was funded through a crowd-sale using a smart contract during its inception. The fund was successful, achieving an Ether value on 21st May 2016 of more than US$150 million, from more than 11,000 investors, attracting nearly 14% of all ether tokens issued to that date. On 16th June 2016, however, the DAO got hacked, causing it to lose about US$50 million of its capital and raising some significant questions, not only about the safety of DAOs, but also about the safety of all blockchain transactions. Could a DAO be hijacked, causing it to lose all its assets? Could the shares of its stakeholders be erased or transferred to others? Could the majority decisions agreed upon by the DAO's shareholders be tampered with, manipulating the trust principle that is so central to blockchain? Nevertheless, the importance of safety must go beyond DAOs to other blockchain applications that

require super security for sensitive areas like those involving IoT applications concerning our smart homes or AVs. The consequences of hijacking the operations of a smart home, for instance, could be detrimental, going beyond money by affecting the safety of one's family and putting in danger its existence, as practically all information could be compromised. The same could be true with AVs, that if hacked could result in huge damages. One only needs to remember the terrorist attack that took place on the evening of 14th July 2016, when a large truck was deliberately driven into crowds of people celebrating Bastille Day on a big boulevard in Nice, killing 84 people and injuring 434 [35]. Imagine what would happen if terrorists could maliciously hack, not only one, but several AV trucks, and throw them into a massive crowd. Super security will be necessary to avoid such cases and other even more critical ones, such as those involving brain-to-computer [36,37] and brain-to-brain interfaces [38,39], that if hacked could mean one's thoughts being stolen and even huge damages being caused to someone's brain. Blockchain provides many advantages, but before it can be applied to sensitive areas, there must be absolute guarantees of super security.

6. Conclusions and the Future of Blockchain

Blockchain is a new technology that must overcome a number of problems before its full advantages can be exploited, but so was the Internet before October 1990, when Sir Tim Berners-Lee introduced three fundamental technologies that formed the foundation of the World Wide Web (WWW) and are utilized until today. By the end of 1990, the first web page was posted on the internet, which people could visit and view information on, mostly transmitted through modems and regular telephone lines. However, such information consisted of text only characters, as sounds, images and videos were outside the communication capabilities of that time. Google, Amazon, Facebook, or YouTube were unimaginable at that time, when even sending an email, before the Mosaic web browser was introduced, was considered a technological achievement. Nobody should be surprised, therefore, with blockchain's current limitations, as it is at around the same stage as the Internet was in the mid-1990s.

In this paper we discussed the core advantages of blockchain and pointed out that its full potential would be unleashed in the not too distant future [40], with new giant firms, the equivalent of Google, Amazon, and Facebook, emerging to exploit the advantages of blockchain technologies. In this conclusion, we would like to reiterate the value of blockchain and its disruptive nature while also deliberating about its future achievements. A recent Deloitte Global Blockchain Survey [41] concluded that 2019 was a turning point for blockchain when a radical shift happened in the attitudes of business leaders who recognized that blockchain is for real and that it can serve as a pragmatic solution to business problems across industries and use cases. That is, these leaders recognized a shift from "blockchain tourism" and exploration towards the building of practical business applications, as blockchain has finally entered the mainstream of business applications. Blockchain guarantees trust, assures immutability/ transparency, and supports disintermediation in addition to providing extra security for transactions executed over the Internet. These are considerable advantages that cannot be ignored, while its disadvantage of the cost of implementation can be depreciated and reduced in a short amount of time, as more experience with applications is gained and blockchain becomes a core technology. Most importantly, however, as usage increases the motivation for improvements will increase, too, as has been the case with the Internet that witnessed substantial advancements over a short period of time. Such advancements will provide solutions to blockchain's inability to scale, significantly reducing usage costs.

The future of blockchain will move in two distinct directions. The first will include all those applications requiring decentralized, super secured networks as those discussed above. IoT [42], AVs [43], BCI and BBI will be included in this category as will smart contracts and DAOs. There will be no choice but to use blockchain in these applications. The other direction will include advances in AI that when combined with blockchain can substantially improve its value. Such advances will include improving the safety of big data as well as its ability to decentralize who holds it, currently exclusively owned by companies like Google and Facebook, and democratize ownership and sharing by creating a

marketplace where such data can be traded. This will mean that individuals can keep control of their data and decide on their own when and how to make it available to third parties. Moreover, smaller AI players will be able to utilize this data and further advance AI in addition to the big firms, thus breaking their data monopoly. Another area where blockchain and AI can cooperate is in cybersecurity, by combining AI and blockchain together to create a double shield against cyberattacks by training ML algorithms to automate real-time threat detection and to continuously learn about the behavior of attackers, while decentralized blockchains can minimize the inherent vulnerability of centralized databases [44].

Blockchain's ability towards security and immutability can also be used for storing the highly sensitive, personal data needed to determine patterns in sensitive cases such as those involving the healthcare sector. Furthermore, blockchain can contribute to breaking the black box of AI by tracing how algorithms work and how their input affects the output of machine learning, while AI can increase the efficiency of blockchain far better than humans, or standard computing. Finally, Bitcoin, viewed as blockchain's first innovative success [45], can contribute to applying the technology to additional areas, increasing the popularity of both Bitcoin and AI, as well as their various applications. Blockchain and AI are new technologies and much will depend on future, yet unknown, technological advancements. However, there is considerable potential that can raise their separate, as well as their combined, usefulness to new, high levels of value and applicability. This has been the case with the Internet, as well as, all new technologies whose future value has been underestimated greatly at the outset.

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